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The acquisition of technological capabilities by large Chinese industrial companies. Between catch-up and engagement in emerging technologies

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To cite this version:

Marina Oulion. The acquisition of technological capabilities by large Chinese industrial companies. Between catch-up and engagement in emerging technologies. Business administration. Université Paris-Est, 2016. English. NNT : . tel-01483966v1

HAL Id: tel-01483966

https://hal.science/tel-01483966v1

Submitted on 6 Mar 2017 (v1), last revised 8 Feb 2018 (v2)

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UNIVERSITE PARIS-EST

ECOLE DOCTORALE ORGANISATIONS, MARCHES, INSTITUTIONS

Thèse de doctorat en Sciences de Gestion

Menée au Laboratoire Interdisciplinaire Sciences Innovations Sociétés (LISIS) d'Université Paris-Est

Soutenue par Marina OULION le 12 décembre 2016

L'ACQUISITION DE COMPÉTENCES TECHNOLOGIQUES PAR LES GRANDES ENTREPRISES INDUSTRIELLES CHINOISES.

Entre rattrapage et investissement des technologies émergentes

---

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L'acquisition de compétences technologiques par les grandes entreprises chinoises : entre rattrapage et investissement des technologies émergentes

Résumé

Parmi les 500 plus grandes entreprises mondiales, une sur cinq est chinoise. En 2014, 94 entreprises chinoises figuraient parmi les leaders mondiaux en R&D. La Chine est, depuis 2016, le premier acquéreur d'entreprises étrangères et vise désormais des entreprises de haute-technologie.

Ces éléments nous questionnent sur le positionnement technologique des entreprises chinoises. Penser ce thème nous oblige à revenir sur leurs conditions d'émergence. A la lecture du modèle dominant du rattrapage technologique (Kim, 1997), la Chine est passée par trois grandes phases: une période d'acquisition des technologies étrangères suite à l'ouverture du pays en 1978, une période d'assimilation des technologies et d'assemblage et manufacture de produits de plus en plus complexes, et une période d'intégration qui leur permet de faire de nouvelles propositions de produits grâce à la reconfiguration et amélioration des technologies existantes.

L'hypothèse qui guide notre recherche est que les entreprises sont désormais dans la dernière phase du rattrapage et sont entrées dans une période de transition vers le leadership technologique. Cela nous amène à poser deux questions. A quoi fait-on référence lorsqu'on parle d'innovation en Chine aujourd'hui ? Ce thème renvoie de manière plus globale à celui de l'innovation par les pays émergents. Quel chemin reste-t-il à parcourir pour atteindre la frontière technologique ?

Nous observons cette transition dans la manière dont les grandes entreprises chinoises s'engagent dans la recherche. L'intégration des technologies émergentes au sein de leurs stratégies de recherche reflète des dynamiques d'apprentissage qui, si elles ne sont pas encore visibles sur le marché, indiquent une dynamique de transition. Nos résultats montrent que la tendance est significative, la moitié des grandes entreprises (48 percent) s'engage en nanotechnologie. Cela reflète l'arrivée à la frontière technologique des entreprises chinoises, ce qui, nous le soulignons, n'implique pas nécessairement le passage à la frontière sur d'autres dimensions, notamment organisationnelles. Nous montrons également que les trajectoires d'engagement dans la recherche sont variées. Si une partie des entreprises s'engagent dans la recherche sur la base d'un modèle similaire à celui des entreprises américaines ou européennes, d'autres dynamiques sont également à l'œuvre, qui traduisent notamment un héritage historique et une inscription dans le territoire.

Pour obtenir ces résultats, nous avons construit une base de données de 325 grandes entreprises industrielles, et observé leurs prises de brevets en nanotechnologie, directement ou via leurs filiales, sur la base de sources en anglais et en chinois.

Mots clés : entreprise chinoise, frontière technologique, nanotechnologie, brevets

The acquisition of technological capabilities by large Chinese industrial companies: Between catch-up and engagement in emerging technologies (English Title)

Abstract

Among the 500 world's largest firms, one out of five is Chinese. In 2014, 94 Chinese firms were among the world leaders in R&D. Since 2016, China is the first acquirer of foreign firms, and is now targeting high-technology firms.

These elements raise questions about the technological positioning of Chinese firms. Studying this topic requires looking at their conditions of emergence. We can look at China's development under the perspective of the technological catch-up model (Kim, 1997). China has gone through three phases: aphase of acquisition of foreign technology following the country's opening in 1978, a period of technological assimilation and production of increasingly complex products, and a period of technological integration characterized by technological improvement and the reconfiguration of existing technologies.

The hypothesis we make is that firms are now in the last phase of catch-up, and have entered a period of transition to technology leadership. This leads to two questions. What is China's innovation today? This topic broadly refers to innovation by emerging countries. How far are Chinese firms to reach the technological frontier?

We observe the transition through the way major Chinese firms engage into research. The integration of emerging technologies into their research strategies reflect dynamics of technological learning which, if they are not yet visible in the market, indicate the transition. Our results show that the trend is significant, half of large firms (48 percent) engages in nanotechnology. This proportion reflects that Chinese firms have reached the technological frontier, which, however, does not mean they are at the frontier on other dimensions, such as the organizational dimension. We also show that there are several modalities of commitment into research. While some large Chinese firms do research by adopting a model similar to that of American or European firms, other dynamics are at work, which reflects in particular their historical legacy, and the impact of their localization.

To obtain these results, we have built a unique database of 325 large industrial enterprises, and have looked at their patenting activities in nanotechnology, directly or through their subsidiaries, based on the exploitation of sources in English and Chinese.

Keywords: Chinese firm, technological frontier, nanotechnology, patent

Résumé long en français

La question centrale de la thèse est celle de la frontière technologique en Chine. Cette question se déploie à deux niveaux. Tout d'abord, au niveau national, c'est la transformation du modèle industriel qui est en jeu ainsi que la place du pays dans le monde. La crise financière de 2008 a mis en évidence, par l'ampleur des faillites qu'elle a générées, les problèmes liés au modèle industriel chinois : notamment des problèmes environnementaux (qui a des impacts considérables sur la santé publique) et des problèmes structurels.

La question de la frontière technologique se pose également au sujet des entreprises. Nous assistons, depuis une dizaine d'années, au repositionnement des grandes entreprises chinoises. En 2015, environ 20 percent des 500 plus grandes entreprises mondiales vient de Chine, et le pays joue désormais un rôle moteur dans les fusions et acquisitions internationales. Certaines acquisitions ont certes été des tournants historiques de par la charge symbolique de la cible et la dimension technologique de l'acquisition. Mentionnons, entre autres, l'acquisition de la section PC d'IBM par Lenovo en 2005, la reprise de Volvo par Geely en 2010 et en 2016, l'acquisition de Syngenta (chimie et agroalimentaire) par l'entreprise d'état ChemChina. Mais fondamentalement le phénomène va au-delà de ces cas emblématiques et concerne également l'absorption de petites entreprises technologiques.

Ces éléments interrogent le positionnement des grandes entreprises chinoises en tant qu'acteurs technologiques. De plus, l'étendue de la tendance nous amène à nous questionner sur les conditions d'émergence des entreprises. Poser cette question nous oblige ainsi à nous replacer dans un temps plus long, même s'il reste relativement court au regard de l'histoire industrielle : deux entreprises parmi les leaders chinois, Huawei et Lenovo, ont respectivement été créés en 1988, et 1984 et le premier investissement à l'étranger par une entreprise chinoise date de 1984(Week in China, 2016, p. 6).

Positionnement de la recherche

L'analyse de la dimension technologique sur un temps historique nous renvoie aux études existantes sur le rattrapage technologique des pays en développement. La littérature sur ce thème est née du constat que les pays en retard sur le plan technique augmentent leur productivité plus rapidement que les pays plus avancés grâce à l'acquisition de technologies étrangères, ce qui assure leur rattrapage économique (Abramovitz, 1986). La dynamique d'apprentissage technologique a été centrale dans le développement des pays industrialisés en Asie, au Japon dans un premier temps, puis à Taiwan, Singapour, Hong-Kong ainsi qu'en Corée du Sud (Amsden, 2003; Kim and Nelson, 2000).

A la lecture du modèle dominant du rattrapage technologique (Kim, 1997), pensé à l'origine

dans le contexte coréen, la Chine est passée par trois grandes phases : une période d'acquisition de technologies étrangères, suite à l'ouverture du pays en 1978 ; une période d'assimilation de ces technologies et de production de produits d'une complexité croissante ; et une période caractérisée par l'intégration et l'amélioration des technologies existantes dans le développement de nouveaux produits. Si le rattrapage technologique commence avec l'ouverture du pays, il serait erroné cependant, de considérer que l'histoire industrielle de la Chine démarre en 1978, avec l'arrivée de Deng Xiaoping au pouvoir. La première phase notable d'industrialisation date, en effet, du premier plan quinquennal qui a donné lieu à la construction d'usines et d'entreprises, dont certaines sont encore utilisées aujourd'hui, et remonte aux années 1950s.

La mobilisation de la littérature sur le rattrapage technologique appelle deux questions. La première tient à la nature de l'innovation dans les pays émergents, en particulier lors de la phase la plus avancée du rattrapage technologique. De nombreux rapports ont montré la capacité à innover des entreprises chinoises (Strategy&, 2014, 2013). Cette innovation est le souvent fondée sur la compréhension des besoins spécifiques des grands marchés émergents (Radjou et al., 2012), ainsi que sur l'avantage compétitif que leur confère l'accès à un personnel qualifié relativement peu cher, et qui permet d'organiser la recherche comme un processus industriel au sein de grands départements (Williamson and Yin, 2014). L'innovation consiste ainsi essentiellement en nouveaux produits qui se basent sur l'amélioration des procédés de production, et sur la reconfiguration des technologies existantes (Zeng and Williamson, 2007). En revanche, comme le montrent de récentes études empiriques (McKinsey Global Institute, 2015), ces entreprises restent encore limitées pour utiliser la technologie avancée comme source d'innovation.

Ce n'est donc pas tant l'innovation qui est en jeu que la capacité à utiliser la technologie comme source d'innovation. La deuxième question découle de ce constat, et concerne le passage vers un modèle d'innovation par les entreprises qui intègre les technologies. Faire l'hypothèse que les entreprises chinoises cherchent à se positionner comme leader technologique requiert de postuler une période de transition vers ce leadership. Le problème est théorique. Comment caractériser ce phénomène de transition ? L'intégration de technologies en tant que sources de nouveaux produits requiert le développement préalable de compétences technologiques. Tant que cette intégration n'est pas réalisée, les produits ne sont pas visibles sur le marché.

En réalité, nous avons assez peu d'outils pour penser cette période de transition à la fin du rattrapage technologique. Cette période, bien que souvent mobilisée, n'a pas vraiment été caractérisée, à l'exception de deux études dans le cadre sud-coréen qui portent notamment sur la redéfinition des politiques d'innovation liée à la transition (Hwang and Choung, 2013) et sur la nature des activités d'innovation des entreprises (Choung et al., 2014). Une étude plus systématique de la littérature nous permet de mettre en évidence que cette transition s'articule autour de deux

dynamiques : la transformation progressive du système national d'innovation et le passage au leadership technologique des entreprises.

Repositionnement de la problématique dans le contexte chinois et mise en œuvre

Tout d'abord, est-ce raisonnable, au regard de l'avancement de la Chine dans le domaine des sciences et des technologies et du niveau de ses institutions, de formuler l'hypothèse d'une transition dans le contexte chinois ? Dans un chapitre consacré, nous montrons que les institutions chinoises présentent un certain nombre de faiblesse, notamment le système de gouvernance d'entreprise, mais que l'étendue des réformes et le développement des institutions justifient notre questionnement. Le système de propriété intellectuelle chinois s'est aligné avec les normes mondiales, ce qui était une condition de l'entrée du pays à l'Organisation Mondiale du Commerce en 2001. En parallèle, le niveau de recherche s'est élevé, ce qui est visible dans la participation des équipes chinoises aux collaborations internationales, et le fait que le pays soit désormais le second en nombre de publications scientifiques.

Les conditions de cette transition technologique s'inscrivent dans les particularités des entreprises en Chine, héritées en partie de l'histoire, et dans le contexte technologique contemporain. Le premier élément tient à la spécificité des grandes entreprises industrielles, que nous mettons en évidence par une analyse détaillée. Nous voyons en particulier que la diversification industrielle n'est pas un modèle dominant parmi les grandes entreprises. Au contraire, les conglomérats véritablement diversifiés représentent moins de 15 percent des grandes entreprises, avec la plupart des entreprises spécialisées sur un secteur industriel. En cela, la Chine présente un modèle qui contraste avec celui de la Corée du Sud, ou avec celui de l'Inde dans lesquels les conglomérats jouent un rôle important.

Ensuite, le passage à la frontière technologique pour ces entreprises s'inscrit nécessairement dans des dynamiques technologiques contemporaines. Il est, comme nous le défendons en nous appuyant sur la littérature sur les *general purpose technology* ou technologies génériques (Bresnahan and Tratjenberg, 1995) impossible de penser la transition des entreprises chinoises sans la remettre dans le contexte actuel. Chaque époque est en effet caractérisée par un ensemble de technologies dominantes qui tirent la croissance économique : la machine à vapeur, l'électricité, la mécanisation des procédés industriels, ou, plus récemment internet. Ces technologies jouent le rôle de moteur, et ont un impact sur les structures industrielles comme sur la compétitivité des entreprises. Comme nous le défendons dans notre thèse, le passage à la frontière par les entreprises chinoises s'inscrit nécessairement par la maitrise des technologies émergentes, afin qu'elles puissent, dans le futur, utiliser ces technologies comme sources de nouveaux produits.

Nous saisissons ainsi la transition vers le leadership technologique dans la manière dont les

grandes entreprises chinoises déploient leur recherche en nanotechnologie, que l'on peut suivre grâce aux brevets qu'elles prennent dans ce domaine. Le choix de ces technologies émergentes est pertinent pour deux raisons. Tout d'abord, les nanotechnologies, qui englobent la manipulation et le contrôle de la matière à des dimensions nanométriques (soit un millionième de mètre) ont des applications industrielles potentielles qui s'étendent à l'ensemble des industries (Shea, 2005; Shea et al., 2011). L'innovation en nanotechnologie est « silencieuse » (Andersen, 2011) car elle consiste en l'incorporation de nanostructures ou nanomatériaux dans le produit final. Ainsi, le principal canal de diffusion des nanotechnologies dans l'industrie se fait via les départements de recherche des entreprises (Larédo et al., 2010).

Cela montre l'importance de développer la capacité de recherche en nanotechnologie par les entreprises chinoises. Pour évaluer ce phénomène, nous avons donc centré notre recherche sur l'identification des plus grandes entreprises industrielles et observé leurs prises de brevets en nanotechnologies, directement ou via leurs filiales. Cela a requis la construction d'une base de données exclusive de 325 entreprises industrielles chinoises, à partir de sources diverses, en anglais et en chinois, et qui inclut, entre autres, des sources venant des marchés financiers, des informations données sur les sites du gouvernement chinois central, ainsi que des informations données par les sites des gouvernements locaux (provinces, municipalités).
Nous avons également travaillé sur la base de données des brevets pris par la Chine dans les nanotechnologies, afin d'identifier parmi eux, ceux qui avaient été pris par les 325 entreprises, Nous avons utilisé la base de brevets développée au sein de l'IFRIS et, sur la base des numéros de publications des brevets, nous les avons extraits de nouveau en chinois à partir du site de l'office chinois de propriété intellectuelle (SIPO) afin d'obtenir des informations plus complètes.

Principales contributions de la recherche

Que peut-on dire des entreprises chinoises au regard de la frontière technologique ? Les résultats que nous obtenons nous permettent de donner deux réponses à cette question. La première tient à la réalité de la tendance. Environ la moitié des grandes entreprises brevètent en nanotechnologies, soit 157 grandes entreprises. Il convient de préciser ici nous observons les dynamiques de 325 grandes entreprises, qui forment un groupe très hétérogène, et que, à aucun moment nous n'avons utilisé de critères d'innovation pour les sélectionner. La prise en compte des nanotechnologies dans la recherche de la moitié de ces entreprises montre un engagement dans la recherche qui ne se limite pas à l'ingénierie mais inclut aussi de la recherche plus fondamentale. Elle suggère également que les entreprises ont atteint la frontière technologique, ce qui n'implique pas, cependant, que les grandes entreprises chinoises soient à la frontière sur d'autres dimensions,

notamment la dimension organisationnelle.

Notre seconde contribution tient au fait que nous avons mis en évidence, au sein de ces 157 firmes, différentes trajectoires d'engagement dans la recherche. Si un certain nombre d'entreprises chinoises se sont engagées dans la recherche selon des modèles similaires à ceux que l'on observe en Europe ou aux Etats-Unis, elles ne constituent pas un modèle unique. Il existe d'autres modalités d'engagement. Celles-ci dépendent de la nature de l'actionnariat et de l'industrie des entreprises, mais également de conditions transversales, à savoir l'importance de la localisation géographique et l'héritage du système de recherche maoïste qui structure, sous des formes diverses, la manière dont une partie des entreprises font de la recherche.

Finalement, une des originalités de notre travail est de proposer un design de recherche fondé sur la théorie afin d'observer les dynamiques de transition technologique en œuvre. Plus spécifiquement, nous avons considéré les brevets en nanotechnologie non pas tant comme un indicateur de capacités technologiques, mais comme un indicateur des dynamiques d'apprentissage liées à la construction des capacités technologiques dans les technologies émergentes. Cela ouvre un champ intéressant d'étude sur la transition à la fin de la période du rattrapage technologique. Nous explorons à peine ce champ dans cette thèse, mais pensons qu'elle montre le besoin d'outils et d'indicateurs conçus pour suivre ces dynamiques de transition dans les pays émergents, au niveau de la recherche des entreprises mais également au niveau de leur production, voire de leur organisation.

Remerciements

Ils sont nombreux ceux qui ont contribué à ce travail.

Je remercie tout d'abord mon directeur de thèse Philippe Larédo, pour m'avoir guidée lors de ces cinq années de doctorat, pour son enthousiasme ainsi que pour sa bienveillance. Je remercie également Bernard Kahane, avec qui j'ai eu le plaisir d'initier ce travail de thèse.

L'accès au terrain chinois a été indispensable pour mener à bien cette recherche. L'aide de Madame Li Youmei et du professeur Zhen Qiang a été précieuse. Je les remercie vivement de m'avoir accueillie au Centre de Nanosciences et Nanotechnologies de l'Université de Shanghai. Je remercie également Rigas Arvanitis, pour son soutien, ainsi que le professeur Qiu Haixiong de l'Université Sun Yat-Sen, à Canton, où j'ai eu l'opportunité de séjourner.

Les données sont un enjeu crucial pour tout chercheur. Le travail remarquable réalisé à l'IFRIS, notamment par l'équipe de l'ESIEE, et particulièrement Lionel Villard, m'a permis d'avoir accès à des bases de données uniques, sans lesquelles je n'aurais pas pu mener à bien cette recherche.

L'écriture elle-même n'est pas un exercice solitaire. En particulier, les discussions régulières avec Axel Lagnau et Thanh-Thao Pham autour de nos textes ont été décisives Je remercie également tous ceux qui ont pris le temps de relire des morceaux du manuscrit : Heger, Axel, Thanh-Thao, Erhard, Géraldine, Lionel, et Antoine.

Avec le recul, en dépit de quelques aléas inhérents, je crois, au parcours de tout doctorant, mon moral a su rester bon. Le soutien et les encouragements de mes amis, de ma famille, et de mes collègues y sont pour beaucoup.

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Chapter 1: **Introduction**

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1. China's technological leadership in question

Recent developments suggest that large Chinese firms, in ten years, have become key players in the global economy. In 2015, about one out of five of the world's 500 largest companies come from China.[1]There is little doubt that China has taken the lead among emerging countries. There are 104 Chinese firms among the top 500 global firms, and 232 among the 2000 largest global firms (Chen, 2016). The fact that China takes the lead is also visible in international mergers and acquisitions. In 2016, the country has overtaken the United-States in outbound mergers and acquisitions, with 601 acquisitions announced between January and October.

This trend includes a technological dimension. In their acquisition strategy, Chinese firms increasingly target high-technology firms. Someacquisitions were highly symbolic. For instance, we can mention the purchase of IBM's PC entity by Lenovo in 2005, that of Volvo by Geely in 2010, and in 2016, the acquisition of Syngenta (chemicals and food industry) by the state enterprise ChemChina. However, these symbolic cases should not mask the whole phenomenon and the breadth of the trend which significantly includes the acquisition of small technological firms. Also notable is the increase in the patenting activity of firms. For three years now, two Chinese firms, Huawei Technologies or ZTE Corporation, in the telecommunication industries, have been the first international patent filer.

Three themes are central regarding this technological dimension. The first one is the changing nature of the source of competitiveness of Chinese companies, linked to the potentiality of their technological leadership. While China used to be known for being the "world's factory",perception has changed. According to a recent survey of executives based in China and working in foreign multinationals, in 2014, 65 percent of them considered that Chinese firms were "*equally or more innovative*" than their firms(Strategy&, 2014). This raises a new question. How

[1] And one out of four from a middle-income country, including higher middle-income (110 firms), and lower middle-income firms (18). This categorization refers to the terminology employed by the World Bank since 2016. The categorization includes low income, lower middle income, higher middle income, and high income. The large majority of firms come from high income or "developed" economies. Conversely, there is no large firm coming from low-income countries. Ten years ago, they represented less than 10 percent of all the world companies, with 31 firms from developing countries in the 2003 global 500 Fortune ranking.In 2015, these firms mostly come from China, Brazil, Russia and India but also from other countries including Mexico, Thailand, Indonesia, Malaysia, and Turkey.

far are Chinese firms from being able to compete on technological innovation? Answering requires looking more closely at the nature of innovative activities in China, and at the distance that remains till they reach the technological frontier.

The second dimension is the national impact of the transition to technological leadership. This dimension encompasses two distinct aspects. The first one is the question of China's global leadership. From that perspective, the technology is not only an economic but also a political and global strategic issue.[1]The history of leadership of China in science and technology helps us understand this proclaimed willingness of China to become a world's science and technology leader. *"China should establish itself as one of the most innovative countries by 2020 and a leading innovator by 2030, before becoming a world-leading science and technology power by 2049" (*President XI Jinping).[2]

The second aspect is the articulation with the transformation of Chinese industries. Chinese officials emphasized the fact that China has entered into a "new normal" of slower but better quality growth (Xinhua, 2014). The idea of an "innovation imperative" has emerged as a key component of quality growth, and has become a topical issue among business actors (McKinsey Global Institute, 2015). Indeed, the 2008 global financial crisis exposed the weaknesses of the industrial model that hitherto had driven the country's rapid economic growth but which also faced important problems: dependence on foreign markets, which precipitated waves of bankruptcies, pollution, waste of resources, and labor shortage, to mention just a few specific issues(Lisbonne-de-Vergeron, 2012; Wu, 2013).

The third dimension is the inscription of the current dynamics of Chinese firms in a wider historical perspective. Firms that compose the corporate landscape are those that survived or emerged in the last decades, either by being competitive or, for some of them, thanks to governmental support. Their conditions of emergence are of significance. It appears that most Chinese firms have a relatively short history that dates from the second half of the 20th century for the oldest ones. For example, Huawei Technologies and Lenovo were respectively created in 1988 and 1989. The first investment abroad by a Chinese firm occurred in 1984 when Citic Group invested in a US-based joint venture that shipped construction timber back to China for about $50 million (Week in China, 2016). Firms' history is quite short in the light of the industrial history, if we compare with established American or European firms. It was also associated with rapid change and technological learning. This rapid change was visible in the manufacturing and assemblage of

[1] This topic is linked with a dimension that we do not mention in the dissertation, the development of science and technology in the military field.
[2] In 2016. Xinhua News Agency (liuxinyong, 2016).

increasingly sophisticated products.

2. Research Question

Our guiding question is the issue of technological leadership of China. We have emphasized that to look at the conditions of transition to technological leadership of Chinese firms we needed to put this question in perspective with their history. This approach places our research in the continuity of studies on technological catch-up. This literature deals with technological learning in developing countries*i.e.* the acquisition and assimilation of existing, generally foreign, technologies (e.g. Amsden, 2003; Kim, 1997; Kim and Nelson, 2000; Mathews, 2002). Emphasizing the 'learning' factor, it has been successful at explaining the economic development of newly industrialized countries (Singapore, Taiwan, South Korea) and provides a general framework that succeeds in describing and explaining dynamics in a variety of settings. These empirically grounded studies offer insights on the trajectories and learning strategies of Chinese firms since the beginning of the reform and opening period in 1978, but we also refer to studies done in various national contexts.

We review this literature with two objectives in mind. Our first objective is to look at what has been written on the transition to technological leadership at the end of the period of technological catch-up. The notion of "innovation transition" appears to be central. It is borrowed from ex-post studies in Korea (Choung et al., 2011a, 2014; Hobday et al., 2004; Kim, 1997; Kim et al., 2004, 2004; Whang and Hobday, 2011). The importance of Korean researchers is explained by the country's history. Sixty years ago, South Korea was among the world's poorest countries, a land mostly surrounded by Sea and separated from the continent by a richer and more industrialized North Korea. In 2015, South Korea had joined the ranks of advanced economies and isparticipating in global innovation. The country, now considered as a developed market, ranks 30thregardinggross domestic productper capita in 2015 and is one of the world largest R&D spenders (OECD, 2014).

Our second objective is to contextualize our discussion within contemporary dynamics. We mentioned South Korea. However, the transition to technological leadership in China can only be understood if put into its historical and national context. This contextualization has two implications. The first one is that we need to look at the specificities of large Chinese firms. We shall dedicate one chapter to this question.

The second implication is that our framework has to integrate contemporary technological dynamics. In particular, the modalities of transition to technological leadership depend on the technological regime and require integrating emerging technologies. Our argument in particular is that it is important to look at trends in nanotechnology, which refers to the "application of scientific knowledge to manipulate and control matter in the nanoscale" (ISO/TS 80004-1:2010).This, also,

echoes to the mobilization of frontier technologies by the Chinese State as part of its development strategy (Medium and Long Term Plan, 2006, and Strategic Emerging Industries, 2010).

3. Researchimplementation and research design

The question of the "transition to technological leadership" is not only a theoretical question, but italso has a strong methodological component. Indeed, how to observe a technological transition? As we argue in the dissertation, during the period of transition to technological leadership, knowledge is not yet visible on the market because it has not yet been embedded in products, and firms are still in the learning process. In order to compensate for this lack, we propose an indicator for the transition that is grounded in theory. Noticing that most research on innovation transition uses market-based indicators such as already commercialized products or national rankings based on performance, we propose to use patent applications in nanotechnology as indicators of dynamics of technological learning.

We have carried out the empirical analysis of nanotechnology patenting activity among the population of large Chinese industrial firms, which we complement with heterogeneous sources of data. More specifically, we identify and select 325 large industrial firms and look at the way in which they, directly or through their subsidiaries, take patents on nano-related areas. This choice of patenting indicators is also justified by the degree of development of China's system of intellectual property rights since in particular its harmonization with global standards before China became a member of the World Trade Organization in 2001. In addition, such choice of indicators appears interesting for assessing dynamics of knowledge acquisition when there is little access to firms.

4. Thesis contributions

Our contribution is to propose an integrated theoretical and methodological framework to observe the dynamics of transformation towards technological leadership of large firms at the end of the period of technological catch-up in emerging countries.

Our framework aims to demonstrate the relevance of mobilizing the notion of innovation transition as an extension of the broad framework of technological catch-up studies and operationalize it in order to look at the contemporary questions raised by Chinese firms. By doing so, we show that the acquisition of technologicalknowledge has been a significant trend among large Chinese firms. While recent empirical research shows limited capabilities in science-based industries, and to a lesser extent, in engineering-based industries (McKinsey Global Institute, 2015), the way firms engage in nanotechnology research gives us further indications about dynamics of technological learning at work in China.

Another contribution of this framework is the possibility it offers to observe the transition to

technological leadership at the nationallevel while capturing some firm-level dynamics. Weshow in particular the existence of different modalities of engagement to research by large firms in China.

5. Synopsis

The overall structure of the dissertation is classic and dividedinto three blocks: the general framework (chapters 2 and 3), the research design and research methods (chapter 4), empirical descriptions (Chapter 5 to 8), and the discussion (chapter 9). Some of these chapters are relatively small in order to emphasize the main argument, as well as to facilitate reading.

Chapter 2 introduces the theoretical framework. It introduces studies on technological catch-up and discusses the notion of innovation transition. It also puts this theme into perspective with contemporary patterns of technological change, and in particular with the development of nanotechnology. Then, in Chapter 3, we discuss the relevance of mobilizing the notion of innovation transition in the context of China.

Chapter 4 introduces and justifies the research design, and it describes our methods. We explain how we identified and selected 325 large industrial firms, and describe the patent data collection process.

Chapters 5 and 6 aim at presenting the population of large Chinese firms we study. Chapter 5 discusses the specificities of these firms in comparison with other countries. Chapter 6 specifically focuses on patterns of research and development by large Chinese firms.

Finally, the chapters 7 and 8 describe nanotechnology patenting activities among Chinese firms. Chapter 7 looks at the generalization of nanotechnology within the 325 large companies we identified. Chapter 8 focuses on the different modalities of engagement in nanotechnology research among them. Chapter9 concludes the dissertation.

Chapter 2: **The conditions of transition to technological leadership by firms in emerging nations**

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1. Introduction

Our guiding question is the transition of China to technological leadership at the beginning of the 21st century, which we look at from the perspective of large Chinese industrial firms. Technological leadership refers to "*the ability to create new markets through new product designs based on in-house research, development, and engineering*" (Whang and Hobday, 2011).

We adopt two major angles to see what the literature can tell us on this topic. Taken together, they make the conceptual framework of the dissertation. This requires first looking at the conditions of a transition to technological leadership by firms in developing countries at the end of technological catch-up.[1]This first angle is generic: we look at the transition to technological leadership from a broad perspective, on the basis of studies done in various industrial settings. The second angle is to consider that such transition cannot be understood without accounting for technological dynamics that preside at the moment of history. Specifically, the dynamics of transition in China need to be replaced in the context of the beginning of the twenty-first century. This requires integrating contemporary technological dynamics, such as emerging technologies, in

[1] For the sake of simplicity, in this chapter as in the rest of the dissertation, we often use the term of "developing countries" as a generic term for all countries which are, at any moment of the history, not among the advanced economies, and "emerging" countries as a term that encompasses the large markets at the beginning of the 21st century (China, India, etc.). We readily recognize that these terms are very liable to be criticised. For instance, the World Bank does not use anymore the concept of developing countries, and prefers to distinguish among the level of income (low-income, middle-income, high income countries).

the transition framework.

2. The general framework of the dissertation: the technology frontier

The first sections are therefore focused on the innovation transition from a broad perspective. Enlightening contributions to that question are found in innovation studies on developing countries. The literature which, in its majority, adopts a historical perspective on developing countries is based on the idea of "catch-up" towards advanced economies. Catch-up refers to the "process in which a late-developing country narrows its gap in income and in technological capability vis-à-vis a leading country" (Odagiri et al., 2010), and therefore covers both economic and technological dimensions. This literature has been able both to explain the performance of the newly industrialized countries (South Korea, Singapore, Taiwan, Hong-Kong) (Amsden, 2003; Mike Hobday, 1995; Kim, 1997; Kim and Nelson, 2000; Lee, 2013; Mathews, 2002) and to identify common patterns in the development trajectories of diverse countries in Asia, and South-America.

It presents a common, general framework and a useful starting point for the discussion on the transition to technological leadership. Conversely, as we argue in this chapter, the transition to leadership is an extension of the literature on catch-up by developing countries.

2.1. The "catch-up" studies, a basic framework for developing countries

As a start, let us briefly introduce the "catch-up literature" and its most important contributions. It finds its roots in two traditions. These traditions share the idea that the most backward countries in terms of productivity have the greatest potential to increase their productivity level, and that they do so by absorbing more advanced technology, mostly from foreign countries (Abramovitz, 1986; Gerschenkron, 1962).[1]

The first tradition offers a global perspective. Economists use comparative and regression models to quantify and identify technological factors explaining differences in economic growth among developed and/or developing countries (Abramovitz, 1986; Boussemart et al., 2006). The American economist Moses Abramowitz contributed to the popularization of this line of thought as he published an article entitled "*Catching up, forging ahead and falling behind*" in 1986. He was among the first authors to use the term "catch-up" to describe the economic growth of Western European Nations, Japan, and Canada during the post-war period (1948-1972) thanks to the absorption of US technologies (Abramovitz, 1986).

How backward countries acquire technological skills and reduce the gap with the most

[1] Abramovitz measures the productivity as GDP per worked hours.

developed countries is the object of another research tradition, to which we refer more directly. This tradition adopts a national (or a regional) perspective and finds its roots in evolutionary economics. The evolutionary economic theory is strongly inspired by Schumpeter's idea of innovation as the driver of capitalism (Schumpeter, 1942) and sees the economy as a process of change based on the evolution of technology and routines (Nelson and Winter, 1982). This line of research pays attention to catch-up dynamics themselves, because it aims at explaining economic growth by developing countries (Amann and Cantwell, 2012; Chao Chen and Toyama, 2006; Mike Hobday, 1995; Kim, 1980, 1997; Lee and Lim, 2001; Mathews, 2002; Odagiri et al., 2010).

Central in this line of thought is the role of learning, present in the notions of 'technological accumulation'(Bell and Pavitt, 1993)and 'technological learning': "the absorption of already-existing techniques, i.e., the absorption of innovations producedelsewhere, and the generation of improvements in the vicinity of acquired techniques" (Viotti, 2002). The major assumption is that in developing nations, technological learning is the primary driver of economic development(Amsden, 1992; Kim and Nelson, 2000). While this idea is now dominant, it was not always the case, as the debate between "accumulation" and "assimilation" theorists in the late 1990son the nature of the "Asian Miracle" has demonstrated. Proponents of the accumulation theory considered that economic growth resulted from "perspiration rather than inspiration" and from the respective countries' ability to mobilize national resources to increase production inputs such as cheap labor force (Krugman, 1994; Young, 1994).

In contrast, for the proponents of the "assimilation theory," the acquisition and integration of increasingly complex foreign technologies into their industrial production by firms in developing countries is the primary determinant of economic development. They rather emphasize the "learning dimension" behind Asia's economic growth (Kim and Nelson, 2000). Technological learning is now recognized as the primary driver of economic catch-up in Asia and in particular of the "four dragons," Hong Kong, Taiwan, Singapore, and South Korea(Chu, 2009; Mike Hobday, 1995; Kim, 1997).

2.1.1. A three-stage historical model of technological catch-up

The dominant "catch-up model" that shapes our understanding of technological catch-up and technological learning was proposed by Linsu Kim, who was a Professor of Management at South Korea University and the Chairman of the Government Reform Council in South Korea. Trained in the United-States, he analysed the South Korean case and conceptualized technological catch-up as a three-stage historical process (Kim, 1980, 1997) with each stage associated with different learning mode, capabilities and relations to foreign companies (summarized inTable2-1). To narrow the gap with leading countries and firms, countries go through three main stages of technological

development (Lee et al., 1988).[1]

Table 2-1: Development stages of the catch-up process

Authors	Stage 1	Stage 2	Stage 3
(Kim, 1980)	Implementation	Assimilation	Improvement
(Stewart, 1979)	Development of capacity for independent search & choice	Minor technological change	New technology development and export
(Cortez, 1978)	Copying	Imitation	Adaptation and Innovation
(Katz, 1984)	Product engineering	Process engineering and production planning	R&D
(Lall, 1980)	Elementary -Learning by doing -learning by adapting	Intermediate -Learning by design -Learning by improved design	Advanced -Learning by setting up complete production system -Learning by innovation
(Lee et al., 1988)	Initiation	Internalization	Generation

Sources: author, adapted from Lee et al (1988)

During the first stage, economic growth is driven by the entrance of firms into established industries through assemblage and production activities. This is possible because it meets the needs of technologically leading firms, as evidenced in the analysis of global value chains.[2] Production in mature industries being capital intensive and requiring non-specialized skills; it is cost-effective for firms from developed economies to delocalize assemblage (Utterback and Abernathy, 1975). This means that, in the first stage, firms in developing countries take a competitive advantage from their "latecomer status" (Mathews, 2002), and leverage their low-costlabor force (Kim and Nelson, 2000, p. 79). They do not need advanced technological knowledge from their workers to start assembling products for foreign clients; the key to entering the industry at this stage is rather the ability to establish new linkages with incumbents, generally foreign firms, with which they have complementary resources (Mathews, 2002).

Firms are not passive actors (Bell and Albu, 1999; Romijn and Caniëls, 2011); technological development requires efforts(Bell and Pavitt, 1993). Firms interact with the foreign companies with

[1] Lee et al (1988)'s literature review shows that most authors consider catch-up as a three-stage developmentprocess, or, less frequently, as a four stage process. The authors propose a review of the literature on the different development stages through which developing countries go through in 1988. While they did this literature review in the 1980s, the general framework has remained stable.

[2] See research on the global value chain perspective. As they catch-up, firms in developing countries progressively upgrade their position in the global value chain (Gereffi, 1999, 2008), and it is possible to match the different catch-up stages of a country with a change of the nature of its contribution to the global value chain. In the electronic technology, Hobday demonstrated it for the Asian dragons (South Korea, Taiwan, Hong-Kong, Singapore) . South Korea and Taiwan moved from being manufacturers to become original equipment manufacturers to original design manufacturer, and finally to original brand manufacturer(Michael Hobday, 1995).

which they work and acquire knowledge on technologies and manufacturing processes (Arvanitis et al., 2006). This role of customer relationships is essential in the learning process and goes beyond technology licensing/collaborations or joint ventures with multinational enterprises (Kumaraswamy et al., 2012). In the process, latecomers develop their production capabilities, but also their absorptive capacity*i.e.* the capability to absorb further knowledge (Cohen and Levinthal, 1990).

During the second stage of the model, the technological "assimilation" phase, firms internalize (Lee et al., 1988) or assimilate (Kim, 1980) existing technologies to manufacture increasingly complex products. Finally, the third stage is the "improvement" (Kim, 1980) or "adaptation" stage. Firms have internalized enough technologies to adapt them and propose new products. This period is characterized by technology improvements or new product developments by firms. Such trajectory is visible, for example, in the upgrading of the South Korean chip-industry (Kim, 1997; Mathews, 2002). Firms like Samsung and Hyundai that manufactured chips in the eighties, managed to develop their technological competences for product development, manufacturing capacity, and mass production, by leveraging the product and process technologies they acquired to US firms (Micron, Intel, Texas Instrument…) and Japanese firms (Sharp), until challenging Japanin the memory chip market in the nineties.[1]

These stages of technological development which developing countries go through (the "catch-up process")are well understood and described in various settings: South Korea(Hobday, 1998; Kim, 1997), Taiwan (Mike Hobday, 1995), China (Xiao et al., 2013). We know abouttechnological learning modes (Arvanitis et al., 2006), capabilities (Amann and Cantwell, 2012; Dutrenit, 2000; Xiao et al., 2013) and strategies (Mathews, 2002; Xiao et al., 2013) associated with each stage. We also know about dynamic capability building (Dutrenit, 2000), and the development of absorptive capacity (Chung and Lee, 2015).

2.1.2. The limits of the catch-up framework in three stages

This three-stage model is consistent and successful in describing the trajectories of developing countries. Such a decomposition in different historical stages, however, leads to asking the question of what happens after the last stage. Indeed, from a theoretical perspective, for economists, catch-up is self-limiting and is not a sustainable driver of economic development, because as countries catch-up, they reduce catch-up opportunities (Abramovitz, 1986). Further catch-up is no longer possible when they manufacture at the technological frontier or are close to doing so because economic growth is based on the increase in production efficiency by firms upgrade (Figueiredo, 2014).

[1] "A New Force in Chip Wars:South Korean Chip Exports Are Growing 35 percent a Year, and the U.S. and Japan Are Worried", August 17, 1992, Los Angeles Times
To conclude the case of the South Korean chip industry, the period of industrial upgrading was followed by a decrease of interest for this technology. In 2015, Samsung announced that it cut investments for chips (Korea Times, 2015)

Therefore, what happens at the end of the period of technological catch-up is both a theoretical and empirical problem. This question ties into contemporary interrogations about emerging countries. Some behaviours of firms, notably in China or South Korea, cannot be explained by the catch-upliterature (Choung et al., 2014). Also, the concept of catch-up is not simple. The term refers to the path during which a country or a firm builds skills at a more rapid pace than leading countries or firms and therefore narrow the gap with them. It might also refer to the situation of a country reaching technological leadership status *i.e.* a successful catch-up. A focus on the first dimension, the development of capabilities during the historical catch-up process, does not answer questions linked to the second dimension, the conditions of transitioning towards a "leadership position."

In addition, catch-up is a historical process that occurs over a limited period of time and is embedded within the broader process of technical change. Few elements exist on these questions. How long does theperiod last during which countries catch-up? How does it end? The first question – how long it lasts – has not been studied despite the concrete implications it has for policy makers, with some rare exceptions (Bell, 2006). Estimates on the basis of existing case studies in Brazil, Malaysia and in Asia suggest that it takes at least – when the process is successful - twenty years to be able to manufacture world class products, with considerable variations, and it can last a much longer time (Bell and Figueiredo, 2012).

2.2. Questioning the end of technological catch-up

Regarding the second question, how does catch-up end? From a theoretical perspective, the technological catch-up process ends, when developing countries reach the "technology frontier."As a theoretical concept, the technology frontier refers to the latest technology available in the world.

Empirically, technological catch-up is successful and thus ends, when a country takes global leadership.[1] This success might encompass several dimensions. The technological frontier is indicated by products considered as the most technologically advanced available. A complementary approach is to focus on particular processes and to consider the most advanced firms in performing a technological process; this notion is somehow similar to manufacturing at the technological frontier (Figueiredo, 2014). Those dimensions are intertwined but not equivalent. A firm that produces the 'best' product does not need to be leader in mastering all technological processes necessary for its development and production or even being the most advanced in terms of technology.

Evidence would predict the need for a transition at the end of technological catch-up. There

[1] This by no mean suggests that all catching up trajectories are successful. Some fall behind. Another risk is to fall in the "middle income trap", a risk for countries including China (Lewin et al., 2016)

are many precedents of formerly catching up countries now contributing to push the technological frontier by proposing new innovations to the world . The technological supremacy has varied since the industrial revolution, with the successive leadership of England, Germany, and the United States. There are also historical cases of countries reaching technological leadership status and then declining such as Netherlands (Davids, 2008). Recent examples of successful catch-up include the economic development Japan in the post-war period (Morris-Suzuki, 1994), or more recently South Korea(Mahlich and Pascha, 2007).[1]

We have limited tools to analyse this period. While there are many studies on the topic on innovation in developing countries, few specifically integrate the possibility of transition in the catch-up framework. Some exceptions exist, mostly onSouth Korea(Choung et al., 2011a, 2014; Whang and Hobday, 2011), but also Brazil (Figueiredo, 2014) or Iran (Kiamehr et al., 2015).

Also, one should emphasize that reaching the technological frontier is different from being able to manufacture at the technology frontier. Following the distinction between innovation and production capabilities (Bell and Pavitt, 1993), firms can approach the technological frontier on these two levels (Figueiredo, 2014). The first path is to adopt and improve existing technologies in a way to produce world-class products, thus relying on incremental innovations: this includes manufacturing at the technology frontier and strategies based on incremental innovations.Industrial upgrading refers to the development of world-class manufacturing capacities and or catch-up in production capabilities.[2]Gereffi, for example, showed how both Mexico and China managed a shift in the technology content of the export from primary and resource-based products towards high tech technology (Gereffi, 2008). However, such industrial upgrading does not automatically position them in a leadership position: a firm can produce world class products without advanced innovative capabilities (Bell and Figueiredo, 2012).

To push the technology frontier forward requires making new technological propositions, even though the separation between the production and technological side is somehow more conceptual than real (Arvanitis et al., 2014). This refers to the capability by firms to propose radically new products, which, and this is the second dimension, can create new markets. Those new markets differ from the ones emphasized by research on frugal innovation (Radjou et al.,

[1] In 2013, South Korea ranks 30th in terms of GDP per capita (ppp), and 14th in nominal GDP. China was at the time the second world economy, but it is 84th regarding its GDP per capita. As a matter of comparison, the first research studies on South Korea's transition date back from the beginning of the 2000s. We cannot resist to quote Kim Linsu in its 1997 book: "*... total South Korean R&D is merely about equal to that of a leading company in advanced economies. General Motors and Siemens alone spend as much for R&D as all of South Korea does. […] As a result, South Korea is squeezed between the advanced countries that have far stronger technological bases than it does and second-tier developing countries that are rapidly catching up with it. South Korea is indeed at a turning point of its modern history. What should the country do to sustain its growth*?" (Kim, 1997, p234-235)

[2]Industrial upgrading refers to a general progress of existing firms in their product lines. It is the "*process by which economic actors – nations, firms, and workers – move from low-value to relatively high value activities in global production networks*" (Gereffi, 2015)

2012). Christensen and Raynor distinguish between low-end market disruptions and new market disruptions (Christensen and Raynor, 2003). Low-end disruptions benefit from low-cost business models to reach the least attractive customers – this is the idea behind frugal innovation. These, however, do not create new markets. This means that the innovation transition is characterized by the creation of new "high-end" markets.

2.3. Characteristics of innovation during the last phase of technological catch-up

Before addressing the issue of transition, we need to review the role of innovation in developing countries. Recent work has highlighted that it was wrong to consider that there was no innovation during the catch-up phase. Instead, innovation is of a very different nature, and not based on advanced technological knowledge. This section reviews their characteristics to better qualify the changes that take place during the transition phase.

Three research streams are useful to characterizing innovation in developing countries: catch-up studies, innovation studies in developed countries, and innovation management studies on emerging countries. Innovation management studies in emerging countries offer insights on strategies of firms and explain how they innovate (Ramamurti and Singh, 2009; Zeng and Williamson, 2007). The two other perspectives – catch-up and innovation studies --, account for technological change but are somehow disconnected with each other as the innovations they study differ. The catch-up literature builds on the assumption that developing countries are followers, and, therefore, pays greater attention to dynamics of technological learning, understood as the absorption of already-existing techniques, than to innovation (Viotti, 2002). Conversely, innovation studies based on the Schumpeterian idea of innovation driving economic development primarily focused on developed economies (ibid).

This remains true despite an increase in the number of research on "innovation in developing countries." A considerable proportion of them focuses not so much on new-to-the-world innovations, as on new-to-the-firm innovations which enter in the general framework of technological learning (technological improvement). It is easy to understand why. For a long period, it made no sense to focus on new-to-the-world innovations by developing countries. Moreover, considering new-to-the-firm innovations is common. For instance, the Oslo Manual integrates new-to-the-firm innovations in its scope (OECD, 2005). This is also common when studies focus on firms' internal processes (Bell and Figueiredo, 2012; Dutrenit, 2000), partly because it is arguable that learning processes do not substantially differ regarding whether firms innovate to the world or to the firm (Rosenberg, 1972).

The reasons why this definition has been prevalent in most studies on developing countries are summarized by Richard Nelson: "*For countries aiming to catch-up, the basic challenge is to*

learn to master new ways of doing things. ...The innovation involved in catch-up is not what economists studying technological advance in countries at the frontier tend to mean by the term. The innovation in catching up involves bringing in and learning to master ways of doing things that may have been used for some time in the advanced economies of the world, even though they are new to the country or region catching up"(Nelson, 2008). Alternatively, "*innovation in developing countries should not be defined just in terms of shifting global frontier technology but in terms of what is new to the country*" (Dahlman, 2010).

We find the same distinction in the context of our discussion; innovation transition can be understood both under a national perspective andunder the firm's perspective. For instance, Gabriela Dutrénit has developed a comprehensive firm-level framework of the innovation transition accounting for both technological and organizational dimensions based on the study of the Mexican glass producer Vitro. She, however, does not focus on *new-to the-world* innovations but on *new-to-the-firms* innovations (Dutrenit, 2000).

Such a perspective, useful as it might be for understanding firms and national dynamics during technological catch-up, is not adapted to look at dynamics of countries advanced in terms of technological learning. Instead, for our purpose, we need to adopt another perspective on innovation and consider itin terms of "shifting global frontier technology," to re-use Dahlman's expression (Dahlman, 2010). This implies that we focus on new-to-the-world innovations, innovations that include technological products, production processes, and delivery processes (OECD, 2005).

For this reason, in this dissertation, we focus on new-to-the-world innovations only, on what we refer to with the notion of global innovation. Developing countries participate in global innovation even during technological catch-up. The possibility of firms to make technological improvements characterize the last stage of the catch-up process (Kim, 1997). However, there is not a strict separation between technological improvements on one side and innovation in the other; most of the time, technological change is "a bit-by-bit, cumulative process" (Tushman and Anderson, 1986).

For a while, the consensus was that firms from developing countries did not innovate. It is only very recently that research, empirically grounded, led to temper this view and to show that the division between advanced and developing countries in terms of innovations was not definitive.[1]

[1]A first step was to recognize the role of emerging markets as "innovation users." The popularized model of frugal or *jugaad* innovation refers to *"good-enough"* affordable products, often developed by multinational subsidiaries, and adapted to local markets (Radjou et al., 2012; Zeschky et al., 2011). In addition, these products could be used by firms in other advanced economies: the notion of reverse innovation comes from the fact that products developed first for developing countries had been adopted by developed markets (Govindarajan and Ramamurti, 2011; Immelt et al., 2009). In 2009, in an influential paper published in Harvard Business Review, Jeffery R. Immelt, CEO of General Electrics since 2000, Vijay Govindarajam andChris Timble qualified as "*extraordinary"* the factthat $1,000 handheld electrocardiogram devices and ultrasound machines had been developed for India and China before being sold in the United States (Immelt et al., 2009).

The emergence of firms led to question their strategies (Ramamurti and Singh, 2009), and, in particular, their specific competitive advantage regarding innovations (Batra et al., 2012; Williamson et al., 2013).

These advantages include generic advantages, like the access to low-cost talents at all skills level and/or the access to local markets. Other advantages might be specific to the institutions of a nation: access to state assets and intellectual property, as well as management autonomy in the Chinese case (Zeng and Williamson, 2007).

Firms in developing nations have to use their resources to develop new products and follow "cost innovation" models which do not require a strong technological base (Batra et al., 2012; Zeng and Williamson, 2007). They can do that by innovating on non-technologically related product features such as design (Forbes and Wield, 2000, 2006) and on inventing other ways of organizing R&D (Williamson and Yin, 2014). An alternative approach is to use architectural innovation(Zeng and Williamson, 2007)*i.e.* the reconfiguration of existing technologies into a new assemblage to form a new product (Henderson and Clark, 1990). An example is a high-performance line of washing machines by the Chinese firm Haier, based in Qingdao. This product line results from the integration of features of existing washing machines in Asia, Europe, and North America. These three nations had followed different paths with differences such as water consumption, electronic sensors, etc. In order to compensate for its technological lag, Haier made a machine that combined a single engine for two separate washing actions, respectively coming from the European and American models and electronics based on Japanese models. It resulted in a product that gained the gold medal at the International Invention Expo in 2004 (Zeng and Williamson, 2007). The use or the reconfiguration of existing components is far from being specific to developingcountries but is often behind emblematic success-stories from developing countries such as the low-cost car TATA (Ray and Kanta Ray, 2011).

When looking at these strategies, we can reach the following conclusions. Firms, in particular in identified countries like India or China innovate. However, in this innovation process, firms still often use as a competitive advantage their "latecomer" status (Mathews, 2002), even though the modalities may differ. Second, firms behind the technology frontier do innovate, through incremental and architectural innovations on already existing technologies. This implies, however, that they do not use technology as a source of innovations. The central issue in the innovation transition is therefore not about innovation itself, but about the capacity of using technology as a source of innovation.

The idea of "global reverse innovation" has rapidly expanded until recognizing the contribution of firms in developing countries at different phases of product development, not only as a result ofmarket opportunities but during the different phases of market ideation, product development, and market introduction (von Zedtwitz et al., 2015).

2.4. The state of the specific literature on the innovation transition

The idea of a transition to innovation leadership at the end of the catch-up is recognized under concepts such as "innovation transition" (Altenburg et al., 2008; Choung et al., 2014; Hobday et al., 2004; Whang and Hobday, 2011) or "post-catch-up phase" , the latter mostly used by South Korean researchers who adopt this prism to study South Korea(Choung et al., 2014; Hwang and Choung, 2013).[1]

The concept of innovation transition is intuitive but remains vague. And, as the concept is vaguely defined, it is difficult to operationalize it. Innovation transition might refer to the "transition from the adoption to the creation stage" (Choung et al., 2014), from production to innovation (Altenburg et al., 2008); from imitation to innovation or "transition from an economy in which growth is based on labour intensive production and imported ideas and technology to one in which growth is driven by domestic innovation" (Dobson and Safarian, 2008). All of these are descriptions rather than definitions or characterizations of the period.

Indeed, most studies describe features of the innovation transition they take as research objects but do not need to characterize it for their purpose. Studies can be grouped into several categories. The first category focuses on a group of firms (in one industry for instance) or on one particular firm: Samsung (Kim et al., 2004). They described how firms become technological leaders or why they fail to do so. Explanations include impeding factors such as the weaknesses in firms' strategic management (Zhao, 2016) or the lack of dynamic capability (Xiao et al., 2013).

Another set of questions deals with when and how a nation becomes a leader, either in mastering a particular technology or in a given industry, which leads to longitudinal studies of technological trajectories (Choung et al., 2014; Lee and Lim, 2001). Finally, alternative topics that have been studied include the role of the domestic market (Whang and Hobday, 2011), the participation of countries or firms to establish formal or informal technological standards (Breznitz and Murphree, 2012; Choung et al., 2011a, 2011b; Gao, 2014) and the change that is required in innovation policy after catch-up in order to take into account the fact that innovation is less centralized than during catch-up (Hwang and Choung, 2013).

3. **Characterizing the transitional phase**

3.1. The innovation transition of a change of objectives and system orientations

It appears from these papers that the transitional dynamics can be observed from two angles: at the firm level and in a systemic approach. Two papers propose advanced conceptualizations of

[1]This expression "post catch-up" is ambiguous, as it is not clear whether it refers to the period of the transition itself or to the period posterior to it.

the innovation transition period (both co-authored by Prof. Choung Jae-Yong, a professor at the Business Department of the public research South Korean university KAIST). The first one proposes a typology of innovative activities specific to firms at the end of the catch-up (Choung et al., 2014). The second paper is from Hwang and Choung. In order to deal with innovation policy during the post catch-up phase, the authors build a simple typology of the values and components of the "post-catch-up" system (Hwang and Choung, 2013) (see p. 36).

3.2. Firms: from latecomers to technological leaders

3.2.1. A trend driven by domestic firms

A first approach, that is adopted also in this dissertation, is the participation of firms in the transition. Until now, we indifferently included foreign and domestic firms under the scope of firms. Domestic firms are, however, central actors. Studies show the prominent role of domestic firms in the innovation transition in South Korea, notably the largest ones, Samsung, LG and Hyundai (Hobday et al., 2004; Kim, 1997). The studies are based on the South Korean case, though. The importance of large domestic firms – chaebols - is explained by South Korea's industrial structure and model of development. Studies also show that foreign firms played a minor role. In the 1960s, South Korea was not particularly attractive for foreign firms to set up, and its development was based on the technological upgrading of domestic firms for domestic and export markets, supported by a developmental state (OECD, 2009). This also influenced their learning modes. South Korean personal computer firms started with assembly thanks to reverse engineering in the late 1970s because foreign firms were not interested in the South Korean market. Domestic firms had to use technology licenses when they were not able to develop the next generation of personal computers(Lee and Lim, 2001).

But what happens to countries that follow alternative pathways? The role of foreign firms and foreign direct investment during catch-up is likely to have an impact on their role at the end of the catch-up period. China opened the country to foreign investment in 1978, with an acceleration since 1992, notably from other East-Asian economies and in favor of manufacturing industries (Naughton, 2007, p. 401). It was, therefore, a major channel of financing growth, by contrast with South Korea that rather emphasized economic independence and relied on long-term loans to finance industrial developments (OECD, 2009, p. 58). The country size is also important. China faced a very different situation than South Korea, as international companies were willing to enter the Chinese market when it opened, leading to massive diffusion of "market for technology" arrangements.

Such variation among national trajectories suggests that the respective contributions of

foreign and domestic firms during the transitional phase to leadership is likely to be a more complex topic in countries like China than it was in South Korea. This requires briefly considering the case of foreign firms. While economic growth during catch-up can be partly driven by foreign firms, the innovation transition requires the development of innovation capabilities by domestic firms. This is encapsulated in the notion of "indigenous innovation", notably in the Chinese context (Tang, 2010).The concept emphasizes the prevalent role of domestic firms.

The respective role of foreign technology and indigenous innovation in catch-up has been studied (Fu et al., 2011). Foreign firms have their own interests that are not necessarily aligned with that of the host country. For instance, foreign equity is associated withlesser investment in R&D in India, even though it has a positive impact for firms created after 1985 (Sasidharan et al., 2015). In addition, when they do invest in R&D, innovation outcomes differ. When multinationals set up R&D in developing countries, most of the added value does not benefit local firms: Successful commercialization based on basic research benefits the country of origin of the firms that do it, because the gross profit is mostly used there (Dedrick and Kraemer, 2015).

Foreign-invested firms or subsidiaries of multinationals sometimes are considered as latecomers. The underlying reason is that they follow technological catch-up strategies and are also engaged in technological process, with learning processes that are partly similar to that of domestic firms (Bell and Figueiredo, 2012; Forbes and Wield, 2000). For instance, Hewlett-Packard's subsidiary in Singapore has started in the 1970s by stringing computer core memories, then moving from component manufacture to product manufacture (1973), setting up R&D operations (1983) that made possible process improvements (or process innovation), product development and design innovations starting from the end of the nineties (Forbes and Wield, 2000). However, these firms are integrated into the multinational firm's network and do not share with latecomers two particular challenges: access to resources and market (Mike Hobday, 1995).

The presence of foreign firms also impacts the level of knowledge and scientific capabilities of their host countries through spillovers effects such as reverse engineering, skilled labour turnovers, demonstration effects, and supplier–customer relationships (Cheung and Lin, 2004). The impacts have been shown to be mostly positive during catch-up. During technological catch-up, domestic firms have weak capabilities, and the strategies they implement are largely defined through the relationship they maintain with frontier firms, generally foreign (Xiao et al., 2013). As the gap closes, the situation changes. Local R&D in firms becomes more important in countries that succeed in the initial stages of catch-up (Kim and Nelson, 2000, p. 81). The nature of the impact of the presence of foreign firms on R&D performance of domestic firms is not as direct on the technological performance of domestic firms. Domestic firms only benefit from R&D spillovers if they have in-house research and sufficientabsorptive capacity (Fu 2008).

3.2.2. Strategic options for firms that approach the technological frontier

We focus on the role of domestic firms.[1] At a country level, the national innovation transition is characterized by the fact that latecomers engage in the transition to leadership (see studies in table 2-2). The literature explores the strategy of latecomers during catch-up (Mathews, 2002), but also when they approach the technology frontier (Hobday et al., 2004; Kiamehr et al., 2015; Xiao et al., 2013). These latecomers present specific features: they are neither "late entrants" (or new entrants) from an advanced economy nor "start-ups' (Mathews, 2002). In contrast with new entrants from advanced economies, latecomers are mostly concerned with overcoming their "resource deficiencies" in technology and market access (Mike Hobday, 1995) by targeting resources from foreign firms that are the least rare, most transferable, and most imitable resources (Mathews, 2002).

In other words, they want to escape from their condition of "latecomers" (ibid). However, as Kiamehr notes, at first, latecomers are not concerned with the technology frontier (and in some particular cases nor with overseas markets). For instance, "*the senior management team of Mapna [*an Iranian firm, in the thermal energy generation industry*] did not initially intend to enter overseas markets or compete at the technology frontier with the most advanced firms. Instead, they had the limited ambition of replacing high-cost foreign imports of electricity plants by providing low-cost project management services, and sourcing complex capital goods and sophisticated engineering services from abroad."* (Kiamehr et al., 2015).

As they go closer to the technology frontier, firms have broader strategic options. During catch-up, the range of strategies is narrow (Mathews, 2002), and is limited to dependent or imitative strategies (Xiao et al., 2013). Dependent strategies are based on technological dependence: latecomers initially focus on getting production capability through licenses or joint venture deals with the leading firms. Firms that adopt imitative strategies remain dependent on technological technologies, but they do not pay for it, and the learning process includes more unbundle and reverse engineering (Xiao et al., 2013). Additionally, Freeman proposes a third additional strategy, which is a defensive technology strategy: "*inwhichthefirmdevelopsitsownmore-or-lessinnovative technology,notreallynovelbutdistinctenoughtogive IndependentIP,andthusbreaksthrougha'patentblockade'"*(Freeman and Soete, 1997).

As they approach the technology frontier, the range of strategic options broadens (Choung et al., 2014; Hobday et al., 2004; Xiao et al., 2013), leading to a new situation. For the Korean case, Hobday formulates it in these terms:

As leading South Korean firms approached the innovation frontier and began to compete on

[1] Of course, the frontier is not always very clear between foreign and domestic firms, as illustrates the case, among others, of international joint-ventures.

the basis of new products supported by in-house research and development (R&D) they appear to be confronting a new and difficult strategic dilemma. Should they continue with their tried and tested formula of low cost 'catch-up competitiveness' relying on the global leaders to generate new products and new markets? Or should they try and compete as leaders on the international stage by deploying in-house R&D to develop their own leading edge products and systems? (Hobday et al., 2004).

3.2.3. From the innovation dilemma to a diversification of technological strategies

Indeed, if they adopt a technological leadership strategy, firms enter in competition with firmsfrom advanced economies that benefit from market and technological knowledge. The latter "*hold a deep knowledge of the industry and have a sharper sense of the dynamics of technologies and the changing nature of markets*(Kiamehr et al., 2015). Firms from developing countries, in addition to the lack of capabilities and smaller knowledge base, also suffer from their reputation. The last point is particularly important in industries that produce complex product systems such as aircraft, high-speed trains or capital goods when firms have no "track record" that would help them win new contracts (Kiamehr et al., 2015).

In response to these difficulties, scholars have proposed "design innovation" as a strategic alternative (Forbes and Wield, 2000, 2002). Firms that approach the technological frontier should focus on innovating on design features. Firms might benefit from putting their R&D efforts on following the technological frontier rather than aiming at going beyond it. However, design-based strategies, which are part of the "cost innovation" strategies, are still characteristics of the last stage of technological catch-upWhile empirically relevant, this approach is prescriptive and does not tackle the "innovation dilemma" between the cost of engaging in technological leadership and the erosion of latecomers' competitive advantage (Hobday et al., 2004).

The innovation dilemma is solved by the adoption of hybrid strategies by latecomers. The analysis of corporate strategies of South Korean firms shows that the proximity to the technology frontier is associated with a growing diversity and mixing of technological strategies (Hobday et al., 2004) and a greater diversity in the nature of developed products (Choung et al., 2014). This correspondsto the idea that the relevant unit of analysis for technology product development within a large firm is not the firm anymore, but the division (Utterback and Abernathy, 1975).In advanced economies, incremental innovations represent most innovative activities (Rosenberg, 1990). For instance, Bell and Figueiredo notice that "*nearly two-thirds of Canadian firms had engaged only in the kinds of incremental innovative activity that have commonly been considered the reverse of firms in developing countries*"(Bell and Figueiredo, 2012). Strategies are not mutually exclusive, and large firms can simultaneously combine offensive or frontier technologies with "followership"

strategies (Hobday et al., 2004).Making new technological propositions is associated with a diversification of firms' market propositions. The innovation transition requires a diversification of the nature of innovative activities by firms. The phase is associated with innovative activities of all types, and with the capacity of firms to engage in mature and immature technological markets (Choung et al., 2014), as well as to innovate through the creation of new "artefact" and knowledge than through architectural innovation (Hwang and Choung, 2013).

The modality of technological leadership depends on the nature and maturity of the industries. Firms follow different transition paths regarding the degree of maturity of their industry (Choung et al., 2014). A technology deepening pattern "*occurs when latecomer firms enter the market at the product's mature stage and advance all the way to introduce frontier*products" (Choung et al., 2014). The second architectural innovation pattern "*occurs when latecomers enter the product lifecycle immediately after the dominant design for a system is established*." Finally, a third path is available to firms, the radical innovation pattern, when "*latecomers possess original technology and enter the life cycle at the fluid phase*." In their typology, the first two paths are two different types of incremental innovations that operate on markets more or less mature. During the transition, *"the entry timing from the mature stage to the fluid stage becomes diverse"* (Choung et al., 2014). This typology can be put in perspective with the nature of the technology used. Firms can follow different catch-up patterns (path-skipping, path-following, path-creating) depending on the degree of tacitness of the knowledge in the industry: the more knowledge is tacit, the more it is difficult to assimilate external knowledge, and thus to internalize existing technology for catch-up (Lee and Lim, 2001).

3.3. Innovation system: From active "technological learning" to "innovation"

3.3.1. The evolution of the institutional environment

Innovation requires a different institutional environment than technological learning (Viotti, 2002) and technological catch-up (Choung et al., 2014; Hwang and Choung, 2013). On the one hand, this transformation can be interpreted as a functional change of the innovation system: Innovation transition requires the reorientation of institutions from a 'learning' strategy aiming to master technology and absorb it into production, to a system that supports the development and commercialization of new products (Viotti, 2002). Indeed, the difference between national innovation systems led Viotti to develop the notion of "national learning system" (Viotti, 1997, 2002). He identifies three states of national systems of technical change: a national passive learning system (absorption of production capacity), a national active learning system (technology absorption) and a national innovation system (Viotti, 1997, 2002). National learning systems are in

place during the catch-up period, and developing countries face a transition from a passive to an active learning system, a transition that not all countries achieve: Brazil failed while South Korea achieved it at the time.[1]Shifting from a national active learning system to a national innovation system requires a second transition at the country level (which of course implies that the country was successful in the first transition).

On the other hand, elements that compose the national innovation systems become not adapted: for instance, South Korea's dirigist state and chaebols that allowed a rapid technological learning have become generator of rigidity, and associated with the lack of small technological firms (Kim, 2000) which requires a reconfiguration of the components of the innovation system, and the redefinition of national innovation policies (Hwang and Choung, 2013).The transition does not consist only in the improvement of existing institutions, but also in a redefinition of their functions. Hwang and Choung, have compiled several elements (Table 2-2) on the redefinition of innovation policies in South Korea(Hwang and Choung, 2013). A element they emphasize the changing nature of key innovation actors: they observe a shift from a catch-up based economy driven by a few large firms, towards a more diversified economic structure, which requires changes in the nature of interactions of these firms with other firms (ibid).

Hwang and Choung's study illustrates that South Korea's transition has been shaped by the specificity of the South Korean situation, the centralization of actors and the developmental state. It shows that the reconfiguration of the South Korean innovation system cannot be understood without reference to the modality of its development, and illustrates the necessity to consider national specificities when looking at the modalities of transition in other national settings.

Table 2-2: Catch-up and post catch-up innovation system: case of South Korea

System Component		**Catch-up system**	**Post catch-up system**
Key innovation agent and capabilities	Main innovation agent	Selected large corporations	Diversified economic actors
	Innovation capabilities and characteristics	Shortened learning time, productivity, manufacturing capability, incremental innovation	Fundamental knowledge production, utility value, radical innovation
	Relationship among corporations	Vertical integration	Horizontal integration among specialized corporations
	Private firm- public research relationship	Coordination by public research institutes in system development and linkage of large chaebol firms supply firms	Creating ripple effect from basic knowledge production, technical commercialization focused on technology-intensive SMEs
Institution arrangement and its	Goal of innovation policy	Short-term achievement of economies of scale, R&D efficiency	Diversity creation by converging technology and knowledge, R&D effectiveness

[1] Viotti's article was published in 2002, based on his doctoral dissertation. The author used indicators in four categories: national patterns of education and training of the labour force; national patterns of technology acquisition (imports, license); national patterns of commitment to resources to technological learning (R&D), and indicators on the outcome of the national technological effort (patents, diffusion of robots, etc). This transition towards incremental innovation is a condition for being a candidate for innovation, as it is unlikely to develop and commercialize new products without being able to improve existing ones.

principles of operation	Regulation method	Discipline by development state selective support and targeting strategy	Ecological regulations between network state-innovation actors, trust and consensus
	Adjustment mechanism	Government-centric top-down planning and control	Consensus with various stakeholders, bottom-up planning
Interaction with external environment	Market environment	Subordinate partner of global production network by export	Securing external openness based on global frontier firm – internal resources
	Knowledge environment	Fast-follower by adopting existing technology, Entry in growth period of techno-economic paradigm	Global knowledge producer, Entry in introduction phase of techno-economic paradigm

Source: Reproduced from Hwang and Choung (Hwang and Choung, 2013)

3.3.2. The role of institutions in the transition to leadership

We shall briefly describe the elements that are part of a reconfiguration of the institutional environment. The first category of institutions ensures that the scientific and knowledge bases provide firms with competences and skills they need, notably through their human resources. The second category brings together institutions that are part of the general business environment, and that create incentives (or barriers) to innovate. This section is voluntarily brief. It is not intended to provide a systematic discussion on institutional changes during the innovation transition, which is not the core question of this dissertation, but it rather aims at introducing a framework easy to operationalize in order to discuss the relevance of the innovation transition in the case of China.

i. The development of skills and competences in the country

How to ensure that firms have access to the technological skills they need in order to develop new products? A major disadvantage of latecomers is their lack of access to scientific and technological knowledgecenters(Mike Hobday, 1995). As a way to develop capabilities, and meet their specific needs, developing countries need to develop their own scientific capabilities, through universities and higher education institutions (Mazzoleni and Nelson, 2007).

People is the major channel of innovation in a country. The role of human resources is primordial for firms that want to innovate at the technology frontier, as they need engineers, and researchers to join their R&D teams if they want to extend their knowledge (Lee and Allen, 1982). The national educational system plays a primary role in providing skilled personnel. This includes people trained in management, and in science and technology. South Korea built its innovation transition on national and individual investments in education (Kim, 1997).[1] Another major resource for a nation is the diaspora and people trained in universities abroad. Returnees have been, in particular, determinant in China (Welch and Hao, 2013).

[1] Linsu Kim proposes a cultural explanation, and links the success of South Korea with the emphasis put on education in the Confucian value system (Kim, 1997, p. 204)

ii. The general institutional environment

Engaging in the development of world-class products requires a change of technological strategy. This choice is conditioned by internal factors (Nelson, 1994). Strategic options are also constrained by institutional factors, especially in weak institutional environments (Wright et al., 2005).

Some institutions have a considerable impact on the readiness of firms to engage in innovative strategies. A determinant institution is the system of intellectual property rights. Its impact on catch-up has been analysed in several countries that include Israel, South Korea, and China, Brazil or Argentina (Odagiri et al., 2010). The intellectual property rights system is important for catch-up (Odagiri et al., 2010; Xiao et al., 2013), but it plays a contrasted role. It has a differentiated impact regarding the degree of economic and technological advancements of a country (Kim, 2004). When the degree of technological advancement is low, strong IP protection constrains latecomers by providing barriers to the access of foreign technology, and to the commercialization of protected technologies even though they have manufacturing capabilities to do so (Xiao et al., 2013).The intellectual property rights system obeys to a different system of incentives in an innovation-oriented economy. Even though there is a debate on its impact on industrial development (Maskus, 2000), an adequate system for the protection of intellectual property rights is recognized to provide incentives for firms to invest in research and development, by ensuring that they will get the rewards from research and technology commercialization. By contrast, a weak intellectual property system reduces the incentives to develop in-house R&D(Liegsalz, 2010).

The innovation dilemma that firms face further calls for intellectual property protection. Therefore, as countries engage into the innovation transition, and firms into the transition to leadership strategies, a strong system of intellectual property rights appears to be necessary to protect new technologies developed by firms.

The second institution is corporate governance. Corporate governance refers to *"elements of legislation, regulation, self-regulatory arrangements, voluntary commitment, and business practices*" that impact on the way firms are administered and managed (OECD, 2015). The relation between corporate governance and firm performance is a well-developed topic (Maher and Andersson, 2000), but the impacts of deficient corporate governance on innovation are a less common topic (Cai and Tylecote, 2008; Liu and Tylecote, 2009; Xiao et al., 2013). Poor corporate governance, independently from the level of technological capabilities, negatively impacts on the willingness of firms to engage in technological leadership strategies (Xiao et al., 2013). This is an issue as poor corporate governance tends to characterize developing countries (Oman et al., 2004).

3.4. Conclusion

To sum up, we have characterized the transitional phase with three elements. The first is the importance of domestic firms in the transition to technological leadership. They are not the only actors of the transition; foreign firms, especially in a country like China where they played a great role during the period of catch-up, have an important role to play in the transition. However, the transition to technological leadership by domestic firms is a major condition of innovation transition. This has led us to the second section. As they approach the technological frontier, these domesticfirms, which are latecomers in technology, have a series of strategic options before them. The way to solve the innovation dilemma they face at that time is through a diversification of their strategies towardsstrategies including technological leadership. Finally, this transition operates at the firm level and is also systemic. The capacity to engage in innovation needs a supportive environment, which includes formal and informal institutions such as the intellectual property right systems, and corporate governance.

4. How do latecomer firms integrate contemporary technological constraints?

4.1. Introduction

Till now, we have not contextualized our discussion and have not situated the transformation of latecomers within the scope of contemporary technological patterns. Indeed, we barely mentioned emerging industries. Putting all this into historical context is, however, crucial when dealing with the question of the technology frontier.

This is justified by the catch-up theory itself. As long as a country bases its economic growth on technological catch-up, it does not contribute to technical advances as understood in the Schumpeterian senseand has few impacts on technological change (Viotti, 2002).[1]During the first stages of technological catch-up, firms first enter in mature industries, in which technologies are stable and dominant designs exist, and therefore, the country does not participate in global innovation.

It was noticed that, as they progress, firms engage in industries following a "*reverse"* product life cycle model(Lee et al., 1988). This idea, now central to catch-up studies, comes from an extension of the dynamic model of innovation built by Utterback and Abernathy (U&A model), when Lee et al. first remarked that it was only observable in developed countries (Lee et al., 1988). The U&A model is known as a three-stage model for the evolution of technology across time.[2] It distinguishes between the fluid (or emerging) phase, the transition, and specific phases (Abernathy and Utterback, 1978; Utterback, 1994; Utterback and Abernathy, 1975). The fluid phase is characterized by market uncertainties and experiments; firms have no clear directions about where to invest in R&D. The transitional phase is the period during which the market and product features are consolidated, with a progressive stabilization of the technology around the emergence of a dominant design. Finally, the specific (and mature) stage is characterized by the proliferation of products around the dominant design, with an emphasis on process innovation and incremental

[1]In Schumpeter's vision, technical change is driving development thanks to the generation of novelty. However, as A Viotti emphasizes, its definition of development somehow differs from what is understood today when studying development in advanced economies or developing countries. "*Schumpeter's notion of development, as it was formulated in the "Theory of Economic Development," was much more related to the idea of the capitalist development, in general, than to the idea of the development of national economies, in particular. If there was any idea of national economies implicit in his formulations, it was an idea of development associated specifically with the leading capitalist economies, i.e., with those national economies that were leading the process of capitalist development by means of their strong innovation process."* (Viotti, 2002, p. 656). It results that the dynamics of technical change for development as conceptualized by Schumpeter strongly differ from the notion of technological learning, and refer to "new-to-the-world type of technical change

[2] Indeed, the model as it has been popularized results from the compilation of different articles published in 1975 (Utterback and Abernathy, 1975), 1978 (Abernathy and Utterback, 1978) and popularized by Utterback in 1994 (Utterback, 1994), leading to the commonly accepted model (Akiike, 2013).

product innovation (Afuah, 2003).

At first, firms from developing countries only engage in mature industries and do not enter emerging industries prior to the establishment of a dominant design. Hence, they enter industries in the "reverse" sense (Lee et al., 1988). Conversely, the reverse technological life cycle model predicts that as companies catch-up in technological capabilities and reduce the existing gap between them and the technological frontier, they become increasingly able to generate innovations and enter into the market when technologies are still in a fluid phase, with no dominant design and many uncertainties still unsolved.

4.2. Linking innovation transition and contemporary patterns of technical change

Conditions of transition to leadership depend on contemporary technological patterns, which we have not considered yet. Technological waves have a differentiated impact on industrial structures.[1] At each historical period, a set of technologies acts as "engine of growth," which is conceptualized under the notion of general purpose technology (Bresnahan and Tratjenberg, 1995; Helpman, 1998). The term encompasses "generic" knowledge and technologies that form a common core of techniques used in apparently unrelated products, and are sources of innovations for firms. Each period has a dominant general purpose technology (Bresnahan and Tratjenberg, 1995).

In order to put this in historical perspective, we mention the successive driving economic roles of steam during the "age of steam" (Von Tunzelmannick, 1978), electricity machinery in the cutting and shaping of metals (Rosenberg, 1963) computers, the internet.[2] Recently, information and communication technologies drove the economic growth of the USA in the mid-nineties (Liao et al., 2016). The degree of pervasiveness varies: electrification was, for instance, more pervasive than information technologies (Jovanovic and Rousseau, 2005), but a common feature is an industrial impact across industries.[3]

Structurally, each technological wave has its own characteristic and modality of technology diffusion(Larédo et al., 2010). General purpose technologies are as diverse as new equipment, the Corliss steam engine in the late 19th century (Rosenberg and Trajtenberg, 2001), new utility companies like electricity or a new sector producing mass intermediary goods: information

[1] Of course, the impact of technology goes beyond the scope of our dissertation, industries and firms, and provokes "*changes that transform both household life and the ways in which firms conduct business*" (Jovanovic and Rousseau, 2005).

[2] There was an acceleration after the industrial revolution. However, we can follow Lisney and consider the following technologies as general purpose technologies (Lipsey et al., 2005): the term refers to techniques as diverse as the domestication of plants, for the 20th century the automobile airplane, mass production, computer, lean production, the Internet or biotechnology, and for the recent period, nanotechnology (Lipsey et al., 2005).

[3] The categorisation of electricity as general purpose technology is questioned by the fact that they do not display the same patenting features (Moser and Nicholas, 2004).

technologies and semiconductors. Understanding how a general purpose technology has an impact on industries is crucial for public policies (Larédo et al., 2010), and managerial decisions (Shea et al., 2011).

In each case, technology does not generate innovations according to the same channels. Sources of innovation vary, because the modalities of technological diffusion depend on the technology under considerations. Patterns of innovative activities vary with the nature of technologies (Pavitt, 1990). This is determined by a series of attributes, which is contained in the notion of technological regimes (Breschi et al., 2000; Winter, 1984). This means that technological leadership requires the mastering of skills linked to the dominant general purpose technology, and cannot be dissociated from the technological regime during the period.

4.3. Impact of general purpose technology across a broad range of industries

A second implication of the pervasiveness of a general technology is that it has an impact on all industries, and not only on those that drove technological catch-up. Innovation is a systematic and collective process (Lundvall, 2010). A systemic approach suggests that the innovation transition engages a larger diversity of actors. In that regard, we previously mentioned that the transitional phase was associated with a diversification of actors in South Korea(Hwang and Choung, 2013).

This diversification can be also questioned at the industry level. The driving role of a few industries in technological catch-up, notably in Asia, is reflected in the focus of studies on mass-production, export industries: automobile industry (Kim, 1997; Kumaraswamy et al., 2012; Zhao, 2006) or China (Zhao, 2006), in electronics (Zhao, 2006), semiconductor (Chao Chen and Toyama, 2006; Hwang and Choung, 2014), etc. In addition, two other types of industries form the industrial structure: “complex product system” industries, and resource-based industries. Complex product system industries are industries “*where a small number of leading suppliers compete for a comparatively low volume global market … where complex capital goods are often customized to each client’s needs and are often delivered through projects, where design of a new complex system, such as a gas turbine requires inputs from several advanced technological fields…”*(Kiamehr et al., 2015). Examples include high-speed train, aircraft manufacturing, etc. Kiamehr identifies different stages of development in these industries (i) overcoming market entry barriers and building project capabilities; (ii) building manufacturing capabilities; and (iii) generation of engineering and design capabilities for market expansion. And possibly (iv) transition to leadership (Kiamehr et al., 2015). The nature of linkages with foreign and domestic firms and clients and how they leverage them differ from other industries: firms leverage the linkages they build with domestic firms to learn and, in the second time, contract with foreign clients. Besides and complex product system, and mass-production industries, resource-based industries also follow alternative catch-up patterns. This is the

case of industries with continuous manufacturing processes such as resource processing because the catch-up process is marked by discontinuous ruptures linked the replacement of machineries(Figueiredo, 2010). An example is the catch-up in the pulp and paper industry in Brazil (Figueiredo, 2014).

These first sections on general purpose technologies and innovation transition aimed to emphasize two elements. The first one is that the transition to leadership by firms is contextual, and depends on the dominant technological trends. The second one is that general purpose technology has a pervasive impact on the industrial structure of countries, which might cover a more or less broad scope of industries.

4.4. Current driving forces: knowledge-based technologies such as nanotechnology

If we go back to our guiding question, the transition of China at the beginning of the 21st century requires paying attention to contemporary dynamics and to the current candidates to general purpose technologies.

Which technology is likely to have a large impact on economic growth? In no previous time in the history were so many theories and frameworks available to analyze emerging technologies, anticipate their societal and economic impacts, and try to answer that question. Candidates include business visualization, artificial intelligence, nanotechnology, interactive internet, etc. Emerging technologies are, by definition, characterized by their uncertainty (Rotolo et al., 2015). Uncertainties encompass a continuum of situations with go from total unpredictability to uncertainty within a delimited range of options (Courtney et al., 1997).

It appears from this analytical framework that not all emerging technologies are totally unpredictable. Some of them have already been invested by a considerable number of actors. Nanotechnology, in particular, is expected to have an impact on industries. A majority of the world largest R&D players already did research in nano-related areas by 2008 (Larédo et al., 2010). 10 out of 13 manufacturing-related S&P industry sectors are involved in nanotechnology patenting, excluding service sectors, media retailing, and real estate (Shea et al., 2011).[1]

Born as a science-fiction concept (Modrea, 2014), and conceptualized before they became concrete (Drexler, 1987; Feynman, 1959), nanotechnology refers to the understanding and control of matter at dimensions of roughly 1 to 100 nanometres.[2] The birth of nanotechnology is attributed to a speech of Richard P. Feynman, one of the most influential physicists of the twentieth century, which he delivered *at the Annual meeting of the American Physical Society*, and in which he

[1] Standard & Poor's

[2] A nanometre is a unit of spatial measurement that is one billionth of a meter. *Nanometre is "as small in relation to a metre as the diameter of a one cent piece in relation to the diameter of the Earth."*

predicted the emergence of a new whole field. Interestingly, Feynman, who was a researcher, emphasized the "enormous numberof technical applications" of nanotechnology.[12]

Nanotechnology became a reality in the eighties thanks to "inventions of a method of inventing" that drive technological waves(Darby and Zucker, 2003), in microscopy, and lithography (Bhushan, 2010). Two inventions are generally mentioned: the 1981's Scanning Tunneling Microscope, and the Atomic Force Microscope in 1986 (Binnig et al., 1986), both inventions by IBM. In the absence of a consensus, 1986 can be considered as the starting date for nanotechnology.[3](Zucker and Darby, 2005).

Even though the eventual scope of nanotechnology differs from Feynman's vision, the importance of potential applications is still a crucial element of its definition. In 2010, 33 countries within ISO agreed on a definition for nanotechnology in ISO/TS 80004-1:2010, where nanotechnology is the *"application of scientific knowledge to manipulate and control matter in the nanoscale in order to make use of size- and structure-dependent properties and phenomena, as distinct from those associated with individual atoms or molecules or with bulk materials"*[4]. This is linked to nanotechnology's specificities. The manipulation of the matter at the nanoscale allows the improvement or the modification of materials and structures, thus enhancing a vast range of products, such *as "materials and manufacturing, nanoelectronics, medicine and healthcare, energy, biotechnology, information technology, and national security, leading some to mention nanotechnology"* as the next "industrial revolution"(Bhushan, 2010). There is a considerable amount of studies on industrial applications in the textile industry(Noor-Evans et al., 2012), inmedicine(Caruthers et al., 2007), etc.. A list of potential applications in industry is reproduced below for illustrative purpose (table 2-4).

Its characteristics led nanotechnology to be considered as the next general purpose

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[1] *"I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, ``What are the strange particles?") but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications.What I want to talk about is the problem of manipulating and controlling things on a small scale.*(Feynman, 1959)
http://www.its.caltech.edu/~Feynman/plenty.html Accessed on 15/09/2016

[2]December 29, 1959 at the California Institute of Technology, "There's Plenty of Room at the Bottom".

[3]There is a stronger consensus on the starting date of biotechnology, the year of the Cohen-Boyer invention of genetic engineering (recombinant DNA) in 1973. Or to take other general purpose technologies, the defining moment for electrification can be the startup of electrification the first hydro-electric facility at Niagara Falls in 1894. Another example is the arrival of IT with the invention of the key component of the personal computer, the 4004 micro-processor in 1971 by Intel (Patel and Pavitt, 1991).

[4] Alternatively, Nanotechnology is defined as the "*understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometres in one or more dimensions, where the onset of size-dependent phenomena usually enables novel applications, by utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter to create improved materials, devices and systems that exploit these new properties*" (ISO/TC 229 Nanotechnologies)
http://www.iso.org/iso/iso_technical_committee?commid=381983. Accessed on 17/10/2016
Or in the US national nanotechnology initiative, as*"the understanding and control of matter at the scale of approximatively 1 to 100 nanometers where unique phenomena enable the design and production of materials, devices and systems which have novel applications."* (US National Nanotechnology Initiative)

technology (Graham and Iacopetta, 2009; Kreuchauff et al., 2014; Palmberg and Nikulainen, 2006; Shea, 2005; Shea et al., 2011; Youtie et al., 2008). Based on indicators such as the volume of patent citation, forward citations, or case study of nanotube (Shea et al., 2011), nanotechnology presents the three characteristics of a general purpose technology: pervasiveness, innovation spawning and improvement (Shea et al., 2011; Youtie et al., 2008). Pervasiveness in nanotechnology across technology classes is similar to that of the computer at a similar stage of development (Youtie et al., 2008).

Table 2-3: List of potential industrial applications of nanotechnology

Industry	Applications
Medecine	Less invasive highly-selective cancer treatment Long-life, slow-release treatments for diabetes and neurodermatitis Specific-effect pharmaceuticals with fewer side effect Preventative diagnosis systems for home use
Optics	Energy-saving lighting systems with adjustable coulour selection Tap-proof data exchange systems Powerful components for consumer electronic
Energy	Economically priced solar cells and performance-enhancing photovoltaic components Efficient accumulators with any required level of ductility Super-insulation systems for windows and building component Thermoelectric for energy retrieval
Environelmental technology	Corrosion-resistant components for everyday products Energy-efficient treatment systems for drinking water Stable, lightweight construction elements for buildings, machines, cars and planes The replacement of toxic substances with nanomaterials
Consumer Products	Self cleaning surfaces for kitchen equipment and home furnishings Multifuntional textiles (dirt-repellent, scent-releasing, varied designs) Foodstuff packaging with sensors to display the freshness of the product Highly effective sun protection and other comestic devices
Information and communication technology	Miniaturized data storage units Laptops as powerful as today's computer centres Large, rollable flat display screens using organic LED

Based on (*Nano-Initiative - Action Plan 2010*, 2007)

5. Impact of contemporary technological patterns on the transition to leadership by latecomers

5.1. The modalities of nanotechnology diffusion in industries

Nanotechnology appears, therefore, as a major technology for emerging countries (Niosi and Reid, 2007). Going through the technology frontier requires latecomers to master it, and more specifically, to be able to use nanotechnology as a source of innovation. "Manipulation at the nanoscale," associated with novel properties, is considered as the generic function. Innovation in nanotechnology is "silent" (Andersen, 2011) with nanostructures, or nanomaterials incorporated into the final product, with most improvements that come from R&D. Therefore, the major channel of nanotechnology diffusion in industries is the research departments of firms (Larédo et al., 2010). From this perspective, nanotechnology differs from previous trends in mechanical industries (Patel

and Pavitt, 1994), or computer industry (Youtie et al., 2008), and suggests a greater importance of developing research capacity in nanotechnology.

This emphasis on research-based innovation or nanotechnology is part of a broader move, characterized by the increase of research activities as a modality of technology diffusion, and the generalization of science-based technologies. Science-based technologies are technologies that rely on the exploitation of scientific discovery and techniques by R&D labs (Mowery and Rosenberg, 1989). Science has taken a major role in determining the competitiveness of firms across industries. It appears as a driver in the second half of the century, when "*its main competitive advantage [of entrepreneurial activity] is … its ability to respond to international threats and opportunities emerging from changing tastes, technology, related prices, and competition. Essential features of this ability are capabilities in R&D and design, and the ability to couple them to developments in world markets*" (Pavitt, 1979).

To what extent is that a new phenomenon? The rise of research in industries is not new. Basic research was considered as the "pacemaker of industrial development" in the 1940s (Bush, 1945). However, in spite of appearances, Patel & Pavitt observe the persisting contribution of production-related technologies, or mechanical technologies, as sources of innovations during the second half of the 20th century (Patel and Pavitt, 1994). Based on patent data, they estimate that around 40 percent of technical change was due to production-related technologies (ibid). They showed that the use of technological indicators such as R&D expenditures, and the fact that mechanical technologies are often secondary to the core "product" of a firm, led to underestimate production related technologies as identified by Mowery and Rosenberg, which include "*non-electrical instruments, and machinery and components for cutting and shaping metal, specialised applications, treating fluids and gases, and heating*". (Mowery and Rosenberg, 1989; Patel and Pavitt, 1994).This is in the continuity of dominant models in the previous century. Until the late 19th century, economic growth was driven by advances, mostly in mechanical technology, on the basis of "*unassisted human observations*" (Rosenberg, 1974). Newtonian science's role in the British industrial revolution is not negligible (Bekar and Lipsey, 2002), but process improvements depended on skills that owed little to advances in science (Landes, 2003).

As such, the breadth of the generalization of corporate research as a source of innovations, in which nanotechnology plays a major role, constitutes a new trend, which has implications on the mode of acquisition of capabilities in the new general purpose technology.

5.2. Implications for latecomers from emerging countries

The idea that nanotechnology can be used for catching up is not new and justifies financial and political support by emerging countries to its development (Huang and Wu, 2012). It also

brought the attention of scholars on the opportunities linked to nanotechnology for development in emerging countries, including China, India and Latin American countries Brazil and Mexico (Ramani, 2014).

The opportunities created by emerging technology in general, and nanotechnology in particular, come from the possibility of technological leapfrog associated with them (Carlota Perez and Soete, 1988). Technological leapfrogging considers the opportunity to enter an industry at its infant stage when technologies are just emerging (Carlota Perez and Soete, 1988). Entering the process of technology development early in its cycle life lowers entry costs because the technology is new for everybody on the market (Carlota Perez and Soete, 1988). The idea of leapfrog comes from the observation that a country (or a firm) can directly position itself at the advanced level of technologies without going through intermediate stages (Sharif, 1989).Let us remind the reader that we consider technological leapfrog from a capability perspective. The alternative (and common) use of the term refers to technological leapfrogging in technology adoption: infrastructures, adoption by developing countries of the most recent generation of product generations, etc. A popular example includes the direct adoption of mobile telephony skipping the fixed-line technology of the 20th century (James, 2009; The Economist, 2008).

In the perspective of this dissertation, technological leapfrog refers to the generation of products on the basis of advanced technology. Firms leapfrog with technological leaders by going directly to the next generation of technologies without going through the intermediate technological stage (Lee, 2016). At the firm level, it can follow different paths. Lee & Lim consider the case of the South Korean automobile company Hyundai. It developed a new electronic injection-based engine, rather than developing the standard carburetor based engine, dominant in the industry (Lee and Lim, 2001). This is an example of path-skipping “catching-up” type of leapfrog that can be distinguished from a more radical one, the creation of a new technological path (such as the mobile phones based on CDMA technology) (ibid). Technological leapfrogging is also understood at the product level: this encompasses mastering new generations of vehicles like electric vehicle (Howell et al., 2014).

Nanotechnology provides with opportunities to leapfrog towards the next generation of “nano-enhanced” products. However, latecomers need to prepare and develop capabilities in order to seize windows of opportunities (Niosi and Reid, 2007; Carlotta Perez and Soete, 1988). This requires investment in developing capabilities during the nascent period of the general purpose technology. Whatever the technology considered, the general purpose technology “does not deliver productivity gains immediately upon arrival” (David, 1991). For example, Paul David (1991) explains the surge in U.S. productivity during the 1920s as a delayed response to the introduction of the electric dynamo in the 1880s.

5.3. Modalities of the construction of competences in nanotechnology

How do firms develop capabilities that can allow them to benefit from nanotechnology as a source of innovations in the future?

Research in nanotechnology can lead to innovations that are incremental or radical(Shea, 2005), which the literature associates to different types of competences (Henderson and Clark, 1990; Hill and Rothaermel, 2003). Because nanotechnology acts as a source of innovations in a continuum range between radical and incremental, this literature that focuses on the relation between the competences needed by a firm to develop a new product, and the "radicalness" of innovations is not fertile in the case of nanotechnology.

Instead, we notice how research activities are increasingly a source of generation of new products, and research in nanotechnology has pervasive effects on industries. Nanotechnology might allow firms to develop products as diverse as antitranspirant socks or medical nanodevices. There is, however, a common feature that is the modality of nanotechnology diffusion. We previously mentioned that the major channel of technological diffusion is through the research departments of existing firms. Conversely, this requires the acquisition of capabilities in terms of nanotechnology research.Nanotechnology finds its roots in basic science, and it is based on bodies of knowledge related to nanoscale phenomena. The nanoscale phenomena are studied mainly in: material science, information science, life sciences, optics, and mathematical sciences.[1]Such nanotechnology research makes the next "state of the art."[2]

6. Synthesis: two propositions on large Chinese firms

In order to understand the potential transition to technological leadership by Chinese firms, the review of the state of the literature led us to two propositions.

Our first proposition deals with theimportance of paying attention to the transition to technological leadership by latecomers, both at national and firms levels. It is derived from the analysis of the literature on technological catch-up, which suggests the existence of a transition at the end of the last phase of catch-up. However, since Chinese firms do not commercialize innovations in science-based industries (McKinsey Global Institute, 2015), the innovation transition cannot be captured empirically by focusing on market-based indicators, because the transitional phase is characterized by the acquisition of competences for the next state-of-the-art.

Our second proposition is that, in order to observe this transition to technological leadership,

[1](Center for Research and Development Strategy, Japan Science and Technology Agency, 2016)

[2]At any moment of time, there is a set of technologies and knowledge embodied in the "state of the art", and"*Technology leapfrogging" refers to the adoption of advanced or state-of-the-art technology in an application area where immediate prior technology has not been adopted*" (Fong, 2009).

we need to focus on the acquisition of technological capabilities in technologies which have the potential to become general purpose technologies. In this chapter, we further argued for the relevance of focusing on nanotechnology as an indicator of this transition towards technological leadership.Nanotechnology appears as the major source of future industrial opportunities for firms in China because specific properties at the nanoscale enable improvements in materials, devices, and systems. The acquisition of competences in nanotechnology comes from the modalities of its diffusion across industries, and needs to be associated with the construction of a research capacity in nano-related areas by Chinese firms.

We defended the importance of contextualizing the transition into contemporary dynamics. In the first section, we mentioned that national specificities condition the transition to technological leadership. The framework of the dissertation therefore needs to be repositioned within the Chinese context. We dedicate two chapters to that question. The next chapter, Chapter 3, briefly discusses the relevance of mobilizing the notion of transition in China; it also introduces the interest inherent in studying the Chinese case. Later in our dissertation, Chapter 5 pays attention to the specificities associated to large firms in China.

Chapter 3: **Why the "innovation transition" concept is relevant to understand Chinese firms**

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1. Introduction

Our dissertation mobilizes the concept of innovation transition to question the contemporary role of Chinese firms in global innovation *i.e.* their participation to technological change and new-to-the-world innovations. Addressing the latter question through the theoretical lens of "innovation transition" raises two related questions. First, why is the "innovation transition" concept relevant to understand the dynamics of Chinese firms? Second, is China a "good candidate" for "innovation transition"? There are three distinct aspects to be considered. This first aspect is whether China is sufficiently advanced in the process of technological catch-up for the mobilization of the innovation transition framework to be relevant. We deal with that aspect by introducing the level of advancement of China's institutions. Also central to that question is the position of Chinese firms regarding innovation and technology. The second aspect relates to the interest of mobilizing the innovation transition framework in the Chinese context. We take some distance to question the specificity of China as a country of analysis.

Finally, a contextual element justifies our choice. Our research question has become a topical issue. Innovation has become omnipresent in China's official speeches and government policies. The idea of innovation transition is regularly mobilized (implicitly or not) and has an impact on innovation policies. It appears, therefore, necessary to dedicate a few paragraphs to this question.

2. **China's innovation transition: A salient issue**

The innovation transition - not necessarily named this way by the actors who mobilize it - is of growing importance in China's political agenda. In 2006, the Medium and Long Term plan for Science and Technology gives a clear indication of this trend and formulates China's policy imperatives in the following terms:

> *In our effort to build a well-to-do society, we are faced with both rare historic opportunities and grave challenges. The nation's economic growth shows an excessive dependence on the consumption of energy and resources, with high associated environmental costs; the economic structure is irrational, characterized by a frail agricultural base and lagging high-tech industry*

and modern service industry; and firms lack core competitiveness and their economic returns are yet to be improved as a result of weak indigenous innovation capability. There are a whole range of problems concerning employment, distribution, health care, and national security that need prompt solution … We must place the strengthening of innovative indigenous capability at the core of economic restructuring, growth model change, and national competitiveness enhancement. Building an innovation-oriented country is, therefore, a major strategic choice for China's future development.

Extract of the preface of the *plan for Science and Technology*, Ministry of Science and Technology (MOST), 2006[1]

This extract of the preface of the plan for Science and Technology reflects China's government's awareness of the necessity of transitioning towards an innovation-oriented economy, and the technological dimension associated with it. Two themes are mobilized as responses to these challenges, namely, environmental issues as well as structural economic problems linked to social and strategic issues faced by the country.[2][3] The first theme is the idea that China's economic growth is no longer sustainable without a change from the current economic model to an innovation-oriented one. The theme, notably present in the previous years through the promotion of a Chinese national system of innovation since 1998, has become omnipresent since the 2008 global financial crisis destabilized the Chinese economy and exposed its weaknesses. A second theme is the role of technology in such a transition. As mentioned in the 2006 plan, "*leading the future reflects a vision in deploying for frontier technologies and basic research, which will, in turn, create new market demands and new industries expected to lead the future economic growth and social development*" (Preface MLP, 2006). This orientation was reinforced in 2010 by another specific policy document emphasizing seven Strategic Emerging Industries (energy efficient and environmental technologies, next-generation information technology, biotechnology, high-end equipment manufacturing, new energy, new materials, and new-energy vehicles).[4]

It is noteworthy to mention that the 2006 plan and the 2011 strategic emerging industries plan mark the victory of a "bureaucratic" or a "techno-industrial" approach of innovation policies (Chen and Naughton, 2011). Technologies to develop and to finance are selected and supported through a policy mix implemented to direct funds and subsidies towards selected projects or entities.[5]Indeed, the Chinese State considers that fostering innovation is part of its duty, which is

[1] Compiled by Sydney University

[2] See for example (Lisbonne-de-Vergeron, 2012) for a review of the weaknesses, and Wu Jinglian for a discussion of the impact of the financial crisis (Wu, 2013)

[3] Two other elements that are not in the scope of our topic shall be mentioned. A first one is the contribution of domestic demand. The second element is the importance given to the environment and to green economy.

[4] "*the Decision on Accelerating the Development of Strategic Emerging Industries*" October 2010, State Council

[5] An alternative channel for government intervention is the use of "certifications" or labels, at either national or local levels. It might concern an entire organization or some of its entities (technological centers, research labs, etc.),

associated with a bureaucratic model of innovation policies. It fixes quantitative goals, such as the goals fixed for the overall level of R&D. The 12th five-year plan (2011-2015) targeted an increase in state funding for research and development from 1.75 percent ofgross domestic product (GDP) to 2.20 percent in 2015, a goal that has been achieved as anticipated.

More recently, another set of innovation policies has taken a more general approach to technology by focusing on industrial upgrading at the firm and industrial levels. The 10-year plan "*Made in China 2025*" is concerned with the industrial upgrading of all industries, including high-tech and medium-tech industries and with an emphasis on equipment and machinery industries. Targeted industries include new advanced information technology, automated machine tools & robotics, aerospace and aeronautical equipment; maritime equipment and high-tech shipping, modern rail transport equipment, new-energy vehicles and equipment, power equipment, agricultural equipment, new materials and biopharma and advanced medical products (Ministry of Industry and Information Technology, May 19, 2015).

These programs can be however considered as the broad framework of innovation programs. In parallel to these general plans, there are national innovation programs targeted at firms in specific industries. The "National Guidelines for Development and Promotion of the Integrated Circuit (IC) Industry (State Council of China" June 2014) set targets for industry revenues, production volume, and technological advances.[1]In addition, it shall be noted the role of local governments in implementing national programs. Innovation policies tend to be quite centralized in comparison with other types of policies, but they are still implemented at the provincial level by local governments (The US-China Business Council, 2013). Local modalities of implementation also vary. For instance, the existence of financial supports, the nature of the subsidies (e.g. subsidizing applications or granted patents), and subsidized amounts vary considerably between places (Dang and Motohashi, 2015). Policymaking has contained a large experimental dimension ("*touchingstonestocross the river*") (Nolan, 1994).

Innovation is among the keywords of Chinese politics.[2]In that regard, Chinese policy makers

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generally under the label of key labs, high-tech enterprises, etc. Objectives include channelling subventions towards particular projects and organizations. In addition, certifications often give fiscal or related advantages. For instance, Hi-Tech or Technology Enterprises have preferential corporate income tax rate of 15 percent for three consecutive years.

[1]The government's investment set a five-year investment target of about $19 billion for integrated circuits, puts a greater focus on creating segment winners, or national champions, through mergers and acquisitions and other consolidating moves, and has a more market-based investment approach by giving local private-equity firms responsibility for allocating public funds.

[2]For illustrative purpose only, we reproduce here a part of the Communique of the 5th Plenary Session of the 18th CPC Central Committee in 2015:*Meeting participants stated that to persist in innovative development, there is a need to place innovation in the core position of the overall situation of national development, constantly promote theoretical innovation, systematic innovation, sci-tech innovation, cultural innovation, and in other areas of innovation, and let innovation run through all the work of the party and the state, and enable innovation to become a trend in society. We need to place the basic point of development onto innovation, give shape to and promote the system and framework of innovation, and bring about more pioneering type development that relies on innovation and that gives play to adva*ntages.

were influenced by the notion of national innovation system (Lundvall, 2010), which was brought to them by the Chinese Academy of Sciences (Tang, 2010). The reference to innovation is systematic since it was popularized under Hu Jintao – Wen Jiabao period (2002 – 2012), and innovation policies are part of a broader context of industrial and development policies. Governmental intervention for innovation, which has become part of industrial policies, is growing. The innovation and technology policy shifted in this direction in 2003 and has reached two new peaks with the already mentioned publication of the medium and long term plan in 2006, and the strategic emerging industries program in 2010 (Chen and Naughton, 2011).[1]

3. Mobilizing the innovation transition in the Chinese environment

In a 2015 report, the consulting firm McKinsey writes "*China faces an innovation imperative. As two sources of growth—labour force expansion and heavy capital investment—fade, innovation (broadly defined) will need to contribute up to half of GDP growth by 2025, or $3 trillion to $5 trillion in value per year*".[2] In the political world, former Prime Minister Gordon Brown declared in 2013: "*China knows it will have to move quickly to exploit the Third Industrial Revolution, from 3D printing and digital design to nanotechnology, biotechnology and genetics, hence its one million research and development workers and its plans for 100 million more graduates".* [3]These two examples illustrate the emergence of a wider consensus that go beyond the emphasis given to innovation by China's government: China needs to engage in the innovation transition to ensure social, economic (and political) stability.[4] The transition towards an innovation-driven economic model is perceived as necessary to "save" the economic model. There remain many skeptics.

Indeed, the innovation transition requires the country to be sufficiently advanced in the technological catch-up process, adapted institutions and the integration of innovation capabilities by domestic firms.In that regard, there are still a series of weaknesses. Recognizing that the transition is systemic, we nevertheless focus on two types of institutions determinant for innovation: higher-education and research institutions, which constitute the scientific and technological knowledge base of the country, and general supporting institutions, which impact firms' innovation strategies

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Communique of the 5th Plenary Session of the 18th CPC Central Committee, 2015, Oct 29th
This (somehow extreme) example illustrates the importance of the mobilization of the theme of innovation.

[1]Industrial policies were characterized by alternating underlying models that include more or less government intervention: an emphasis on market force, a focus on economic planning and the importance of industrial policies – either national or cross-sectorial – closer to a neo-Keynesian approach of economic development (Heilmann and Shih, 2013).

[2] McKinsey (McKinsey Global Institute, 2015)

[3] Quoted by China Daily, 5 October 2013

[4] In that regard, the mobilization of economic success to legitimize political institutions in China shall be noted. The capacity of China Communist Party to promote economic development has legitimized its staying into power (Huchet, 2006).

by creating or not incentives to innovate at the frontier.[1]

3.1. The role of China's scientific and technological base[2]

Three dimensions are central to China's scientific and technological base. The first one is the training of qualified personnel. Higher-education figures reflect efforts made to increase the level of education in the country.[3] They also reflect the transformation of the universities since 1978 and the efforts to catch-up with the disastrous state they were at the end of the Cultural Revolution, where formal academic and scientific had stopped (Simon & Rehn, 1988, p. 14). In 2014, 7 million of persons came out from Chinese universities, including Bachelors, Masters, and graduates from technical colleges.[4] 457 806 Master's Degrees were awarded in 2013. The repartition between disciplines also shows the emphasis given to the training of engineers. In 2013, engineering degrees represented 34 percent of all Master' Degrees (158 105 degrees), followed by Administration Master's degrees (62 093 degrees, 14 percent of the total) and Medicine Master's Degrees (50 322 awarded degrees). The same year, high-education institutions delivered about 3000 master degrees in philosophy.

The number of qualified people is difficult to estimate. For example, it is hard to determine how many Chinese engineers the country counts. By the mid-2000s, McKinsey estimated this number at 1,2 million persons, using national statistics as a source. This figure was questioned by two experts of China's Science &Technology human resources. Based on a thorough analysis of sources, they considered the actual figure to be closer to 200 000 persons, which represents a considerable gap between the two figures (Simon and Cao, 2009).

The employment situation reflects the difficulties of adjusting the demand and the supply. On the one hand, Chinese firms report lacking qualified people. Recruiting quality personnel is especially a major concern for large private firms (All-China Federation Of Industry & Commerce, 2014). The situation is expected to remain the same. It is estimated that in 2020, Chinese employers will need 142 million more high-skilled workers (who went to the university or had vocational training), 24 million more than the number of workers likely available (Chen et al., 2013). A particular issue is the lack of senior managers that are capable of supervising projects and transferring knowledge about technology aspect as well as management(Simon and Cao, 2009). Meanwhile, university graduates struggle to find job positions, and the unemployment rate is higher for educated personnel (Simon and Cao, 2009). This reflects the inability of university training to

[1] We only briefly introduce the institutions. For a comprehensive review of China's institutions linked to the innovation system, refer to the innovation policy review done by OECD in 2008

[2] A large part of our conclusions comes from the knowledgeable book on the topic: "China's emerging technological edge: assessing the role of high-end talent" (Simon and Cao, 2009).

[3] We only briefly review this topic. For a more comprehensive introduction, see Simon & Cao, 2009 and OECD (2008)

[4] Source: China's National Bureau of Statistics

meet firms' needs in terms of qualified personnel. It is notable that Korea met a similar problem of unemployment in the 1960s. This shortage of jobs appears early in the history of South Korea's development. It was soon resorbed (Kim, 1997:64).Specialized personnel is also needed for their scientific and technological expertise in the context of the innovation transition. An indication of the level of advancement of China in that regard is the number of doctoral students and postgraduates. It has increased regularly reaching 53139 Doctor's Degrees awarded in 2013. The repartition among disciplines reflects the orientation of the Chinese education system towards science and engineering research at the doctoral level: about 70 percent of the doctoral degrees are in engineering (18 331 doctoral degrees awarded in 2013), science (10 396 degrees in 2013), and medicine (8228 doctoral degrees).

Besides scientists trained in China, a major role has been played by returnees trained abroad(Welch and Hao, 2013). Since the 1990s, the government has implementedmeasures to attract them, such as access to funding and better work conditions, while the country was renewing its attractiveness for graduates(Zweig, 2006). Returnees include both foreign-born Chinese as well as Chinese who went to study abroad and returned to work in China. They play a major role in Chinese innovation, and notably participated to the creation of start-ups in emerging fields nanotechnology (Cao et al., 2013, p. 57). To some extent, thee setup of R&D centers by multinationals (Bruche, 2009) has also contributed to training local personnel. By 2009, there were 1100 R&D centers established by 900 multinationals, among which more than the half employ more than 150 R&D personnel(Li and Cantwell, 2012). These dynamics have led to an increase inengineers and scientists. The should however be put in perspective with the size of the country.

For instance, the number of researchers, "*professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems, as well as in the management of the projects concerned*" (OECD) is now superior to 2 million people, which represents 1.9 researchers per 1000 employees. 2 million researchers is five times more than the number of researchers in South Korea. However, the proportion of researchers per employees is much lower than the proportion in South Korea (13 researchers per 1000 employees in South Korea) and in the United-States (9 researchers per employees) in 2013.[1]Current China's proportion is also inferior to that of South Korea in the late 1990s (4.6 researchers per 1000 employees in 1998).

Another element is the progress of China's research system. Quantitative indicators show that China's science and technology took off in the 2000s (Gao and Jefferson, 2007). National R&D

[1] OECD Data. 2013 is the year of reference for South Korea, and 2012 for China.

expenditures indicate a significant increase in R&D.[1] Investment in research and development by Chinese institutions, which include firms, government laboratories, and universities, has caught up with that of institutions from advanced economies. Since 2011, China is the second largest spender with $154 billion that year, and the share of expenditures devoted to research and development has reached European levels. Since 2014, China's R&D intensity, the ratio of expenditure on R&D to GDP, with 2 percent that year, has become superior to that of the European Union (28 nations).[2] This integrates the fact that the 28 EU nations have disparate economies. China is below leading European nations and is inferior to the average of the OCDE nations, whose performance is driven by South Korea (4.2 percent), Japan (3.5 percent) and the USA (2.8 percent).

Another indication of China' Science &Technology take-off is the increasing number of scientific publications. Scientometric studies show the emergence of China as a scientific power in the 2000s. China took the second place in numbers of scientific publications (Hvistendahl, 2013; Zhou and Leydesdorff, 2008), and has become one the most prolific countries in nanotechnology (Zhou and Leydesdorff, 2006). This reflects an increased contribution of Chinese institutions and individuals to global scientific production. The most prolific institutions are the Chinese Academy of Sciences, and leading universities located in the eastern part of the country: Tsinghua University in Beijing, Zhejiang University, Peking University, Shanghai Jiaotong University, University of Science and Technology of China, Nanjing University, Fudan University, and Shandong University (Kostoff et al., 2006). Chinese scientists' participation in international collaborations reflects the increase in the general scientific level and has contributed to an elevation of research quality by fostering exchanges. The increase in international collaborations does not follow the total increase in the number of scientific publications (Zhou and Glänzel, 2010). A momentum in the increase was reached in 2010, suggesting that all the researchers who have the scientific and language skills to engage in international collaborations have done so (Zhou, 2013) .

The increase in China's scientific productions does not go without problems. Indeed, many Chinese journals have low-impact factors. It shall also be noted the existence of a black market for publications, showed by the magazine Science. This market includes options as various as "paying for an author's slot on a paper written by other scientists but also self-plagiarizing by translating a paper already published in Chinese and resubmitting it in English; hiring a ghost writer to compose a paper from faked or independently gathered data; or simply buying a paper from an online catalogue of manuscripts—often with a guarantee of publication" (Hvistendahl, 2013).

[1] Source: Chinese Bureau of Statistics

[2] China's R&D intensity grew from 0.6 percent in 1996 to 1.98 percent in 2012, to reach the level of the European Union (1,97 percent) and overtook over with 2,01 percent in 2013.

Finally, a dimension associated to the scientific and technological base is its geographical distribution. Where are scientists and engineers localized?There are important disparities between regions. Chinese innovative activities are concentrated in the East and in the South, in the Guangdong Province, Beijing, and Shanghai with relatively "empty" regions. Also, there is barely anything in some western and central provinces (Tibet, Qinghai, Ningxia). In that regard, China is characteristic of the spatial structure of an "emerging" innovation system, by contrast with mature systems, such as those found in Western Europe or in the United States where the concentration of innovative activities in a few regional centres is associated with a moderate activity in other areas. (Crescenzi et al., 2012).

3.2. Are Chinese institutions supporting innovations?

The general environment also conditions technological strategies available to firms by providing weaker or stronger incentives for them to innovate. We made a choice to restrict this introduction to two institutions: intellectual property right systems, and corporate governance, which both involve formal and informal dimensions.[1] Understanding formal Chinese institutions presents two difficulties. The first is they are relatively recent and posterior to 1979. The second difficulty is that they differ from those familiar to western scholars, which might be misleading. The issue seems sufficiently important for Jiang and Kim, who work on corporate governance in China, to mention that "… *many papers seem to misunderstand (or are not aware of) important regulatory issues; the legal, financial, and institutional environments; and business customs and practices in China*" (Jiang and Kim, 2014).

A first element is the question of the intellectual property right system. There have been important improvements of that institution. Formally, the China's system of intellectual property rights has reached world standards, thanks to a patent amendment in 2000 when China became a member of the World Trade Organization.[2]The prescriptive requirements linked to the World Trade

[1] We could have included the market and the financial system. It impacts the capacity of firms to finance their R&D for innovation. For incumbent firms, the political connections tremendously matter. State firms and large firms with political connections are privileged over smaller and medium firms (Schwab, 2015). The intensity of political connection is determinant. Similarly, private firms with political connections also have easier access to finance (Song et al., 2015).
Another element is the market. Does China's market environment provide incentives for Chinese firms to invest in science-based innovation? The marketization of China's economy and the foundations to create a basic competitive environment are relatively recent. Institutions gradually evolved from socialism (1949 – 1978) into market mechanisms, generally encapsulated in a system of "socialist market economy." Reforms focused on macroeconomic issues had a direct impact on science and technology. The "*Decision on Some Issues in the Establishment of a Socialist Market Economic System*," issued by CCPCC was central in 1993 (Liu et al., 2011). Other reforms include The Law on Anti-Unfair Competition (1993) and the Antimonopoly Law (2007).
[2] Deli Yang provides a complete account of the development of the intellectual property right system in its early days.

Organization's Trade-Related Aspects of Intellectual Property Rights to which China agreed in 1999 are considered as a decisive element for improving the intellectual property regime in China (Stoianoff, 2012).[1]The intellectual property right system is a popular theme when discussing the capacity of China to innovate. China's intellectual property rights system is born from a dual constraint: the protection of the intellectual property of foreign firms, and the elaboration of a framework favorable to latecomers (Xue and Liang, 2010). Indeed, a strong intellectual property right system might prevent learning by latecomers (Kim, 1997). The worries generated by this institution are clearly related to the difficulties met by foreign firms when setting up in China, related to the enforcement of their property rights. However, as Chinese firms have become increasingly engaged in innovative activities, a strong intellectual property regime is of growing importance to them as well.

Another institution appears of importance to us, corporate governance.Weak corporate governance has been a persistent issue in China (Jiang and Kim, 2014), and is believed to have a negative impact on innovation (Cai and Tylecote, 2008; Liu and Tylecote, 2009; Xiao et al., 2013). The reform of corporate governance institutions occurred later than that of the intellectual property regime. For instance, it is only in 2002 that the China Securities Regulatory Commission edited a corporate governance code for listed companies.

There are several issues specific to the country.[2] The governance structure of state firms raises questions.Firstly, state firms remain a tool for political objectives. Centrally state-owned firms depend on the State Council through a main organ, the State-owned Assets Supervision and Administration Commission (SASAC). The commissionis, therefore, the shareholder of these firms. A first problem associated to state firms is that they obey to non-corporate objectives. This might include social goals. The willingness to maintain employment explains the support to non-productive entities by the governments. State-owned firms are also at risk to be used for politician interests (Shleifer and Vishny, 1997). These are classic problems associated with state ownership in the literature.

In addition, a supplementary element in China is that state-owned firms are under a double institutional constraint. In parallel with the formal governance structure under SASAC, the enterprise decision-making process is also linked to the Chinese Communist Party's decisions. The

China became a member of the World Intellectual Property Organization in 1980, the same year of the creation of the China's Patent Office (the predecessor of SIPO). The Patent Law, first enacted in 1985, and amended in 1992, was modified as part of the Chinese application to WTO. The Law was further amended in 2010 and in 2013. It was the first Patent Law of Modern China after 1949.(Yang, 2003)

[1]Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) was negotiated in the 1986-94 Uruguay Round. It introduced intellectual property rules into the multilateral trading system for the first time." WTO website

[2] Here, we focus on corporate governance issues that are specific to the Chinese context. Of course, Chinese firms are concerned as well with issues raised in any settings (Jensen and Meckling, 1976)

Party is present through party units in all state firms.[1]According to Wang, "the requirements turn the [state-owned enterprises]'s decision-making body into a political assembly that adopts the practice of the Party-line vote for members of the CPC, where every Party member must vote the same way based on the Party's collective will. The explicit, naked requirements for incorporating the Party organization's views into the decision-making of the company […] make the SOE an economic entity almost completely controlled by the CCP." (Wang, 2014, pp. 657–658) p 657 – 658. Issues in China's corporate governance are associated with little transparency from firms. Chinese firms were found to be the least transparent in terms or reporting on anti-corruption programs and organizational structure than firms from Brazil, Russia, India and South Africa, with a few exceptions such as Huawei Technologies (Kowalczyk-Hoyer and Côté-Freemann, 2013).[2]Finally, another element that is too complex to be analyzedhere is the impact of corruption on firms. In the last Global Competitiveness Report, China ranks 67th for incidence in terms of bribery (Schwab, 2015). Corruption is associated to many corporate frauds that affect the performance of the firms in several ways, such as fund distorting from R&D subsidies, etc. A concern arises on how innovation policies could distort financial resources from truly innovative projects towards labeled projects. Other concern is the use of the funds. It is at risk that financed projects are disconnected from firm's commercial strategy. These two concerns are reinforced by the fact that most funds tend to go to the same projects, causing over-supplies of funding in firms who are not the most performant (interview # 1).

4. Chinese firms and the technological frontier

Central to our dissertation is the question of technological leadership. What do we know on this topic?Firstly, some signs indicate that Chinese firms have reached the technological frontier in terms of manufacturing capabilities. This is reflected in a change in the industrial structure of Chinese production. The nature of exportations suggests they developed production capabilities at the technological frontier. The trade balance of China indicates that there was a shift of the content of imports and exports towards high tech products (Gereffi, 2008). In 2013, 27 percent of manufactured exports were high-tech products i.e. "high-technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery."[3] India offers a different perspective with high-tech products representing 8 percent of manufactured exports (World Bank Indicators). In contrast, the proportion of high-tech products in China falls in the same range than that of South Korea, Switzerland (27 percent), or

[1] And this trend is reinforced. A 2015 regulation obliges the presence of the Communist Party unit in private firms and in all government organizations ("China tells workplaces they must have Communist Party units," 2015)

[2]Based on the analysis of 33 Chinese firms based on the Boston Consulting Group list of *Global Challengers* 2011. Report done by Transparency International

[3]http://data.worldbank.org/indicator/TX.VAL.TECH.MF.ZS/countries Accessed on 10/05/2016

France (26 percent).

What about the capacity of Chinese firms to innovate at technological the frontier? Interest for innovation by Chinese firms is booming (Fu, 2015; McKinsey Global Institute, 2015; Strategy&, 2013, 2014; Williamson and Yin, 2014; Zeng and Williamson, 2007). Previously, analysts working on Chinese innovation paid greater attention to the institutional perspective (Gu and Lundvall, 2006; Liu and White, 2001; Tang, 2010) and to technological learning during catch-up (Arvanitis et al., 2006; Huchet, 1995; Ruffier, 2012; Zhao, 2006; Zhao and Arvanitis, 2008). In fact, consultants and business actors were among the first to ask whether and how Chinese firms could innovate. Prof. Peter Williamson, author of the book "Dragons at your door" (Zeng and Williamson, 2007) started his career at the Boston Consulting Group and Merrill Lynch.[1] On the consulting firm side, McKinsey published a major report in 2015; and Strategy& has published an annual report on China' innovation since 2013.[2]

Some of their observations contain very optimistic views. For instance, according to Strategy&, "*there is little truth to the Western image of Chinese companies as followers of others, focusing on low-value-add activities such as copying technologies and products already available on the market. In fact, Chinese companies in mainland China outpace MNCs in high-value-add activities such as advanced and applied research, as well as emerging technologies and trend analyses*" (Strategy&, 2014:6).

This observation comes from the fact that some firms have been identified as being close to the technological leaders. Huawei Technologies have become an important firm of the telecommunication industries. It is also the largest filer of patent applications at the World Intellectual Property Office.Another example is SAIC Motor, based in Shanghai. In the automobile industry, according to Bernstein Research, SAIC is the only Chinese automaker with genuine product development capability and is benchmarked at 70 percent of Volkswagen (Nam, 2015).

Indeed, the trend still needs to be nuanced. On whether Chinese firms are innovative, some analysts show as much enthusiasm as other ones or firms might fear or despise the innovative performance of Chinese firms. The idea that Chinese firms "*outpace multinational corporations in high-value adds activities*" (Strategy&, 2014) does not resist closer empirical scrutiny. Chinese firms are innovative when no strong scientific and engineering bases are required, and particularly productive in industries that depend on production process improvements such as commodity chemicals, textiles, electrical equipment or construction machinery(McKinsey Global Institute, 2015). This is coherent with what we know from existing studies on technological catch-up in

[1]https://www.jbs.cam.ac.uk/faculty-research/faculty-a-z/peter-williamson/ Accessed on 10/10/2016
[2] Formely Bain Company

developing countries. Latecomer firms are better at design and cost innovations than at science-based innovations (Aulakh, 2007; Batra et al., 2012; Forbes and Wield, 2002).

Indeed, Chinese firms innovate on the basis of other features such as architectural, design or incremental innovations. The nature of innovative activities in China reflects the capacity to leverage national specificities. A competitive advantage of Chinese companies is that they have access to a large pool of researchers, whose wages are competitive compared to world standards. This makes it possible to industrialize the R&D process because there are plenty of "qualified but not so good" engineers who can be employed within R&D large organizations(Williamson and Yin, 2014).More specifically, this organization is associated with the "industrialization of R&D"that requires an organization of different teams conducting simultaneously different stages of the innovation processes. For example, Mindray,China's largest medical manufacturer, divides its R&D process into eight steps to which are assigned dozens of persons each, and use SAP's resource planning software adapted from a manufacturing assembly line to manage its innovation process(Williamson and Yin, 2014).

In addition, according to the authors, while there is a strong hierarchy and that the structure might appear bureaucratic, with a top-down and rigid approach of management this is associated with a high degree of horizontal flexibility, with a rapid flow of knowledge between people (ibid).An additional factor of innovation is the adoption of relatively short product development cycles. The reduction of the product development cycle makes it possible to test the market more frequently. Firms launch the products early in the development, and progressively adapt the products to customer demand (Williamson and Yin, 2014).

Regarding the technological frontier, firms meet two difficulties. Chinese firms are less efficient when advanced knowledge is required. As already mentioned, an indication is that Chinese firms are not innovative in science-based industries, which require commercialization of basic research (McKinsey Global Institute, 2015).[1]The main barrier is, however, not only the technological dimension but rather the lack of strategic and managerial capabilities to integrate it as part of the firms' strategy (Zhao, 2016).

5. Conclusion: China's specificities for the transition

Mobilizing the innovation transition is relevant for two main reasons that relate to China's emphasis on innovation, and to the degree of advancements of China's institutions. We mentioned persisting issues in corporate governance. There are however supportive elements such as China's higher-education and research institutions as well as the progress in the intellectual property rights

[1] McKinsey divides industries depending on the dominant level of innovations. Industries like semiconductor design, biotech or branded pharmaceuticals, depend heavily on science.

system.

There is also an inherent interest to pay attention to the Chinese case. Historical examples of innovation transition include Japan and South Korea. Exploring a new case complements and questions the general character of the knowledge and pieces of understanding derived from previous historical experiences. China's experience might be insightful for other countries as it offers an alternative to historical precedents in Asia.

Two dimensions appear important to us. A first one is the nation's size. While seemingly obvious, the size of the country has deep implications for the transition. Chinese provinces average 40 million inhabitants, with great variations among them.The most populated Chinese province is also the richest. Guangdong Province, located in the south of the country, had 107 million inhabitants at the end of 2014. 98 million people inhabit Shandong Province. By contrast, the smaller one is Tibet (318 000). As a matter of comparison, Guangdong Province exports as much as South Korea ($362.4 billion in 2009 versus $363.5 for South Korea).[1]

Another dimension is the degree of 'decentralization' of China's model. To what extent China would adopt a model of innovation transition less centralized than what was observed in other countries? China's economic actors are not articulated as closely with the national government as they were in the Korean and Japanese cases. This is linked to a series of factors. First, the absence of large actors equivalent to Korea's Samsung shall be mentioned. The Korean or Japanese models of development were based on a limited number of firms, intimately close to the national government. A section of Chapter 4 shall be dedicated to defending the view of the particularities of large Chinese firms in that regard.

Also related to that question is the nature of China's capitalism. China has adopted a state capitalism(Bergère, 2013; Naughton & Tsai, 2015) whose major specificity is to be articulated around a diversity of local governments (Boyer, 2016). The importance of local state corporatism was associated with a decentralized development during the period of transition to the market economy (Oi, 1995). Paying attention to local governments is central. Chinawas never governed on a centralized basis, and attempts of centralization during the Maoist period were a disaster as they resulted in a disconnection between local needs and national policies. The central government, in Beijing, gives broad strategic orientations through national outlines and plans, and local governments are in charge to implement them, at the different administrative level. Local governments have flexibility in making decisions as a necessity to respond to local needs.

Regarding the technological frontier, two dynamics are at work. On the one hand, there is a top-down approach to innovation which tends to be associated with centralization of innovation policies. On the other hand, the role of local governments and local corporatism have allowed the

[1] Economist Intelligence, The Economist, 2011

emergence of firms that are not in the scope of the Central Government, and that are disconnected from one another.

China's innovation transition shall likely be conditioned by these dimensions. The size of the country and the articulation between local firms and local governments indicate the limits of previous historical experiences in explaining dynamics in the Chinese case. Indeed, they contrast strongly with centralized models in a smaller environment with a central State such as South Korea.

Chapter 4: **Research design and methods**

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This chapter describes our research design. It is organized into three main sections. In section 1, we make a general argument to defend our research design. The originality of our research is to propose an integrated theoretical method and methodological framework to observe the dynamics of innovation transition.

More specifically, we argue that our proposed research design is original compared to existing methods that are not appropriate to understand the innovation transition dynamics in emerging countries. The absence of studies on the topic is partly due to the lack of methodological and analytical tools. We propose hence an alternative approach with the introduction of nanotechnology patents as an indicator of thedynamics of acquisition of technological capabilities in emerging fields.

Sections 2 and 3present the methodology adopted in this work. Section 2 one explains how we have identified the 325 Chinese industrial firms we study. We discuss in this sectionthe criteria used to select these firms. Section 3 details the methods used to select nanotechnology patents. We build herein the database on which all our analysis is based. The use of data from large scientific and technological database being a collective process, we pay attention to distinguish between our own work and the collective work done by theIFRIS's team.[1]

1. **The general Research Design**

1.1. A need for a specific research design

In our dissertation, we mobilize the concept of innovation transition to discuss the

[1] IFRIS: Institute for Research and Innovation in Society - http://ifris.org/en/presentation/

transformation of China's industrial model. Behind the concept of innovation transition, is the idea that a successful catch-up by a firm occurs if it manages to reach the technological level of its global competitors, the technological frontier. The transitional phase is the uncertain phase when firms have already been accumulating capabilities and get close to the technological frontier but before they effectively become technological leaders. We have further argued the need to contextualize this framework within contemporary technological dynamics and withinChina's context. We concluded with the proposition that the transition to technological leadership by Chinese firms required the acquisition of technological capabilities in nanotechnology.

There are two difficulties inherent in the analysis of dynamics of innovation transition. Firstly, the unique way to identify a successful technological catch-up is by identifying new products (or processes) that are developed by firms and positionthem among the market leaders. The transitional phase anticipates that moment. Regarding firms, the transition phase is therefore characterized by a triple uncertainty on whether it is a real trend, which firms participate in it, and on the future outputs of their current actions and investments.

Understanding the innovation transition also raises the questions of how to articulate firms' dynamics with the national innovation perspective, and go beyond the analysis of a limited number of large Chinese firms.We aim here to look at the firms' individual modalities of engagement in nanotechnology. Because many researchers sharethis concern in the field of innovation studies, we already benefit from recent methodological and theoretical developments in the use of scientific and technological databases.

We shall see that existing research settings do not provide satisfactory answers to these two conditions: articulating the firm and national levels, and looking at transition dynamics.

1.2. A review of previous research settings

We begin with a brief description of the methods used by scholars.The studies look at the end of the catch-up phase or at the transitional phase with a focus on firms. They deal with two series of questions on innovation transition: firms' dynamics, which they study with case studies (Kim et al., 2004)and national dynamics, when they observe an industry or a technology (Choung et al., 2014; Lee and Lim, 2001).

Hence we first look at case studies. Thefirst group of case studiesdeals with how firms have developed capabilities in order to commercialize new products and reach the technological frontier.[1]The question is to understand how researchers did select the firms for their analysis. The analysed firms in these studies were chosen because they have already reached (or are about to

[1] That includes the analysis of firms in the semiconductor and automotive industry in South Korea (Choung et al., 2012), firms in resource-based industry: pulp and paper industry in Brazil (Figueiredo, 2014), or in a complex system industries (Kiamehr et al., 2015).

reach) the technological frontier. Sometimes, the method of selection is explicit: For instance, Choung et al. (2014) selected firms or organizations that introduced “world-class” products on the Korean market and, in a second time, conducted interviews with them.However, looking closely, our understanding is this way of firms’ selection is prevalent, even when it is not explicit. Researchershave identified this category of firms by relying on the following indicators: the use of firms' market shares, theexport proportion of sales, or product rankings by a governmental agency to identify them. These indicators relate to the capacity of firms to have already commercialized products.

Additionally, in these research settings, firms are selectedbased onthe products they developed and/or they commercialized. Such criteria of selection is consistent with the objectives of many researchers, and is in particular, adapted for retrospective studies (Kim et al., 2004). However, thesecriteria are still not appropriate to our research context and, more specifically to the emerging countries context. Indeed, a proposition we make here is that large Chinese firms have entered into a transitional phase, which implies that part of these firms which are developing technological capabilities have not yet integrated them into commercialized products. In addition, this led tospecifically study well-established industries.

The second category of research designs derives from an alternative approach. That approach encompasses several methods used to assess the level of technological capabilities and strategies of some latecomers(Choung et al., 2014; Xiao et al., 2013). They differ from the previous ones as, to identify technological leadership, they use internal data from firms instead of market indicators. In most papers, data are collected through interviews (formal, informal discussion) with firms and related actors, and are combined with economic and S&T data (patent and scientific publications) (Hobday et al., 2004; Xiao et al., 2013). Because it is possible to use them to look at dynamics before products’ commercialization, these methods are more adapted to the study of a transitional phase by Chinese firms on that dimension.

They require however pre-selecting a narrow group of firms based. Hobday and colleagues base their work on an existing framework to divide 25 pre-selected Korean companies by strategies (unaware and passive / reactive / strategic / creative) and consider that the two firms that adopt creative strategies may be at the technology frontier (2004). In the Chinese context, Xiao et al.in their paper on the barriers that appear when latecomers enter a transitional phase use informal interviews and heterogeneous sources of data to assess three previously selected firms (2013). Similarly, Figueiredo (2014) bases his research article on a five-year study about Brazilian pulp and paper firms during which he could identify relevant cases of transitional companies to investigate further.

There are two ways of selecting or preselecting firms: on the basis of market information,

which implies that firms have already developed technologies, and on the basis of in-depth knowledge of a sector. Regarding the second case, what these research settings allow is tomake possible to explore ongoing dynamics or to test a theoretical hypothesis about the innovation transition at thefirm level (Yin, 2003) by focusing on the most advanced firms in emerging nations once “champion” firms have been identified.

1.3. The investment by firms in emerging technologies as a marker of transition

Previously developed methods are adapted to nations where technological leadership is already visible or identifiable, or to retrospective studies. In the present case, the transition framework needs a research design better adapted to China and other emerging nations, for which we cannot take a retrospective approach and study how firms have become leaders with the introduction of products to the market.

Instead, we look at ongoing transformations. We, therefore, must make a step backward and investigate whether latecomer companies invest into new technologies before they managed to exploit them successfully in developing new products*i.e.* when they invest in basic knowledge regarding these technologies. This echoes with the literature, and the catch-up theory that predicts that as firms reduce the gap with the technological frontier, they become increasingly able to generate innovations and enter markets based on emerging technology (Choung et al., 2014; Kim, 1997).

This requires looking at emerging technologies.[1] In that regard, some studies focus on emerging technology in emerging countries, such as nanomedicine in China (Leung, 2013). These studies explain how firms invest, integrate, or shape the development of new technologies, butit is not possible to derive national trends from these studies. This echoes to Chapter 2 in which we introduced the existence of 'general purpose technologies’ characterized by their technological dynamism and their pervasiveness within industries (Bresnahan and Tratjenberg, 1995).

Nanotechnology provides an interesting setting for our research for several reasons.[2]Firstly, as we argued in chapter 2, we are at a stage when, in many countries, leading firms invest into new technologies but beforethey integrate these technologies into products. Those firmsare focused on

[1]Choung et al. (2014) are among the rare authors to integrate emerging technologies in the scope of their research design: Wireless Broadband (WiBro) and Terrestrial Digital Multimedia Broadcasting (T-DMB), but they do not integrate in the scope of their study to identify the position of firms. The first reason is contextual, because technologies are developed by research institutes and not by firms.

[2] Nanotechnology was introduced in Chapter 2. Nanotechnologies gather a set of techniques involving works at the nanometre (one billionth of a meter): “*nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometres (nm), where unique phenomena enable novel applications*” (National Nanotechnology Initiative - Strategic Plan, 2014). Their emergence was triggered by the extension of the possibilities of exploratory and manipulatory instruments during the 1980s (microscopy, lithography). Rather than a simple technology, nanotechnology is based on the introduction of new processes or materials into existing products during the research phase.

building capability and exploratory activities in the long-term perspective of product development. Theresearch laboratories of these firmsare central to the trend, which justifyies the importance of nanotechnology research for Chinese firms. In that regard, nanotechnology research in emerging countries could reflect the comitment of firms in the learning process.

There are however additional elements. Nanotechnology researchgives an indication on the nature of the technological strategies of Chinese firms. These firmsfollow models of innovation based on low-cost innovation or design innovation (Forbes and Wield, 2002; Zeng and Williamson, 2007), which allocates resources to exploitation rather than exploration activities. Nanotechnology research by Chinese firms would suggest that this is one part of the puzzle and that firms also invest in more fundamental research.[1]

It results that nanotechnology research indicatesboth dynamics of acquisition of technological competences and signals firms' technological strategies. Consequently, the combination of these two elements arguesin favour of the idea that investment in nanotechnologies by firms in China is an indicator that they are, at least, entering intoa transitional phase.

1.4. Nanotechnology patent as an indicator of a transitional phase

To observe nanotechnology research within firms, we examine their patents activity. This methodological choice is made possible by the modality of nanotechnology diffusion. The emergence of nanotechnology research has led to a considerable number of patents by actors such as universities, research institutes, and firms. A 'surge' in "nano-patents" has been observed both by researchers who noted the firms' early patenting trend and by lawyers who saw in this surge a dysfunction of the patenting system (Bawa et al., 2005; Lacour, 2010).

This 'nano surge' nevertheless gives us a visibility of the general tendency of nanotechnology research by firms. In that regard, nanotechnology patents make more visible nanotechnology research among firms. Andersen notices how firms in the construction sector in Denmark, including the largest ones, barely mention nanotechnology (Andersen, 2011). Andersen illustrates this with the example of a firm in the glass industry: *"*Pilkington does not officially refer to it as an application of nanotechnology." The term "nanotechnology" is generally avoided and instead they use the traditional term of "coatings" …their low profile is due partly to the unsettled debate on nanotechnology risk issues and partly because of the considerable uncertainty as to what nanotechnology is and what it is not*"*(Andersen, 2011). Such "silence," or invisibility, has two primary reasons. The first one is the nature of nanotechnology itself, as nanotechnology research leads to process innovation, discreet on the market. The second reason is the fear of the reaction of the market to nanotechnology perceived as insecure by the public, including in China

[1] This is of course true for nanotechnology research in any firms from emerging countries

The second particularity of nanotechnology patents is that it offers away to articulate nationalobservations with observations at the firm level. Because of its generic character, nanotechnology has animpact onfirms throughindustrial sectors.Looking at nanotechnology patents helps us obtain a transversal image of the country'sdynamics of acquisitions of capabilities by firms. In our discussion, nanotechnology patents are an indicator helping articulate the firm with the national levels under the assumption that we look to the nanotechnology patenting activities of a representative group of firms.[1]Consequently, we focus hereinon the specific case of large Chinese firms.

Based on that assumption it is then possible tomake a comparison for instance between China and other emerging countries such as Brazil. Especially that the nanotechnology patenting activities have been researched in different settings including firms in Brazil (Kay et al., 2009), and Chinese firms in energy storage (Kay and Youtie, 2013).Furthermore, the availability of data about global firms in nanotechnologyby industrial sector provides uselements to realize a comparison in which we can benchmark Chinese firms (Larédo et al., 2010).

The choice of our methods belongs to a tradition of using science, technology and innovation indicators (Freeman and Soete, 2009). We use accordingly patent applications in nanotechnology as an indicator of dynamics of technological learning by Chinese firms. To our knowledge, this is not the most common use of patents that are generally considered as indicators of technological capabilities. It shall be noted that none of the previous studies about innovation transition has mentioned before the use of patents as a wat to pre-select or select firms. But many have used patents as a part of the heterogeneous set of data. They have mobilized patents to assess or to describe the evolution of technological capabilities. Choung et al. (2000) for instance use patent plus scientific publication data with the purpose to differentiate technological using capabilities and technological generating capabilities of firms in the Korean semiconductor sector. Our method considers also patents as an indicator of technological capabilities, with all the limits this implies (Griliches, 1990), but the limits are secondary in our study.

1.5. Conclusion

The primary objective of this section was to introduce the general framework of our research design: we look at nanotechnology patenting by firms. Here, we argue that nanotechnology patents taken by firms are a good indicator of innovation transition. In fact, patents can reflect the three following elements: the dynamics of acquisition of technological capabilities, the integration of

[1] This therefore requires firms that we study to be representative of national dynamics.

research into firms' strategies and the development of absorptive capacity.

The relevant case of nanotechnology development in China justifies the implementing of ourresearch design. China is engaged in the 'nanotechnology race" (Dong et al., 2016). Indeed, the Chinese State perceived the strategic interest of nanotechnologies for Chinese development early. As China has invested massively through direct and indirect support to research and innovation projects in the field since 2001. In addition, the composition of China's industries makes the method relevant, because it gives an important place to themanufacturing industries (industries in which nanotechnology can be used as a source of innovation). In June 2016, 69 percent of the firms listed on Shenzhen Stock Exchange, one of China's two stock exchanges, 1259 manufacturing firms on a total of 1818 firms, are categorized under "manufacturing."[1] Whether firms patent in nanotechnology and how that might be representative of particular sectors give additional elements about the technological development of China's industrial actors.

[1] http://www.szse.cn/main/en/MarketStatistics/BySectors/ These values were taken on 24/06/2016

2. Implementation of the research design

Our research adopts a quantitative method. This method has consisted in the construction and analysis of a database of the 325 largest Chinese industrial firms to look at their patenting activity in nanotechnology. However, this quantitative work was interpretedin the light of our familiarity with China, through previous work experience and studies in Beijing. Our familiarity with the Chinese language made possible the direct access to some Chinese sources, and notably, the treatment of the patent database in Chinese. In addition, we spent a few months (June – August 2014) at the Centre for Nanoscience and Nanotechnology of Shanghai University, to meet actors of innovation and nanotechnology. While this work did not consist of formalized interviews, it certainly impacted the interpretation of data.[1]

2.1. The construction of a dataset of the large Chinese firms

Our doctoral research exploits a dataset made of the large Chinese firms performing research on nanotechnologies. That dataset was built in three steps: - the selection of a whole corpus of patent applications in nanotechnologies; - the identification of large Chinese firms among applicants; - and the collection of data on those firms. The first step, which we describe in this section, is grounded on the technical possibility to exploit large-scale scientific and technological databases. One major concern is to use firm-level data that can be aggregated in a way to interrogate data based on specific features of firms (ownership, industry, size, etc.). In order to obtain such aggregation of data, this requires to go beyond a statistical use of firm data and to keep their identities.

It is thus necessary that we first identify firms. The use of patent databases is particularly adapted to that purpose because patents and information they contain (technological classifications, names of inventors and applicants) are public data, as well as the identity of the applicant. The research was largely facilitated by our institutional attachment to IFRIS, which provided us with privileged access to purposely developed databases.[2]A database gathering patents taken globally in nanotechnology, developed on the basis of Patstat Database (2011), has been our starting point (NanoPatstat). The objectivity and relevance of the selection method are guaranteed by the delineation method that was used to delineate nanotechnologies. We briefly describe it in the next section.

[1] Access to firms is a difficulty to tackle in research on China. Difficulties might be associated with three factors: the distance with the field, especially for a foreign researcher, and the lack of "guanxi" or personal connections to access people within firms.
However, we also believe that another institutional factor is at work and refers to the level of development of institutions such as the intellectual property regime and corporate governance, which do not favour trust. Finally, in the particular field of innovation studies, firms might be reluctant to share elements of strategies when these strategies are easily imitable (Ogsuz Aladagli and Oulion, 2015).
[2]IFRIS: Institute for Research and Innovation in Society - http://ifris.org/en/presentation/

We restricted our selection to invention priority patents made by Chinese applicants: Invention patents refer to what is commonly known as patents, in opposition to “utility” patents. Invention patents are attributedon the basis of three characteristics: the novel character, the non-evidence, and their application character. Priority invention patents are, as the term does not suggest, patent applications that do not have priorities *i.e*. that are not dependent on a family of patents that already exist. A priority is a prior patent application to which the concerned patent application is an extension. The restriction to selecting priority patents aims at only selecting patents that protect the original inventions, and not all posterior extensions. The selection of invention priority patents with Chinese applicants required basic SQL requests. This first step lets us with a corpus of 56 410 patent applications that cover the period 1990 – 2009.

A major feature of our database is that, on the basis of the patent application numbers, we re-extracted patent data from SIPO’s website in China. This allowed to obtain cleaner and more comprehensive data. First, the original version is more complete with the fields that are filed. This is necessary to obtain the address of each applicant. A second reason relates to the fact that it suppresses ambiguity that comes from the English translations of the Chinese name of the firms.

2.2. Methods of delineation of patent applications in nanotechnology

NanoPatstat is a database developed under SQL that gathers all patent applications in nanotechnologies. The selection of patent applications in nanotechnologies was basedon the implementation of a robust delineation method within IFRIS. The delineation process took several steps. The starting point was the selection of a core of scientific publications in nanotechnology. Those publications were analyzed thanks to tools of lexical analysis (CorText) used to produce a list of 840 keywords characteristics of nanotechnologies. Most of them are composed of multi-term expressions. Those keywords were used as the basis on which patentswere selected if their abstracts contain the keywords. An important feature of this keyword-based delineation is its evolutionover the years. Keywords used to select patents vary annually, making possible to reflect variations of technological trends themselves from year to year. Integrating such a dynamic aspect is necessary as nanotechnology is an emerging technology, and therefore associated with many novelties.

Those developments are made by an IFRIS team skilled in the development of large scientific database and their exploitation. The team is specialized in such treatment as testifies publications on the methods used(Mogoutov and Kahane, 2007). For our research, this ensures accounting only for patents in nano-sciences, excluding other non-relevant scientific domains, and thus provides a relevant source for identifying Chinese firms that do research on nanotechnology.

The second and third step are more directly concerned with completing information on firms. The second step was to identify among the whole corpus of patents those that were taken by

the large Chinese firms, and the third step was to collect relevant data on those firms. This has required several iterative steps in order to clean the data, identify and select our targeted companies. The type of data contained is described in more details in the following paragraphs.

2.3. The organization of the database around the business groups

Here one may wonder how to identify large firms? We have already observed that using criteria based on size (either number of employees, asset value) made difficult the analysis by the co-existence of different organizational structures. At the exceptions of a few well-identified firms, large private firms tend to be smaller whereas some of the central state enterprises are giant groups. Therefore, we propose a combination of alternative methods that are based on a double approach: the size (number of employees) and the appreciation of the economic and political weight of the firms. This includes to pay a specific interest to the listed firms and to firms detained by "high-level" local governments (provinces and major provincial capitals, municipalities), as well as by the Central People's Government.

Several additional dimensions are attached to the organization of the database. An important feature of our research design is that we do not consider individual entities as the unit of our analysis, but the entire business group. That includes identifying groups by gathering their subsidiaries under the parent company even though they have an individual legal existence. This has several implications on the way we build our dataset of firms. Patents are taken by individual entities, and not necessarily –even though this is possible and largely depends on the organization of firms- by the mother company. This requires a preliminary work to research and reconstitute business groups by identifying their subsidiaries. Even though this work is time-consuming, it does not present as large methodological difficulties in the case of China as it would in nations with different organization of corporate ownership. Most Chinese business groups tend to have pyramidal structures(Fan et al., 2005), with few crossed ownership and parent company easy to identify. In addition, subsidiaries of the Chinese groups tend to be wholly-owned by their parent company(Lee and Woo, 2001) which limits the number of trade-offs we must do when weattach subsidiaries to their patent companies.

In addition, this provides a source of data on firms' history, and in particular on centrally state-owned firms, whose research activities are not centralized. While we proceeded to the reconstitution of the business groups, we paid specific attention not to erase these data that can be exploited to describe intra-group dynamics. As a result, we keep in our database different levels of subsidiaries (parent group, subsidiary level 1).

2.4. Advantage and limitations of a patent-based selection of firms

We remind concerning firms that no authors have used before patents as an indicator of theirinnovation transition. Patents were often used as an indicator of technological capabilities of firms. The general advantage and limits of patents are well documented by literature (Griliches, 1990; Nagaoka et al., 2010). For instance, Choung et al.have usedlater, as a complementary source of data, the patenting activities of firms related to the products they study (Choung et al., 2014).

Moreover, patent analyses are widely used methods for the study of technological catch-up. Noticeable examples include a series of eleven research studies on the articulation of the technological catch-up, economic development, and intellectual property rights system in different nations including China, South Korea, and Taiwan (Odagiri et al., 2012). This shows how patenting activities can be used in longitudinal studies of dynamics of change. A change in patents reflects the change in the level of the technological capabilities of firms. In such case, changes in the patterns of patenting activities by firms indicate firm-level changes associated with their technological catch-up. Changes in patterns include the modification in the respective proportion of corporate and domestic, invention patents (compared to foreign patents, utility patents, and patents hold by universities or research institutes). To some extent, the use of invention patent in nanotechnology as a marker of transition follows a similar logic, as it is the study of another pattern in patent activities*i.e.* patenting inventions in emerging fields.

This use we make of patents as an indicator for transition presents some weaknesses that need to be mentioned. One is the temporal discrepancy between the date of the patent applications and the period covered. We identified firms on the basis of a database that covers a period of more than 15 years. In addition, the description of the reform of the intellectual property rights evidence that it is only recently, since the 2000s, that a patent system aligned to worldwide standard was implemented in China. Thus, there is an asymmetry in the value of data across time, and as a consequence, on the validity of our selection method, as it was “easier” to patent in the 1990s than in the last decades. A way to mitigate that problem while keeping the possibility to look at historical developments is to keep patent applications prior to2000, but to separate them from the final dataset the firms.

In addition, it shall be mentioned that the core focus, and the unit of analysis of our research, is not on patent applications themselves but on Chinese firms. The choice is therefore made to mobilize short case studies as a way to accompany the guiding discussion and argumentation of the doctoral research. Those “micro” case studies, based on data collected on the large firms that are constitutive of the database, aim at discussing the transformation of those firms.

2.5. Sources of data on the firms

A final dimension we have not yet mentioned is the data we need to collect about firms in order to be able to aggregate them and use our dataset of firms to answer research questions in relevant ways. With the progressive opening of China, the information environment has witnessed important improvement and data on Chinese firms have become increasingly available, in Chinese, but also to some extent, in English as well. One major source of data on firms is firms' stock exchange data. For non-listed firms, we have used official websites of central and local governments, and the institutional websites of companies. In addition, we have had access to the world-level database on firms, ORBIS.

There are two grand types of data that we needed to collect. The first type of data we need derives from the understanding we have of the Chinese economy that led us to reformulate the question of the impact of ownership on innovation. This requires paying attention to the constitution of a database that identifies central state, local state, and private firms. One of the most systematic sources of data on firms ownership is the China Security Index we found, was borrowed from research in corporate finance (Pessarossi and Weill, 2013): The "CSI Central State-owned Enterprises Composite Index", the "CSI Local State-owned Enterprises Composite Index" and "CSI Private-owned Enterprises Composite Index" respectively include firms directly controlled by the central government or by a local government (Province or Municipalities) and private-owned enterprises traded at Shenzhen and Shanghai securities exchanges (including bonds, stocks and derivatives).[1]

The second set of data we collected is classic in most research that focuses on a population of firms. Finding sources of information on data on large firms are straightforward at the condition to have access to a corporate database. We need to mention though that this requires paying attention in attributing data to a firm or to one particular subsidiary. Data include industry data (industrial classification, industrial sector, and main activities), firm's size (number of employees). We manually collected these data from the database ORBIS whenever they were available, and from information directly provided by firms either directly on their corporate websites, annual reports or in some cases, in newspapers and reviews. We have also integrated geographic information on the localization of firms and of their subsidiaries thanks to data available in the original patent database, andcomplete it with external sources (corporate websites or official firm database). Finally, we have mobilised secondary data coming from existing case studies.

[1]http://www.csindex.com.cn

2.6. A few remarks on the use of data in the Chinese context

We mobilize along this doctoral research data on production, science, and technology activities, that include firm-level data as well as statistical data produced by the National Bureau of Statistics or its provincial counterparts; Therefore, we need to mention the problem of interpreting these data in China, as in many emerging nations. Caution ought to be paid to the fact that data has different intrinsic value than in OECD nations with a longer tradition of data collection.

Chinese statistical data have been considered as a rich but non-trustable source of information, even though the recent reform undertaken since 2008 has aimed – to some extent – to correct the major flaws of data such as the inadequate representation of the private sector not to mention falsification(Orlik, 2014). The validity of Chinese statistics is the object of many publications and discussions that go much beyond the academic circle.[1] Statistics are often criticized for reflecting "manipulations made by actors, in a context of corruption, corporate accounting manipulation in both state and non-state enterprises and more broadly, weak information environment including for listed firms" (Piotroski and Wong, 2010). In addition, manipulations by local governments include debt reporting, inflation of measures of the production and performance.

Strong concerns have also been expressed regarding the qualitative value of science and technology indicators that are used to analyze the Chinese Innovation System, including patents, publications, and R&D expenditures, which raises questions as those figures are used as the basis of innovation policy reports (OECD, 2008). In the research system, the emphasis given to publications in the career of scientists, combined with corruption, has led to many distortions and generated the emergence of an academic black market of scientific publications, in which the product is the authorship of papers in journals indexed by Thomson Reuters and Elsevier (Hvistendahl, 2013). Similar concerns are expressed regarding the reality of the increase in the global level of R&D expenditures, and their effective allocation to research projects. We are aware of those limitations. However, we consider that Chinese data provides relevant sources of information, provided it is carefully exploited.

3. Principles of selection of firms

3.1. Introduction

The aim of this section is to explain how we proceed in selecting large Chinese firms. There are two conditions that need to be respected. A first constraint is to select a population of large firms representative of diverse industries, at the national level. The restriction to large firms creates some

[1]See for example the special section of China Economic Review on China's data and that contribute to clear the way for researchers on China, Volume 30, September 2014.

distortion we discuss in further detail in another chapter of the dissertation. The second condition is to remain neutral regarding the degree of innovativeness of a firm. We describe step by step the constitution of a group of 325 firms, and the sources we used for that purpose. We introduce our selection criteria, and the limits. In parallel, we detail the major sources we exploited to identify the large firms.

3.2. What criteria to use to select firms?

How to ensure that large firms we select are representative of the Chinese context? There are two main conditions. One is to avoid selection biases such as looking only at the most successful firms, which are likely to be more innovative than the average. Another concern is to have a population of firms whose size is still manageable in terms of analysis, to allow firm-level explorations. These concerns led us to make the following choice. Firms are selected thanks to three criteria: their size, their industry (in order to select firms engaged in manufacturing and production); and their country of origin to discriminate domestic companies from foreign-invested companies (i.e. we only want Chinese firms and not foreign invested firms). Based on these criteria, that we will introduce in more details, large Chinese firms are likely to form a group of firms diverse in terms of industry, strategic orientation (specialized or diversified), ownership, size and localization. This is precisely this diversity we are interested in to reach a broad perspective and obtain an adequate economic representation across industrial sectors. It is noticeable though that this diversity may cause some difficulties in comparing and interpreting data.

i. Our definition of large firms: more than 10 000 employees

Focusing on “large firms” requires a first categorization and definition of what a large firm is. Are we talking about global multinationals with hundreds of thousands of employees? Or are we referring to firms which are not classified as SMEs, and that can be more modest in size? Our choice is to adopt a broad view leaning towards the second option. Indeed, we use a simple size indicator, which is based on the level of employment. Our threshold is defined at 10 000 employees, which led us to select firms with more than 10 000 employees, and with no maximum, thus also including “giant” firms.

Using employment figures is quite classic. The number of employees is a classic indicator of the size of a firm. However, firms can also be categorized as large based on other items such as their revenue or their financial value. For instance, Chinese official figures have for long been based on alternative selection criteria. The National Bureau of Statistics defines a large enterprise according to a combination of three criteria: its number of employees, operating revenues, and total assets. Thresholds vary across sectors. Following that definition, 9411 large enterprises operate in China in

2013: this figure includes firms with less than 10 000 employees (it also does not account for whether they are independent or whether they belong to a business group, which is a problem we discuss later in this chapter). In our case, we choose the criteria of the level of employment for simplicity purpose, but also to avoid selection biases towards the most profitable or capital-intensive industries. The number of employees is the least ambiguous size item on which to select an enterprise (OECD, 2002).

A classic categorization is proposed by OECD. The OECD classifies firms according to the following thresholds: 1-9 employees, 10-49, 50-99, 100-249, 250-499, 500-999, 1000-4999, 5000 employees and above. Large firms employ 5000 or more persons in that definition. It seems not appropriate in the present case. The threshold is too low for our purpose, and not adapted to a country's size like China, as it leads to select many firms. China still possesses a manufacturing base more extended than that of many OECD countries. Chinese firms, in proportion, rely more on labor force than on automatized production, which favors the adoption of a higher threshold for employment. In addition, this classification is thought to characterize individual enterprises, not entire firms with several subsidiaries. Adjusting the inferior limit at about 10 000 employees leads to select 325 firms while representing most industries.

ii. Focusing on industries with manufacturing or production capacity

At this stage, we shall remind the purpose of the research. We aim at observing whether firms integrate new knowledge on nanotechnology as part of their R&D. This means that firms must have conception, production, industrial processes concerned by nanotechnology research and integration. We chose to adopt a broad view and to extend our scope to large firms engaged in mining, construction, and resource-processing activities.

In other words, firms included in the scope of our research are those for which technological innovation represents a direct opportunity for their production or their products. And we exclude the other ones, independently on their contribution to the Chinese economy (for instance, innovation in the service industry). For similar reasons, we exclude software and Internet firms (Tencent, Baidu, Alibaba…). Excluding these firms presents a major limitation for the understanding of transition dynamics in China. It is, in particular,arguable that these firms are actively participating in thetransition in emerging countries, and the software sector is particularly vivid in China (Jui, 2010).

iii. The role of domestic firms in the innovation transition: selecting Chinese versus foreign firms

We defended in the general framework of the dissertation the importance of domesticfirms. Foreign-investedfirms or foreign firms are outside our scope of analysis, regardless their impact on

the Chinese economy. We make a few exceptions, though.[1] This includes firms that are headquartered in other countries for legal or fiscal reasons but still maintain their operations in China: Chinese firms that are based in the Cayman Islands or in Bermuda. We also integrate some firms with their headquarters in Hong Kong: the ones that originated in Mainland China, where they operate and still have their management team. This is, for instance, the case of the PC maker Lenovo, a spin-off from the Chinese Academy of Sciences, created in Beijing in 1988. By contrast, we do not integrate firms that were originally established in Hong Kong.

3.3. The diversity of data sources reflects the diversity of firms

A way to get a selection of firms of good quality is to cross several independent sources of data on Chinese firms, including primary and secondary sources. They include websites related to Chinese stock exchange and securities and websites and reports from local and central governments. In addition, various sources are mobilized in order to integrate companies that are neither listed nor held by an important governmental entity. We introduce them in the next paragraphs.

i. Centralization of data on state firms

112centrally state-owned firms: Centrally state-owned firms are the most symbolic firms of what remains of the Chinese planned economic system. There are only one hundred firms under the direct supervision of the Central People's Government, in Zhongnanhai, Beijing. However, they employ millions of people. In addition, they are often granted monopolies in their market (petrochemical, communication, defence, etc.). 112 firms depend on the State Assets Supervision Administration Commission (SASAC), a ministry-level administrative organ established on purpose. SASAC, in turn, refers to the State Council, the highest executive instance in China. It was created in 2003.

Previously, state firms were administered under different reference ministries. Its creation is one of the final steps aimed to provide a unified and legal framework to centrally state-owned firms. During the Maoist period, state firms were not formally separated from their administration. Many steps were, therefore, necessary to transform them into legal firms. Major steps had been the promulgation of the first company Law, in 1988 that gave firms a legal status. This was followed by the creation of a “shareholding status” in 1992. This status made it possible to incorporate state enterprises into legal corporate firms. These entities remained under the supervision of their original ministries till the creation of SASAC.

A large majority of centrally state-owned firms is under this unique shareholder and supervision agency. There are however a few centrally state-owned firms that still depend on their

[1]We integrate Shanghai Alcatel because it is one of the few joint-ventures under the scope and supervision of SASAC

ministries: China Tobacco (Ministry of Tobacco), CITIC and People's Bank of China, under the Ministry of Finance (MOF), and China Railway (Ministry of Transport).[1]

The administration of centrally state-owned firms is centralized under SASAC's leadership. Hence, establishing the list of centrally state-owned firms is straightforward as the 112centrally state-owned firms are listed on the website of the administration.[2] Other centrally state-owned firms consist of a few well-known firms, easy to identify. We base our selection on the number of employees and discard the smaller ones[3].

A variety of locally state-owned firms: These 112 state firms (including their thousands of subsidiaries) constitute a large group of firms. They are however far from representing the totality of state firms. Most Chinese state firms do not depend on the Central State but on lower levels of government.[4] This includes provincial, municipal, city-level and lower level governments.

A small precision is required on the terminology and on the concept of 'local governments.' The word (*guoyou*) translated as "state" refers to the idea of nation. In addition, the differentiation between "central" (*zhongyang*) and "local" (*difang*) state firms comes from the governmental level on which they depend. The central government (*zhongyangzhengfu*) is generally opposed to local governments (*difangzhengfu*). The latter refers to governments at levels below the centre. This includes levels that would hardly be qualified as "local" otherwise; local governments might be governments of provinces with population superior to that of France or Germany.

The administrative system is reproduced at every level of governments, and governments emulate the organizational structure of the central government. Most of them reproduced the central SASAC's model and established local state asset supervision and administration committees. These local SASACs (or equivalent entities) centralize the administration of local state assets.[5] Local governments are transparent on that matter. Provincial, municipal, city-level and lower governments generally indicate the list of firms under their administration on the website of the local SASAC. They provide related information on their websites, on which they regularly publish news and trends about firms. There is, therefore, no major difficulty to identify locally state-owned firms for a given province, municipality or geographic city.[6] Difficulties come from the number of local governments, and in turn, of the number of local SASACs. In turn, we focus on the largest firms are

[1] China Railway is a specific case, as the company has not been corporatized. It was established in 2013 on the basis of the Ministry of Railways.

[2] Number of firms listed in SASAC at the beginning of 2015 (there are ongoing mergers). The figure has been declining since the creation of SASAC.http://www.sasac.gov.cn

[3] Most of the largest Chinese firms are centrally state-owned firms, but the reverse is not true. Not all centrally state-owned firms are large. Some firms employ less than 10 000 employees. This is the case, among others, of central research institutes (CISRI, GRINM) and firms in specialized markets.

[4] Some firms depend on both central and local administrations (双管企业).

[5] This is representative of the double administrative system that is prevalent in the Chinese Administration. Local SASAC both depends on the local governments to which they are attached and to the national SASAC.

[6] Indeed, there is not so much opacity on this topic, and private and state assets are clearly identified. There are however a very important number of governments.

administrated at a higher level of governments.

ii. The emergence of private firms

Identifying provincial and centrally state-owned firms turns relatively easy. Such is not the case for private firms which, obviously, do not depend on any such entity. However, they are increasingly visible because they play a growing role in the economy. Therefore, to identify them, we crossed several sources of data. We relied on a combination of heterogeneous sources: stock exchanges, global database (Orbis database), Chinese industrial and national rankings, international rankings, etc. These sources are detailed in the next section.

iii. Other sources of data

Stock exchanges and listed Chinese firms : The existence of developed stock exchanges in China facilitates the implementation of the research design. There are 2614 firms listed in Shanghai and Shenzhen. Many of them are subsidiaries of larger groups. This provides an extensive base of information on large Chinese firms themselves, or on their listed entities. In addition, during the last 25 years of existence of stock exchanges, all types of firms have gone public. Shanghai and Shenzhen Stock Exchange were established primarily to raise capital for the state sector, in 1990 and 1991. It was therefore aimed to support state firms that were not making profits, and many state firms have listed their entities. However, the private sector is also represented in Chinese stock exchanges, since private firms started to go public later.

Information disclosure is a legal obligation for listed firms (in China or anywhere in the world). Their corporate annual reports provide comprehensive information. That includes general and financial information, the analysis of the activities of the year, as well as detailed items on R&D expenditures. They also give information on the ownership structure of the firm.

Listed firms are required to provide detailed information on their shareholders in annual and quarterly reports. Some corporate databases conveniently centralize these annual data. Orbis database, for instance, does it. Orbis Database provides firm-level information that includes general, financial and ownership data, as well as indicators of independence, responding to a growing need for micro-level analysis in addition to macro-level data, making it possible to take into account the individual characteristics of firms (Ribeiro et al., 2010). It is an important source of information on corporate groups worldwide, and provides information on the number of entities in the group, and shareholding relations between entities. Is it noteworthy that requests on Orbis database give results more complete for China than for other major emerging countries. We performed the same request in China, India and Brazil, request that aimed to look at the head of the group with more than 5000

employees.[1] We found 349 Chinese industrial groups (145 for more than 10 000 employees), 22 Brazilian and 50 Indian ones.[2]

In addition, institutional websites also provide China-specific information on the nature of firms' ownership. We mentioned in the previous section the role of local and central governments, as well as the private sector in the economy.

The China Securities Index (CSI) Website provides lists of central state-owned, local state-owned and private-owned enterprises indices. It indices include firms, which issued securities (mostly domestic shares) either in Shanghai or Shenzhen, and classifies firms as follows: (1) The company is a Central State-owned Enterprise if realistically controlled by the State-owned Assets Supervision and Administration Commission of State Council (SASAC) and the Ministry of Finance; (2) Local State-owned Enterprises are companies finally controlled by local State-owned Assets Supervision and Administration Commission, local municipal government and local state-owned enterprises; (3) Private-owned Enterprises are finally controlled by domestic natural persons (including HK, Macao, and Taiwan).

This makes it possible to identify the nature of the shareholder of a listed entity and, in turn, that of its parent company. It also makes it possible to classify firms perownership and to perform macro-level analysis that integratesthis criterion.

We cannot rely only on stock exchanges to identify private firms, though. Not all groups go public, including among the largest ones. For example, the telecommunication firm Huawei Technologies, a Chinese global leader in R&D, never went public to maintain control and not be subject to information disclosure.[3]

Information from corporate and industry associations:Firms within industrial sectors are organized into industry associations. Industry associations centralize news and information and organize events. They also act as a medium for business lobbying on behalf of firms (Deng and Kennedy, 2010). This includes associations like China National Coal Association, China Association of Automobile Manufacturers, etc. There are 711 national associations, and most of them depend on the state-owned assets supervision and administration commission (42,9 percent), and on another ministry or commission (36,6 percent) (Deng and Kennedy, 2010). Nevertheless, their members are both private and state firms. They are thereforesource of information to identify firms in each industry. The identity of the largest members is generally public. Otherwise, they also publish reports on the state of the industry.

[1]Shareholding of more than 50, 01 percent.
[2]A similar request for South Korea gives no results. This probably reflects specificities of Korean firms (crossed-ownership and size).
[3] Distinct from Huawei Technology Co Ltd (骅威科技股份有限公司), a listed toy manufacturer

In addition, there are non-governmental and non-sectorial associations. The All-China Federation of Industry and Commerce (created in 1953), China's non-governmental chamber of commerce, is a large organization, with local and sectoral branches.[1]It publishes the lists of the top 500 private groups, and the top 500 Chinese firms. Firms that appear in these lists are ranked by their profits. Screening these rankings and select the ones that meet our criteria is a reliable way to identify firms.

Table 4-1: Source of data used to build the database of firms

Sources	Available data	Selection of firms in panel
Identification of large Chinese firms		
Central SASAC	List of state firms- 112 firms on SASAC General news and trends	83 firms (including firms dependent on other ministries)
Local SASACs and equivalent		136 large firms
All-China Federation of Industry and Commerce	List of Chinese firms 500 top China, 500 top private firms General news and trends	105 firms[2]
Main sources of characterization of firms		
Shanghai and Shenzhen Stock Exchanges	Industry; market data:	996 listed companies on SSE 1618 companies on SZSE 1557 manufacturing firms
ORBIS database *Global database of listed and unlisted firms, Bureau van Dijk*	General and financial information Ownership and shareholders for listed and non-listed firms	R&D expenditures for 2013 for 2380 listed firms (> to 0 Yuan)
Chinese Securities Index Co Ltd	Industry; Ownership; Market Value	Types of ownership: private, central state and local governments for 2442 listed firms
Corporate websites	Diverse information : Organisation, history, products, technologies, etc.	
Industry associations	Sectorial news and reports List of corporate members	

3.4. Conclusion

In this section, we detailed the selection criteria and data sources we used to look at Chinese firms. This led us to select 325 large firms (Table 4-1). Such method of selecting the largest firms with no innovation-based criteria to observe their technological capabilities is not new. Patel &

[1]It is under the leadership of the United Front of the Communist Party of China.
[2] There is in addition one collective firm, which presents very specific feature (Nanjiecun group), as Nanjiecun is the last collective farm.

Pavitt selected the 400 largest firms in the world in order to look at their technological profiles over time (Patel and Pavitt, 1997). What is new is the fact that we did it by crossing several data sources, in the Chinese context. While it remains necessary to interpret data with caution, Chinese firms have become increasingly transparent. All large Chinese firms have their own websites. They give details, in Chinese and, often, in English. These corporate websites provide extensive information on the firms' history, their industries and products, and their organizational structures. Firms also provide elements on their innovation strategies, and how their R&D is organized. Because of this increasing transparency, firms that we have not integrated into our population of firms, are likely to be local firms at lower level governments, with local implantation and markets.

A second remark can be made on the variety of sources used. While using various sources further ensures the relevance of our selection, it also creates disparities. Available data are either consolidated data (for the whole firm) or non-consolidated ones (only referring to one entity of the firm). This is the case for R&D expenditures or the number of employees. We do the best to harmonize data we use

Chapter 5: **Large firms in China**

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1. Introduction

This chapter presents the specificities of large Chinese firms on the background of the historical, political and industrial factors which impacted their trajectories. Understanding these trajectories and their determinants is key for understanding China's innovation transition.

This chapter serves two purposes. The first one is to identify the main keys to understanding the trajectory of Chinese firms. Of course, there is diversity among individual firms, and each firm is different, but our aim is to focus on patterns that differentiate them from large firms in other countries. Focusing on such a population of firms is quite common : large Chinese firms are the topic of general studies (Jolly and Girard, 2011; Larcon, 2009), and of studies on narrower topics such as their globalization (Nolan, 2001a; Nolan and Zhang, 2002), global strategy (Peng, 2012), or, a topic discussed in this dissertation, their innovation strategies (Zeng and Williamson, 2007). The second purpose of this chapter is to showthatunderstanding the transition to technological leadership requires articulating the firm level with the national level.

In addition to describing individual trajectories, we shall try and discuss the specificities of Chinese firms from a broad perspective. Accounting for the geographical repartitionof large Chinese firms, and the contribution and role they have in the economy as well as their contribution to it as a group, allows for a better understanding of China's dynamics.

To accomplish the two purposes, the chapter is organized into three sections. First, we shall identify the specific features of large firms in China. We do this essentially by questioning their proximity or difference with other firms, in Korea and emerging countries. The first section thus adopts a comparative country approach. In a second section, we look at the diversity among Chinese firms and identify the primary historical dynamics that explain it. We illustrate this diversity in the following section by describing the 325 large Chinese firms identified in the previous chapter (Chapter 4, Section 3, p. 75). Finally, we conclude the chapter on the specificities of the population of large industrial Chinese firms.

2. A comparative approach between large national firms

The comparison between countries helps identify the specificities of national innovation transitions. Each country has its own history and development path. Specifically, we compare Chinese firms to three contextual frameworks: Korean firms, firms in advanced economies (USA, Japan, and Europe), and, firms from emerging large nations (India, Brazil…).

2.1. Relevance and limits of comparing Korean and China's innovation transitions

South Korea was among the world poorest countries in the 1960s when Park came into power. In fifty years, the country has achieved the rank of "developed markets," for investors represented by the FTSE or S&P (Johnson, 2016), ranks among the largest R&D spenders (OECD, 2014), and has witnessed the emergence of large Korean multinationals (Kim et al., 2004).[1] In 2015, Korea was the 11th country in terms of GDP in 2015 (IMF) and it is considered to be a successful case of innovation transition. It is, therefore, reasonable to use it for the comparison with China. In addition, the comparison between China and Korea comes from the geographic, and cultural proximities between the two countries. They are Asian countries with similar cultural traits – including Confucianism, language proximity (notably because of the familiarity of Koreans with Chinese characters) and common references (popular culture such as sitcoms, celebrities, etc.).

In addition, both countries have witnessed a rapid economic growth based on technological progress and manufacturing of products of increased technological complexity.[2] China's economic situation at the end of the 2000s shares similarities with that of Korea in the 1990s. The 2008 global financial crisis accelerated China's economic difficulties and increased the pressure on Chinese firms to innovate. In a similar way, the Korean economy was threatened by the 1997 Asian financial crisis.[3] In 1997, Linsu Kim concluded his book on Korea's technological learning in terms that could be applicable to China today: "In conclusion, Korea has dynamically achieved phenomenal growth in technological learning in the past three decades. But Korea, facing many problems of its own, is being squeezed between advanced countries and second-tier newly industrializing countries. As a result, Korea may not be able to grow as fast as it did in the past. But by turning future crises into creative learning, it is Korea's vision to join the industrially advanced community (G-7) by 2020."(Kim, 1997).

The severity of the 1997 crisis marked the limits of Korea's economic development: according to The Washington Post, 14 of the 30 largest Korean companies were "wiped out" during

[1] Financial Times Stock Exchange 100 Index

[2] There are of course many points of dissemblance, notably the role of foreign investments, which was modest in Korea, and a primary factor for China.

[3] This was not the case of China. The 1997 Asian crisis had a moderate impact on the Chinese economy, because at the time, China's economy was less open than its neighbors to the global economy.

the 1997 Asian financial crisis (Harlan, 2012). However, the crisis contributed to foster investment in corporate R&D, because it weakened the performance of industrial strategies that firmspreviously followed and that were based on industrial diversification rather than specialization.[1]

We can make a parallel between the two historical situations. The question of the innovation transition in China is related to its capacity to seize the risks and opportunities attached to the current economic situation. Scholars explored questions in the Korean context that are now raised in China. The validity of a theoretical framework derived from the Korean experience to China, therefore, depends on the examination of the two situations in a comparative perspective. In particular, research on innovation transition derives from studies on Korea.

We have formulated the hypothesis that large Chinese firms develop their knowledge base on emerging technologies while they are catching up on other dimensions because the innovation transition is characterized by the implementation of different technological strategies across divisions / subsidiaries within a firm (leadership, challenger, and catch-up). This hypothesis is built upon the Korean case (Hobday et al., 2004; OECD, 2009), and in particular the case of Samsung, which is considered as having achieved the transition to innovation (Kim et al. 2004). The organization of Korean large firms into large business groups has been favorable to this strategy, which is still visible in 2012. The largest Korean firm, Samsung sells key elements for Apple's iPhone while competing in the smartphone market(Harlan, 2012).

This leads to putting in perspective the nature and features of Chinese firms with that of Korean firms. The comparison between the two countries, however, shows many differences in the contribution of large firms to the economy, in their organization, as well as their industrial strategies.

The degree of dependence of a national economy on its large firms varies across countries and strongly differs between China and Korea. Large firms drove Korea's transition (OECD, 2009). These firms, formed into *chaebols,* include Samsung, LG or Hyundai among the most famous ones.[2] A few of them account for a dominant proportion of Korea's GDP. Chaebols made 71 percent of Korean GDP in 1987 (Lee and Jin, 2009). This trend has persisted. Samsung alone accounted for

[1]However, by contrast with the Chinese case, this occurred despite a slow-down in terms of R&D investment "…the rate of growth of R&D spending overall fell immediately after the crisis from an average of 10 percent per annum in the period 1992–1997 to 5 percent in 1999 … and R&D spending as a proportion of overall GDP] fell from 2.55 percent in 1998 to 2.4 percent in 1999" (Hobday et al., 2004)

[2] The Korean 'Chaebol" refers to South Korea's large firms, mainly formed in the 1950s (Sig Choi et al., 2008). These firms that are horizontally and vertically constitute a unique model of conglomerates, that play a role during the period of economic growth. They are characterized by a series of distinctive features. The first one is their specific ownership structure, where founding family members keep control of firms through cross ownership. This ownership structure has helped chaebol firms to engage in internal market transactions (member firms purchase and sell intermediate goods in the group), while major firms guarantee bank loans and provide collaterals for others. One of the major feature of chaebol firm is therefore the internalization of market transactions. While they origin in Japanese zaibatzu,they differ in that regard because they were prohibited to held shares in commercial banks (Park and Yuhn, 2012).

23 percent of Korean GDP in 2013 (Le Monde, 2014).[1]Thus, understanding the development of these firms explain to a large extent Korea's economic development.

The configuration is different in China, where large firms have a much smaller weight in the economy. In 1995, the top 30 largest firmsaccounted for 1 percent of the Chinese GDP (Lee and Woo, 2001). Even though the proportion might have varied since then, the smallness of this percentage clearly indicates a lower dependence of the economy on the largest firms.

In the case of Korea, there is a direct impact of the development of innovative capabilities of a few large firms in the nation. In China, the persisting fragmentation has an impact on industrial transition. The innovation transition does not rely on the technological strategies of a few firms and is distributed among a greater number of smaller firms, with less individual impacts.

Consistent with what was presented in the paragraph above, large Chinese firms are, on average, smaller than Korean ones. In 1995, the average asset size of the top 30 Chinese firms was seven times smaller than that ofthe average top 22 chaebols (Lee and Woo, 2001). What we observe in the population of the 325 industrial firms confirms this pattern. The average number of employees for each firm is about fifty thousand persons.[2] There is, in addition, variety among Chinese firms themselves. The group of 325 includes firms of various sizes. 162 firms (50 percent) employ less than 21 500 employees.[3] On the other hand, there are 44 firms in the group (representing 14 percent of the group of 325 firms) which employ more than 100 000 persons.

One explanation of this difference can be found in their respective national histories. We detail the trajectories of large firms in China in the next sections, but we can already draw attention to the fact that they have grown following other dynamics than those in Korea. The "octopus-like" growth strategy followed by Korean firms still explains the current organizational structure: Chaebols, which were created in the 1960s and 1970s, grew by diversifying and creating new entities in other industries, following opportunistic market strategies under the influence of a dominant family that aimed to keep control of the entities (OECD, 2009).[4] This explains the complex ownership structure of Korean firms, with crossed ownership between subsidiaries (Lee and Jin, 2009). It results that some Korean firms under the same brand are not even legally related (OECD, 2009). The dominant model is the conglomerate: in 2010, they account for about 80 percent of the largest 50 Korean companies by revenue (Hirt et al., 2013). Chinese firms did not adopt such a diversification strategy even though it is clear that Chinese leaders have visited

[1] Samsung is by far the largest chaebol in Korea. While Samsung Electronics is well-known outside Korea, the group has diversified activities through its subsidiaries. The omnipresence of the firm explains the nickname of Korea as "The Republic of Samsung" (Harlan, 2012)
[2] 50 884 employees on average
[3] Median: 21 500 employees
[4] Control was notably kept thanks to personal connections. There is an intersection of business and family interests through marriages notably between different chaebol families.

chaebols (and Japanese keiretsu), and were familiar with the model of these network-based groups(Ma and Lu, 2010).[1]

2.2. Chinese large firms and other emerging nations

Another reference framework, quite common, is that of "emerging countries." One could consider that large Chinese firms belong to the broad group of emerging market multinationals (emerging multinationals or similar appellations). Emerging market firms, as a group, are the subject of general analysis (Batra et al., 2012; Huchet et al., 2015; Ramamurti and Singh, 2009; Williamson et al., 2013) or are studied regarding specific topics such as their internationalization (Bonaglia et al., 2007) or the role of family firms (Fernández-Pérez and Fernández-Moya, 2011). This categorization implies that Chinese, Indian, Brazilian and other firms share common difficulties and opportunities, and adopt similar strategies in response to their environment. By default, it also implies that firms in emerging countries share with one another features that contrast with firms from advanced economies. Most global firms, especially leading industrial firms, come from the highest income countries. These firms, therefore, operate as an alternative model. The United States are home to the largest number of global firms in Fortune rankings (Fortune, 2014). In 2014, there are 613 American firms among the top 2500 global firms in R&D (EU R&D scoreboard, 2014).

Since the 19thcentury and the generalization of large business corporations in the United-States and in Europe, the organization of firms has become increasingly complex. In order to operate in several markets – either different geographical market or different product ranges - large firms organize their activities in divisions, entities that are bound together with links of coordination, subordination, etc. and organize in business groups. Business groups are defined as the "collections of firms bound together in some formal and/or informal ways characterized by an intermediate level of binding, namely neither bound merely by short term strategic alliances, nor legally consolidated into a single entity" (Granovetter, 1995). This classic definition emphasizes the diversity (or collections) of entities and links within large firms themselves. Large firms, or business groups, produce a range of products and services that are more or less diversified in terms of industries. Large business groups tend to operate with separate entities in diversified industries but are not equivalent. We encapsulate the way these different activities are organized under the

[1]Alternatively, one can extend the comparison to Japan. There are important differences between the Korean and Japanese models. Differences are notably due to the fact that Korean firms are prohibited to hold share in commercial banks, which lead to alternative model of internal markets (Park and Yuhn, 2012). It is however arguable that Korean and Japanese large firms present more similarities with each other than they both do with Chinese firms. They originate in the same model. This is further illustrated by the vocabulary: 財閥 both refers to chaebols and zaibatsu (Chinese characters used in Japanese and in Hanja that respectively mean "wealth" and "clan"). Zaibatsu are Japanese pre-war business groups from which derived the present keiretsu (Mitsubishi, Nissan, etc.).

notion of organizational structure.

Organizations differ across countries. Diversified firms have been considered as a major driver of the economic growth of developing countries including Argentina, Brazil, India, Malaysia, Mexico, South Africa, South Korea, Taiwan, Thailand, and Turkey (Amsden and Hikino, 1994).In developing countries, there is a stronger trend for industrial diversification by firms constituted in business groups. Associated with diversification is the organization in conglomerates. Conglomerates are either business groups with a holding company and various listed and unlisted subsidiaries (Tata in India, Samsung in Korea, Bouygues in France, Mitsubishi in Japan, etc.), or a multidivisional corporation, which houses several industries within the same entity (e.g. Nestlé). Tata Group, for instance, is a large Indian conglomerate organized into a business group. Established in Mumbai as Tata in 1868, it has grown and now has leading subsidiaries in automobile, steel, tear, soda, communication (TATA, 2014).

The basic argument that explains industrial diversification is when a firm with investment capability operates in a sector with lower demand and technological capability constraints.[1]Conglomerates exist everywhere, but they play a specific role in developing nations because a diversification strategy is appropriate in an environment with less developed market infrastructures and property rights. Deficiencies like the lack of information, the lack of infrastructures and poor institutional mechanisms complicate access to resources and to customer markets(Khanna and Palepu, 1997). Being organized as a diversified business group mitigates the difficulties caused by market deficiencies such as difficult access to bank loans. The organization of business groups facilitates internal financing and the circulation of personnelbetween the different entities of the group and enables leverage on their unique corporate brand across industries(Khanna et al., 2005; Khanna and Palepu, 1997).

The industrial diversification of firms is often analyzed as a strategic response to institutional constraints. In that perspective, firms adopt a diversified structure to fill the institutional voids of emerging markets, some of which we already mentioned in the previous section, or as an opportunistic approach to development. For instance, the dominant models among Indian firms are conglomerates. In 2008, the top ten Indian conglomerates accounted for 40 percent of the total market capitalization of the top 500 Indian firms (Business Today, 2014).This can largely be explained by economic planning under Jawaharlal Nehru in 1947(Ruet, 2015), which limited some sectors of the economy to the private sector. In each industry, the government lets the private sector foster its initial development but after a while takes back the project. As a result, each time a firm was blocked from expanding into its industry, it was going into another sector in which

[1] This is not limited to the developing countries. For instance, this argumentexplains, in the 1950s, the growth of American conglomerates coming from sectors like public utilities, transportation, textiles, mining, and food, as they use their available cash from prior investment to invest in other industries (Amsden and Hikino, 1994).

he had the license to operate(Ruet, 2015).

Each country has its particularities, and generalizations might be misleading. The debate over what terms are the most appropriate to categorize these countries, among emerging countries or markets, developing countries, middle-income range countries, etc. reflects the existing diversity among these countries. The World Bank at the moment of writing distinguishes four groupings according to the level of incomes: low (31 countries in 2014), lower-middle (51 countries), upper-middle (53 countries), and high income countries (80 countries).[1] What we observe is that this categorization is not consistent with the acronym "BRIC" (or BRICS): China and Brazil are both categorized among the upper-middle income countries, Russia as a high-income country, and India as a lower-middle income country. This illustrates the limits, at least in the context of our research, of comparing China to other countries such as India (population 1,311 billion[2]) and Brazil (population 208 million).

The Chinese word for (large) business groups (da) qiyejituan appears for the first time in 1986 in the State Council official documents (Ma and Lu, 2010). It is now commonly used to name large firms. The National Statistics Bureau of China defines them as "legally independent entities that are partly or wholly owned by a parent firm and registered as affiliated firms of that parent firm" (Ma and Lu, 2010)[3]. While Chinese firms are organized as business groups, there is no equivalent to Tata or to Samsung.

Some of the largest firms are state-owned enterprises and are sometimes identified as conglomerates. They are however business groups that are vertically or horizontally integrated, and their core industry is easy to identify. China Petroleum & Chemical Corporation (Sinopec) is such an example of a business group. The firm describes its activities as follows on its website:

The scope of its business mainly covers oil and gas exploration and production, extraction, pipeline transmission and marketing; oil refining; production, marketing, storage and transportation of petrochemicals, chemical fibers, chemical fertilizers and other chemical products; import, export and import/export agency business of crude oil, natural gas, refined oil products, petrochemicals, chemicals, and other commodities and technologies; research, development and application of technology and information. The Company is China's largest producer and supplier of refined oil products (including gasoline, diesel and jet fuel, etc.) and major petrochemical products (including synthetic resin, synthetic fiber monomers and polymers, synthetic fiber, synthetic rubber, chemical fertilizer and petrochemical intermediates). It is also China's second

[1] On 215 countries and territories (include islands) https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries

[2] Source: Estimates of the United Nations (Word Population Prospect). Data available at https://esa.un.org/unpd/wpp/ China's estimated population in 2015 is 1,376 billion people. See chapter 3.

[3] The core company should have a registered capital of over 50 million Yuan, at least 5 affiliated companies, and a total registered capital to be over 100 million Yuan in the definition of the State Administration for Industry and Commerce.

largest crude oil producer (2006).[1]

This description illustrates both the coherence of its core activities that are carried out within 100 entities including wholly-owned, equity-holding and equity-sharing companies, and the horizontal diversification within industries, here from oil extraction to petrochemical products such as resins or synthetic fibers, and chemical products.

The low diversification is illustrated by the sectoral distribution of the group of 325 large industrial firms. Most firms operate in well-determined sectors such as the metallurgical sector, the car industry, construction or electronics. This is coherent with other sources. Seven firms listed on the Shenzhen Stock Exchange are classified as 'conglomerates,' compared to the 1640 firms listed in Shenzhen at the time.[2] However, this figure only acts as an indicator. The difference in the proportion comes from the fact that conglomerates often list specialized entities, and data on listed firms, in turn, leads to underestimating the number of conglomerates in the economy.

This is the reason why in the last section of this chapter we argue that conglomerates are not the driving forces of the Chinese economy. Altogether, 42 firms operate in diversified activities without any dominant core activity. They employ on average 39507 persons for a maximum of 200 000 persons.

On average, large Chinese firms have adopted industrial specialization strategies. It might be argued that these kinds of strategies are closer to that of firms in advanced economies. Their size is aligned with global average as well. Large Chinese firms in our data employ from 10 000 (the minimum thresholds we adopt) to 1,5 million employees, with an average level of employment of 50 884 persons. It is difficult to obtain a relevant point of comparison, but these figures for Chinese large firms are in the magnitude of figures for large firms ranked in the 2014 European Innovation scoreboard.[3] The average level of employment of the latter is 49 040 employees, with maximum 580 000 employees. It appears that Chinese large firms tend to be relatively modest in size. Moreover, some of the centrally state-owned firms often seen as “giant” companies, including Sinopec and Petrochina, are not large according to global standards (Nolan and Zhang, 2002).

We observed that three features are associated with firms in developing nations: the role of industrial diversification(Khanna and Palepu, 1997), the role and characteristic of conglomerates and business groups, notably in India, and the nature of ownership. State ownership is a feature commonly shared in developing nations. Large corporations around the world are mostly controlled either by one State or by one family, with ownership not widely dispersed and with pyramidal structures (Porta et al., 1999). Based on these three features, Chinese firms do not follow a model

[1] http://english.sinopec.com/about_sinopec/our_company/20100328/8532.shtml Accessed on 15/08/2015
[2] http://www.szse.cn/main/en/MarketStatistics/BySectors/
[3] only selecting firms with more than 10 000 employees in similar sectors

that would be “typical” of emerging nations, even though there are conglomerates and diversified business groups. As we mentioned above, some features are more similar to those of firms in advanced economies like size and industrial specialization.

Similarly, firms in developing nations operate in a weaker institutional environment. Xu and Meyer list four identified features of emerging markets. Markets are less efficient; governments are not only setting the rules, but they are active players in the economy; network-based behaviours are common, because of less efficient markets and to some extent of social traditions; and high degree of risks and uncertainties make it more difficult for companies to design their strategic decisions{Citation}. To what extent does China also share these features? Market efficiency and the level of risk and uncertainties are difficult to assess. In these two dimensions, there are certainly roads for improvement. China has not yet reached the standards of developed nations regarding the level of its financial markets, and uncertainties remain high. The situation is, however, better than for other developing or emerging nations. By contrast, it is recognized that China shares the two other features: government intervention and intrapersonal network. Governments are active players in China, as is illustrated by thedebates on the model of “state capitalism” proposed by China’s specialists (Bergère, 2013; Naughton and Tsai, 2015). The second element, network-based behaviors, is also well documented. The concept of *guanxi* is often mobilized to explain China’s mode of intrapersonal relations; *guanxi* creates reciprocal obligations and impacts on varying aspects of business, including business performance (Chung, 2011; Yeung and Tung, 1996).

Table 5-1: Comparison of Chinese large firms with other firms

	Chinese groups	**Korean groups**	**Emerging nations Companies**	**Western firms**
Dominant growth strategy	Specialization	Diversification (internal growth)	Diversification (internal growth)	Specialization (internal & external growth)
Weight in national economy	Low 1 percent of GDP for 30 top groups	Very heavy 71 percent of GDP (Samsung = 17% of PIB)	Varied	Varied
Ownership type	Concentrated ownership	Crossed ownership Family behind ‘chaebol.'	State and family-owned groups	Concentrated ownership (Porta et al., 1999)
Governmental links	State ownership Network Specific role of CCParty	Network	State ownership Network	State ownership Network
Size	Average Fragmented	Very large	Large	Average (source: EU scoreboard)

2.3. Conclusion

This introduction to the differences between China and other countries has evidenced two elements regarding Chinese firms. First, the South Korean case appears limited to explain the

innovation transition in China. Chinese firms and Korean firms have adopted different organizational structures. Chinese firms are smaller and more diversified.Moreover, they do not have the same weight in the economy. We noticed in Chapter 3 that China was more decentralized because of the importance of local governments. Then, China also presents very distinctive features from India.

3. Histories and trajectories of today's large Chinese firms

I returned to mainland China in the early 1990s… the Chinese had no concept of what a company was, they only had enterprises. And, at that time, a state-owned enterprise was really just an arm of the state, and they fulfilled the designed role by the state for each of the enterprises. Which was, of course, a very different notion than what a company is all about. But, over time, many of the Chinese enterprises turned into companies. But, when they interact with multinationals they actually find out that, "Hey, there's actually another way of running a business.

Edward Tse, Chairman, Greater China, Booz & Company[1]

3.1. Introduction

The preceding section presented the specificities of large Chinese firms. These specificities can be explained by the way large firms have emerged and grown till today. Each corporate history is obviously unique but, in the Chinese context, we can identify two primary dynamics that are associated with the evolution of their organizational structure and industrial strategies. These dynamics are intertwined with the political decisions that led China's transition to market economy, and the choice of a "state-led" transition. The first dynamic is the fact that large Chinese firms emerged along two paths: they were new entrants after 1978 or, they originated in the transformation and expansion of prior industrial capacities. The second dynamic is the evolution of the respective role of state and private firms in the course of years.

3.2. Two primary growth paths

Large enterprises emerged following two primary paths: the growth of traditional plants into bigger groups since 1978 and the construction of new plants; and the growth of new entrants during the reform and opening period (Nolan and Yeung, 2001). Let us emphasize the fact that these two paths do not coincide with the "state versus private" narrative, a topic we discuss in the following sections.

[1] In interview of Edward Tse - China Boom Project Available on http://chinaboom.asiasociety.org/

The first growth path is the path followed by thefirms created after 1978. Many international Chinese firms in consumer markets, mostly private firms or locally state-owned firms, fall into that category. Many firms were established in the 1980s and 1990s, and they do not only include private firms. The first administrative decentralization created incentives for local governments to develop their local economy. Thus, many new entrants were state-owned, and their creation was supported by local governments. Local governments acted as entrepreneurs by establishing new firms, and/or by supporting them (Naughton, 2007).

The importance of local ownership in China should not have us forget that the recent period witnesses the emergence of family businesses, especially in Zhejiang Province. The role of family ownership in China is very interesting. There has been a surge in the number of family owned firms since 1999. In particular, in 2008, there were more than 100 family-owned listed firms in China (Ding et al., 2008) out ofa total of around 1600 firms listed in Chinese markets. Family-owned firms are firms with people from the founding family in a management position. Due to the recent history of the Chinese firms, which were created in the last thirty years, there may not be 'dynasties' like those that can be found in the United States, in Europe or in South Korea. The existence of family firms is often associated with a longer-term vision, greater investment in the firms by managers, as well as maintained control on business activities. Listed family-owned firms are smaller than state-owned firms. The largest ones are specialized in electronics, retail, and sectors of the car industry. Some of these firms are included in the 325 large firms, categorized by private ownership. The largest family firms in 2005 were Guangsha Group (Lou Family), Wanxiang Group (Lu family), Hengdian Group (Xu family), Youngor Group (Li family), Chint Group (Nan family), Hangzhou Wahaha (Zong Family), Jiangsu Sanfangxiang Industry (Bian family), Delixi Group (Hu family) and Nanshan Group (Song Family)(Lubinski et al., 2013, chap. 6).

Most current large private firms were created after 1978. The emergence of private firms is not linked to the privatization of state firms during the transition towards the market economy, but to later creations. Few firms were privatized contrary to what happened during the market transition in the URSS where privatization was massive and rapid (Filatotchev et al., 1996). During the first period, the institutional change allowed private ventures to grow and develop, even though at first they represented a very marginal as an activity (Nee and Opper, 2012). Among the private firms that compose today's industrial large firms and for which we have the year of creation, 89,5 percent of them were created after 1978. Among the nine private firms created before, there is a high proportion of family firm businesses. There are very few cases of private firms founded by individuals disconnected from local institutions or businesses.

An alternative path has been the growth and expansion of the traditional plants, which existed before 1978. This is the path followed by an important proportion of the 83 centrally state-

owned firms in our data. 36 percent of them (30 firms) were founded before 1949 (6 firms) or during the planned economy period (between 1949 and 1978).[1] In a broad movement of restructuration and corporatization of the soviet-style Chinese industrial system, centrally state-owned firms were incorporated as firms with industrial purpose and integrated state plants and facilities that depended on their former ministries in their scopes.[2] The origin of these centrally state-owned firms can, therefore, be traced back to the 1950s and the first 5-years plan (1953-1957) modelled on the soviet planning system established since 1920s and 1930s in Russia and inspired by Marxist thinking as well. Many of them find their roots in the system that was first implemented in the 1950s, with the help of the Soviet Union. During the first 5-year plan, 156 large turnkey facilities were imported in heavy industry, power generation, mining, refining, chemicals and machine tools (Liu and White, 2001, p. 1097).

Because of central planning, the economy was organized in industrial sectors (or industrial bureaus), which encompassed, beyond manufacturing plants, research institutes, design bureaus, engineering research institutes and experimental facilities depending on branch ministries. However, one element that differentiated China from Russia was the deployment of the structure at the different administrative levels, with the fact that each governmental level adopts the same structure than the Central' People Government. This basic organization remained unchanged until the 1990s. It is visible in thedescriptions of the R&D organization of industrial firms in China (Fischer, 1983).

The restructuration since the 1990s was not directed by market-based decisions. Instead, the integration or the growth of large state firms is coordinated and supervised by administrative authorities. There has been in particular repetitive attempts to consolidate the industry by grouping small actors (Huchet, 1999).[3] In 2015, the railroad equipment manufacturing, the two large centrally state-owned firms China, CNR Corporation Limited and China South Locomotive & Rolling Stock Corporation Limited (CSR), were merged in 2015 to form a new firm.[4] According to an official of the State Assets Supervision and Administration Commission (SASAC), "the merger is an experiment by the government aimed at reforming state-backed firms", and "the new company will help accomplish the government's 10-year plan for upgrading manufacturing capacity and help SOEs' expand abroad"(Caixin, 2015).

Clearly, these two paths are schematic and there is not always a clear separation line

[1] For some firms, we use as data the year of the legal incorporation of state assets into the firm, which happened much later in the history.
[2] a few firms were not corporatized (China Railway) and are under the Law on Industrial Enterprises Owned by the Whole People (1988)
[3] Huchet notes for example the importance of the fragmentation in the cement industry, with more than 8000 cement producers at the time. It is noteworthy that the problem has persisted.
[4]China North Locomotive and Rolling Stock Industry (Group) Corporation

between the two paths. Quite naturally, entrepreneurs have used existing facilities prior to 1978 to create and develop their business. For instance, Hisense grew out of Qingdao No.2 Radio Factory in 1969 and was incorporated as a company in 1992. In addition, there is also important variety within the group of centrally state-owned firms. There are also examples of large central state owned enterprisesthat were originally created under the leadership of an entrepreneur. This is, for instance, the case of China National Chemical Corporation (ChemChina), whose official story goes back to the creation of a small solvents factory "Bluestar Company" by Ren Jianxin in 1984 with a 10,000-yuan loan, and which grew by integrating troubled state-owned factories while maintaining state ownership. ChemChina was created in 2004.[1]

Their history, marked by several discontinuities and change in their trajectories (Ruet, 2015), has consequences on the level of industrial diversification of large Chinese firms. Conglomerates and diversified firms are a recent trend in China, compared to Korea or India. "*According to McKinsey, China's conglomerates (excluding state-owned enterprises) represented about 40 percent of its largest 50 companies in 2010, up from less than 20 percent a decade before"*(Hirt et al., 2013). This shows an increase in the number of private conglomerates in the first decade of the 2000s. Moreover, many large state-owned "conglomerates" tend to maintain more specialization than their counterparts. Large firms that were restructured on the basis of traditional plants and institutes were created to cover the needs of the market for a particular industry. For instance, "*Sinopec was under the direct supervision of the State Council and was tasked to operate downstream, including the formulation of policies for producing refined oil products and petrochemicals, supervision of the construction and operation of refining and petrochemical plants and the marketing of refined oil products and petrochemicals in China*" (Zhang, 2008). The specialization that derives from their incorporation "for industrial purpose" suggests that when a business group diversified to other sectors, the diversification occurred later in the firms' history.

The organizational structure of large central firms results from the integration and restructuration of state assets, through mergers and acquisitions, in addition to the construction or extension of further production facilities. Therefore, the specialization towards core industries does not necessarily mean that a firm presents an integratedorganizational structure. In some cases, there is barely any coordination between them. A former engineer of the centrally state-owned firm FAW (First Automobile Works), a fortune global 500 company (2015) mentions how separate entities, in the automotive industries, operate independently: *You may better understand the FAW Group, when seeing it as a bundle of different firms rather than a whole. I spent my entire career in Changchun, where FAW's matrix operations are located. During a long period of my career, many of FAW's*

[1]https://www.pirelli.com/corporate/it/about_us/management/default_Ren-Jianxin.html Accessed on 12/10/2015

current affiliates, such as the Tianjin and Hainan Automotive, were independent firms controlled by different local governments, and had developed varied culture, conventions, and technology bases. Coordinating this historic legacy in favour of the centre's strategy would be challenging.

Former engineer of FAW, cited by (Nam, 2015, p. 267)

3.3. The rebalancing between private and state firms

State firms are over-represented among large firms in China. Chinese state has not disengaged from firms during the reform period, which explains the remaining importance of state ownership.

This is reflected in the composition of the group of 325 firms we look at. Two-thirds of the firms are state firms. This includes central state ownership, but also ownership by local governments. In this regard, local governments played a double role in the formation of large firms. 25 firms (23 percent of locally state-owned firms) originate from facilities existing prior to 1978. This shows that local governments also participated in the creation of new firms after the start of the reform period and that this pattern is not marginal. Locally state-owned firms account for 42 percent of the population of 325 large industrial firms, with 136 locally state-owned firms, which represent the largest category. We can note that among large firms, state ownership dominates private ownership, which is related to the role of local governments. The proportion - one-remaining third of private firms (32 percent) - is consistent with other sources of data. For instance, in 2011, China's most profitable 500 firms included 194 private firms according to the survey realized by the All-China Federation of Industry and Commerce (Shim, 2012). This represents 37 percent of the top 500 Chinese firms in terms of profit.[1]

This distribution is not representative of the entire Chinese economy, in which the private sector has become dominant. It represents 60 percent of the GDP in 2012 (All-China Federation of Industry & Commerce, 2012). Private firms have a lesser weight among large firms. There are less of them, and on average, they are smaller than large state firms. This can be explained by the top of the list and the size of very large central state owned firms. In 2011, total profits by the most profitable 184 private enterprises were only half of the top 10 state-owned firms (Shim, 2012). Indeed, if we look at employment figures, private firms and locally state-owned firms belong to the same range, even though locally state-owned firms tend to be slightly larger: 28 000 employees for the private firms, and 31 000 for locally state-owned firms.[2][3]The real contrast exists with centrally state-owned firms which employ an average of 86 500 employees.

The convergence between state and private firms would depends on two features. The first

[1] 37 percent of the top 500 Chinese firms
[2] 27 737 employees
[3] 30 977 employees

one is the nature of the governance of state firms. State ownership is often associated with political costs for the firm. In theory "the SASAC was founded "on the principle of separating government administration from enterprise management and separating ownership from management" (Trade Policy Review, 2006). Manylarge state firms, especially centrally state-owned firms, are managed as administrations. Processes such as executives' careers advancements or allocation of financial profits follow administrative rules and depend on ministry-level decisions. For instance, the amount of dividends that Chinese centrally state-owned firms need to give its shareholders (SASAC or other ministries) is defined by law (and can be revised). State firms are likely to adopt strategies decided by the government, this included for example firms that are "required" to merge to acquire the assets of another one in the perspective ofconsolidating the industry (Huchet, 1999).

The Chinese Communist Party still has a major role among Chinese firms, including listed firms (Yu, 2009) and state firms (Wang, 2014). These roles might overlap, the firm's chairman being the Party Secretary. This raises questions about their managerial capabilities: there is some evidence that the party secretary "is likely to be a person with more political reliability (that is, connections) but less professionalism than other managers" (Yu, 2009). While the role of the party is not limited to state-owned firms, it is stronger in the case of state firms where they both ensure political decisions, and also impact corporate decisions notably through executive appointments (McNally, 2002). Private firms use the Party secretary as a channel with the government (i.e. political ties)(McNally, 2002).

In addition to corporate governance issues specific to state firms (see p. 56, Are Chinese institutions supporting innovations?), another aspect is the difference of treatment between private and state firms. There has been an official and continuous support to the central large firms by the Chinese government, which if it did not exclude private firms, tended to favour the state-owned ones.

The historical support to large state firms had varied across the years (Eaton, 2014). Large firms were not a driver of economic development at the beginning of the reform period. Smaller collective enterprises and town and village enterprises led the first waves of development(Naughton, 2007, p. 271). They gained more importance from 1989, and the arrival of Li Peng.[1] Since then, the importance of leading a "large enterprise strategy" has made consensus among political elites (Eaton, 2014), and led to implement measures to promote large firms. It includes traditional mechanisms such as the implementation of financial supports (tax credits or subsidies), market control mechanisms (price controls, localization constraints, licenses). The

[1]Zhao Ziyang, premier till 1987 and general secretary of the central committee Party from 1987 to 1989was criticized for giving too much support to smaller enterprises at the detriment of large enterprises. However, it seems that this political choice does not reflect a real opposition to supporting large and central enterprises, but was rather a pragmatic choice towards TVEs (Eaton, 2013).

support to large firms was largely oriented towards state firms, which were privileged in many aspects. They have easier access to bank loans. They can provide better employment conditions, social security or pension system than private firms(Venture Outsource, n.d.), which created competition for human resources by private firms.

There has been a progressive harmonization in the treatment of private and state firms, however. In 2005, the Chinese government publicly announced equal treatment for private and public sectors in terms of investments" that allow private investment into monopolistic industries.[1] Introducing market competition for state firms has also become a topical issue under Xi Jinping since 2012. The harmonization of treatments was progressively extended to innovation policies, and notably on those regarding emerging technologies. In 2012, China's National Development and Reform Commission expressed its commitment to providing private sectors with financial support for strategic emerging industries (Shim, 2012).[2] There are however persisting worries of misallocation of resources towards state led innovation projects (Chen and Naughton, 2011).

4. The description of the large Chinese firms

In the preceding sections, we have presented what we consider to be important features of Chinese firms, and have highlighted some elements that characterize their histories. It is now time to provide a more detailed and systematic description of the population of large industrial firms we study. In describing the large Chinese firms, we shall emphasize two main elements: their geographical location and their sectoral coverage.

4.1. The geography of large firms

Geographic localization is related to the trajectories of firms, and their specificities. The localization of the headquarters of the 325 large firms (Map 5-1) partly reflects the economic geography of China's economic development. Of course, firms do not base their operations close to their headquarters only, but rather operate through several entities among China. However, the headquarters' localization still represents the administrative, historical localization, and the place for decision-making.

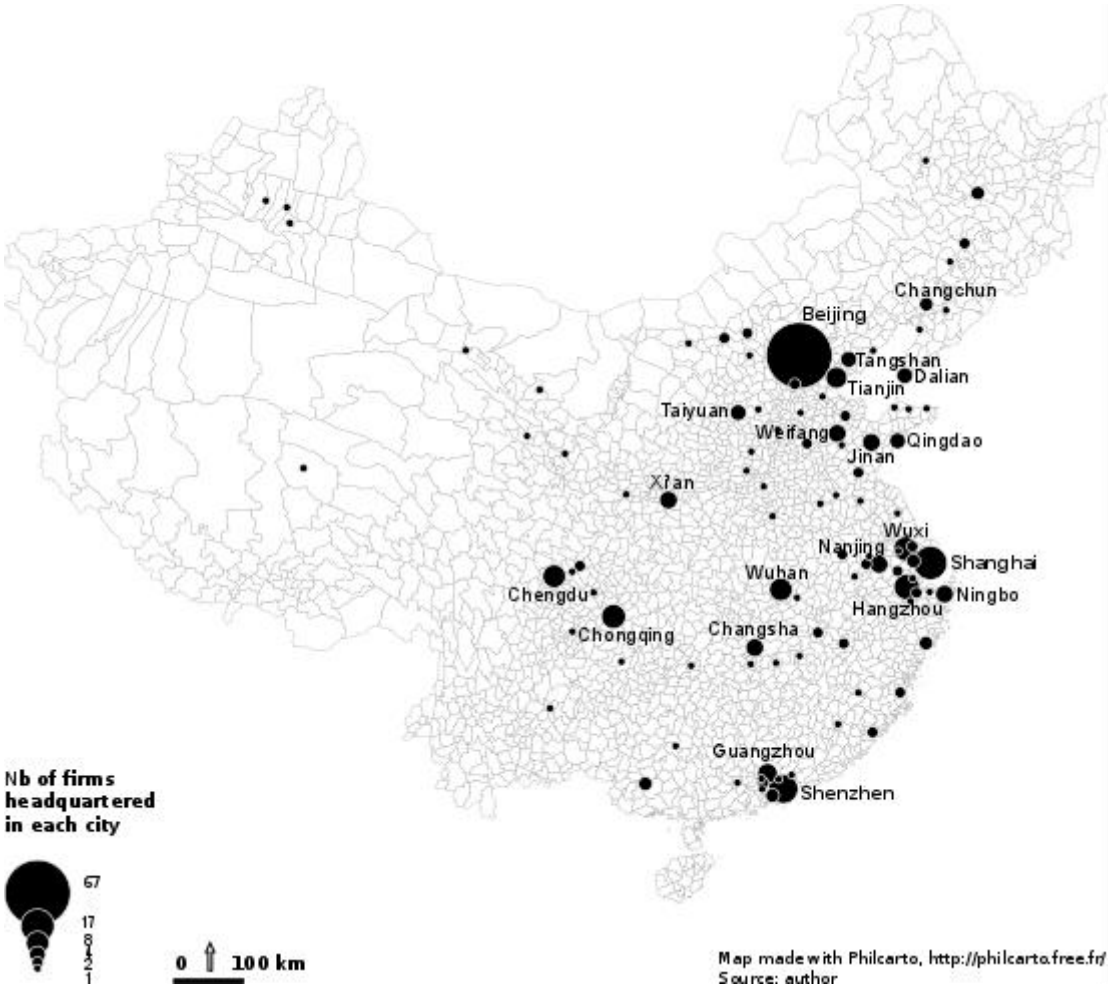
4.1.1. Three dominant economic centres

The geographical distribution of China's economic development is illustrated by the localization of the headquarters of large industrial Chinese firms (Map 5-1: Localization of the

[1] Known as the "Non-Public 36 articles (民间投资36条), 2005. It was followed in 2010 by the "New 36 articles" that stipulate subdivided areas.

[2] Opinions on the Implementation of Encouraging and Guiding Private Enterprises to Develop Strategic Emerging Industries, NDCR, July 2012, China

headquarters of large firms). Two thirds of the whole population of large industrial firms, 215 firms (66 percent) have their headquarters in one the three most dynamic regions: The Bohai Bay, the Pearl River Delta area, and the Yangtze River Delta area. China's economic growth after opening was based on rapid industrialization of a concentrated number of areas, mostly localized in eastern and coastal China. The three geographic areas previously mentioned, close to the sea or to the ocean, concentrate wealth and industries. They are respectively located around Beijing-Tianjin (Tianjin is located at 107 kilometres of Beijing), Shanghai and its surroundings (mostly some parts of Jiangsu province, Zhejiang province, and to a lesser extent, Anhui Province), and around Shenzhen – Guangzhou (the Pearl River Delta area generally refers to the megalopolis formed by nine cities (Shenzhen, Dongguan, Guangzhou, Huizhou, Zhaoqing, Foshan, Jiangmen, Zhongshan, Zhuhai).



Map 5-1: Localization of the headquarters of large firms

The three dominant regions, however, house different profiles of firms. The area home to the highest number of firms is the Bohai Bay economic area (around Beijing). More than one third of the total, 117 firms (36 percent) have their headquarters in this region, which includes the

municipalities of Beijing and Tianjin, but also most cities of Shandong Province (Qingdao, Weifang, Shenyang), Liaoning Province (Dalian), and Hebei province. The trend is particularly pronounced in Beijing. Beijing not only has the highest number of headquarters in the Bohai Bay economic area but also houses the most firms' headquarters in all China. 67 firms, which is more than half (57 provinces) of the large firms in the Bohai Bay economic area, are headquartered in the capital city. This accounts for 21 provinces of all firms across provinces and cities.

The weight of Beijing as a home to many headquarters, however, is not due to economic or industrial reasons. A large part of the pattern is explained by administrative reasons, and by the status of Beijing as the capital city, where China's Central Government is located. More specifically, the State Asset Supervision Administration Committee (SASAC) that supervises central state assets since 2003 is in Beijing.[1] Beijing tends to house the headquarters of many centrally state-owned firms, which are close to the government. This is further indicated by the distribution of Beijing-based firms among ownership types. 69 percent of Beijing-based firms (46 firms out of 67 Beijing-headquartered firms) are centrally state-owned firms administrated under SASAC or similar ministry-level organizations. This does not mean that of all their operations are located there, however. Besides Beijing, 50 other firms are headquartered in 22 cities of the Bohai Bay area. Other important cities include Tianjin, Jinan, Weifang, Qingdao. More specifically, seven locally state-owned firms are headquartered in Tianjin, all depending on the Tianjin government. There are also five firms in Jinan, the capital of Shandong Province, five firms in Weifang and four firms in Qingdao (only locally state-owned firms); both Weifang and Qingdao are cities in Shandong Province.

A second dynamic region in terms of industrial development is the Yangtze River Delta area, around Shanghai (Liu and Li, 2015). The Yangtze river flows into the East China sea in Shanghai. The area includes cities from Jiangsu Province at the North of the river (Nanjing), from Zhejiang Province at the South (Hangzhou, Jiangyin), and cities from the eastern part of the inland Anhui province. The dynamism of the region is reflected in the fact that 67 large Chinese firms are headquartered in the area (21 percent). The distribution of firms illustrates that the regional economy has other drivers than the Bohai Bay economic area. It relies more on the private sector. Private firms (39 firms) are the majority (58 percent) of firms in the entire region, which is a higher percentage than the national average (32 percent), and a much higher proportion than in the Bohai Bay (20 percent with 23 firms). By comparison, the proportion of private firms among firms headquartered in Beijing is below 14 percent.

[1] Not all central firms depend on SASAC. Some firms refer to other ministries or other institutions. Datang Telecom is the company sponsored by the China Academy of Telecommunications Technology (CATT) which is the controlling shareholder of the company.

There are, however, disparities within the different locations of the Yangtze River Delta area, with profiles of firms headquartered in Shanghai that contrast with those from the adjacent provinces. The private sector is well represented with respectively 64 percent (14 out of 22 in Jiangsu) and 84 percent of private firms (21 out of 25 in Zhejiang) in Jiangsu Province and Zhejiang provinces. The proportion illustrates the role of the private sector in developing these industrialized coastal regions: Jiangsu and Zhejiang provinces are among the provinces with the highest provincial GDP. Zhejiang province, in particular, is home to the majority of the large family businesses in China, which are privately owned (Lubinski et al., 2013), including Geely Automobile, Wanxiang group in the automobile and parts sector. This prevalence of the private sector in the region reflects a sharp contrast with Shanghai (which is in the middle). Less than one-fourth (24 percent) of Shanghainese firms are private firms (i.e. 4 private firms out of a total of 17). The rest of the firms depend on the municipal government of Shanghai (6 state firms) and on the central state (7 state firms), illustrating the governmental influences, both at national and local levels, on Shanghai's firms.

By contrast, fewer firms have their headquarters in the southern part of Guangdong Province that forms the Pearl River Delta area, facing Hong Kong city. Guangdong Province is among the provinces with the highest provincial GDP of China (7 281 266 million yuan in 2015, accounting for11 percent of total Chinese GDP), along with Jiangsu (10 percent) and Zhejiang provinces (6 percent), and with Shandong Province (9 percent of Chinese GDP) in the Bohai Bay, and Henan Province (5 percent).[1]

Therefore, put in perspective with the contribution of the region to the economy, there are relatively few firms' headquarters. More specifically, the region is home to 31 firm headquarters out of 325, which is less than 10 percent of the national total. The proportion is much lower than firms in Bohai Bay (36 percent) and Yangtze River area (21 percent). Several explanations come to mind. The first one is the low number of centrally state-owned firms' headquarters in the area. There are only four of them. Among the 31 firms headquartered there, 18 are privately owned, which represent 58 percent of the firms in the region. Another explanation is the important foreign presence in the region (foreign firms are excluded from the scope of our analysis). For instance, the electronic manufacturer from Taiwanese origin, Foxconn, is a major player in Shenzhen since it opened its first manufacturing plant in 1988.

4.1.2. The distribution of large Chinese firms in the territory

Altogether, the three dominant regions, Bohai Bay, Yangtze River Delta, Pearl River delta, are home to two-thirds of the 325 firms (215 firms). The remaining 110 large firms, or about one-

[1]2015. Provinces which represent more than 5 percent of China GDP

third of the population of large industrial firms, have their headquarters located in other areas, outside the three main dynamic economic regions. The location of these 110 firms reflects the distribution of firms in the territory and questions the role of second-tier cities in China's development. Indeed, what we observe is the absence of other leading locations of firms. Instead, large firms are headquartered in 105 different county-level cities. The municipality of Chongqing homes the headquarters of 9 large firms (for a population of 32,8 million persons in 2010), and the adjacent Sichuan province 14 firms. These two areas represent the largest concentration of firms outside the three dominant economic regions we already presented. There are also 9 firms headquartered in Hubei province. In all other provinces, there are less than 8 firms (less than 3 percent of the total population of large firms). This further indicates that the location of large firms outside of the three dominant economic regions is highly dispersed across provinces: Guangxi, Heilongjiang, Gansu, Yunnan, Inner Mongolia, Shanxi, Shaanxi, Fujian, Jiangxi, Hunan provinces.

This is associated with local government initiatives that set up local firms in their own localities (or provinces). Local state-owned firms account for 59 percent of the large firms not localized in the major economic regions, against 23 percent for private firms and 17 percent for centrally state-owned firms.[1] The proportion is higher than what they represent in the entire group (42 percent of the total) of firms. Locally state-owned firms are more represented in regions outside the three dominant economic areas (they account for respectively 36 percent of Bohai Bay firms, 29 percent in the Pearl River Delta area, and 30 percent in the Yangtze Delta area). Moreover, one more fact must be emphasized: that central state owned firms are also in a higher proportion in this remaining group of 110 large firms than both in the Pearl River and Yangtze delta areas (17 percent against 13 percent and 12 percent). While the choice of location by a local government is quite straightforward (even if there are exceptions, they remain marginal), there are other determinant factors for centrally state-owned firms. Location might result from strategic choices of the central state government, or former strategic choices, not made under economic or practical considerations. The second automotive works (SAW), out of which emerged the current Dongfeng motor Group, was established by the central government in 1964, in Shiyan, a small town in Hubei Province. Shiyan was located in a mountainous area, with limited road and railway access, was not well suited for large scale production, but the location was chosen in a context of international political tensions in the 1960s as a "natural fortress"(Nam, 2015).

4.2. The coverage of most industrial sectors by large firms

A striking element that appears when observing large industrial firms is the fact they operate in most industries. This is illustrated by the distribution of firms across sectors. In this chapter, as

[1] The remaining 1 percent is the sole collective firm of the entire population of large firms.

well as throughout this dissertation, we use the Industry Classification Benchmark (ICB) as a basis to classify firms' industrial subsectors[1]. Each category then gathers one or several subsectors adapted from the ICB classification. Based on this categorization, we can highlight several features characteristic of the composition of a large firm. A first element is the importance of firms which tend to be specialized (167 firms, 51 percent of total), and the smaller proportion of diversified firms (42 firms, 13 percent). Two other features correspond to characteristics of emerging economies: 72 firms (22 percent of total) are in resource-based industries,29 firms (9 percent of total) are in the construction industry and only 15 firms (less than 5 percent of total)are conglomerates and/orstrategic firms.

The composition of the group shows the role of manufacturing firms in the economic development of China. There are 167 large firms, which are rather specialized towards one industry. On average, they employ 31 002 employees. They might operate in other industries besides their core activity, but we classify firms in this category when they can be associated with a core industry. For instance, Zoomlionis a local state company created in 1999, whose controlling shareholder is Hunan's SASAC.[2] It originated in Changsha Construction Machinery Research Institute, previously under the former Ministry of Construction. The company is cross-listed in Hong Kong and in Shenzhen. Engaged in the machinery industry, it is an example of firms that are specialized in one business. This is seen in the operating segments in which the firm intervenes: Concrete machinery, 17 million in revenue (44.60 percent), Crane machinery 12 million (32.38 percent), Environmental and sanitation machinery 3 million (8.52 percent), Road construction and pile foundation machinery 2 million (4.49 percent), Earth working machinery 0.8 million (2.00 percent), Finance lease services 1,5 million (3.79 percent) (source: Zoomlion's annual report 2013).

What needs to be emphasized is the diversity among specialized firms (table 5-1). Distribution among different ownership types is as follows: private firms represent 41 percent (68 firms) of "specialized" firms, which is slightly more than the national average where private firms represent 32 percent. There are 61 locally state-owned firms (37 percent) and 37 centrally state-owned firms (22 percent). Firms in this group often operate in more than one industry, but they all have a dominant activity as is well illustrated by the case of BOE technology: display devices represent 89 percent of the operating revenues of BOE Technology in 2014 (annual report, 2014). The private 76 firms operate in eleven industrial subsectors, with three dominant sectors: personal goods (12 private firms), automobile and parts (11 private firms), and electronic and electric equipment (16 private firms). By contrast, locally state-owned firms, which form the largest group are dominated by automobiles and parts (12 percent), and chemicals (9 firms). Finally, centrally

[1] This classification is useful because it is the one used by the EU R&D scoreboard that we use for comparison.
[2] Zoomlion Heavy Industry Science and Technology Co Ltd

state-owned firms are the most numerous in industrial engineering (11 firms), and technology hardware and equipment (8 firms).

Table 5-2: Details of firms in Specialized Manufacturer

ICB classification	**Description of the industrial sector**	**Firms**
Alternative energy	**Renewable energy equipment**: firms that manufacture renewable energy equipment	2 private firms Average size: 15 000 employees
Automobile & Parts	**Automobile:** Makers of motorcycles and passenger vehicles, including cars, sport utility vehicles, and light trucks **Auto-parts:** Manufacturers and distributors of new and replacement parts for motorcycles and automobiles **Tires**	**28 firms** (12 locally state-owned firms; 11 private firms; 5 centrally state-owned firms) Average size: 34 028 employees
Beverages	**Brewers; Distillers & Vintners; Soft drinks**	**5 locally state-owned firms** in 5 provinces
Chemicals	**Commodity chemicals:** producers of simple chemical products primarily used to formulate more complex chemicals or products, including plastics and rubber in their raw form, fiberglass, and synthetic fibre **Specialty chemicals:** producers of finished chemicals for industries or end users, including dyes, cellular polymers, coatings, special plastics and other chemicals for specialized applications.	**15 firms** (9 locally state-owned firms; 4 private firms s; 3 centrally state-owned firms) Average size: 27 601 employees
Electronic & Electrical Equipment	**Electrical components & Equipment;** makers of electrical parts for finished products **Electronic equipment**: manufacturers of electronic products used in different industries	**23 firms (**16 private firms; 4 locally state-owned firms; 5 centrally state-owned firms) Average size: 27 794 employees
Food producers	**Food products**	**16 firms** (9 private firms; 5 locally state-owned firms; - 1 centrally state-owned firm; 1 collective firm) Average size: 46 586 employees
Forestry & Paper	**Paper:** producer of all grades of paper	**2 locally state-owned firms** Average size: 11 547 employees
Household goods & home Construction	**Durable household products; Non-durable household products; Furnishings; Home construction**	**9 firms** (4 locally state-owned firms; 5 private firms) Average size: 27 794
Industrial engineering	**Commercial vehicles & trucks**: manufacturers of heavy agricultural and construction machinery **Industrial machinery:** manufacturers of industrial machinery and factory equipment	**21 firms** (12 centrally state-owned firms; 6 locally state-owned firms; - 2 private firms) Average size: 41 400
Leisure goods	**Consumer electronics; Recreational products; Toys**	**1 centrally state-owned firm** Average size: NA
Personal goods	**Clothing & Accessories; Footwear** **Personal products**: makers and distributors of cosmetics, toiletries and personal-care and hygiene products	**18 firms** (12 private firms; 5 locally state-owned firms; 1 centrally state-owned firm) Average size: 22 431
Pharmaceuticals & Biotechnology	**Biotechnology:** research into and development of biological substances for the purpose of drug discovery and diagnostic development **Pharmaceuticals:** manufacturers of prescription or OTC drugs	**6 firms** (5 locally state-owned firms; 1 centrally state-owned firm; - 1 private firm) Average size: 22 911
Technology hardware & Equipment	**Computer hardware; Electronic office equipment** **Semiconductors:** producers of semiconductors and other integrated chips **Telecommunication equipment:** makers of high-technology communication products, including satellites, mobile telephones, fibres optics, switching devices, local and wide-area networks, teleconferencing equipment and connectivity devices for computers	**18 firms** (8 centrally state-owned firms; 6 private firms; 3 locally state-owned firms)

Source: author

Another category of firms with importance for the transformation of the Chinese economy is the providers of resources and intermediate products. There are 72 'Resource' companies located upstream in the industrial production chain. They constitute a significant part (22 percent) of China's large firms. Are classified in this category firms that mine or extract resources (metals and other materials, oil and gas), as well as firms that process these resources and/or manufacture intermediate products for use by other industries.

Resource companies are often overlooked in innovation studies because scholars tend to study firms in discrete manufacturing processes(Figueiredo, 2010, pp. 1090–1091). However, these firms are interesting from several points of view. First, natural resources and materials play a specific role in the patterns of industrial progress and growth of nations with an important endowment. In addition, they can be leveraged as a strategic national resource. For instance, in Cleantech, China managed to leverage its abundant resources in rareearth to force technology transfers, notably restricting access to these resources to foreign industrial firms that enter into a minority joint-venture with Chinese firms in key sectors (Ruet, 2016). From another perspective, firms follow different patterns of capability accumulation than assembly-based industries (Figueiredo, 2010).

The distribution of the large firms provides information on how national resources are managed. The state sector has the monopoly on the exploitation of most resources, and in most cases, local governments are granted the rights to exploit local resources. This explains the absence of large private firms and the leading role of locally state-owned firms in the mining sector and among oil and gas producers. Mining firms are both central and locally state-owned firms: 21 locally state-owned firms and 5 centrally state-owned firms are engaged in mining (mainly coal: *engaged in the exploration for or mining of coal, in the exploration, extraction or refining of minerals not defined elsewhere*).[1] The oil and gas production is concentrated in the hand of three centrally state-owned firms (engaged in the exploration for and drilling, production, refining, and supply of oil and gas products).

The metallurgical sector has the highest number of large firms. There are 43 firms classified under "industrial metal and mining." It encompasses aluminium, non-ferrous metals, and iron and steel. Aluminum includes firms that "mine or process bauxite or manufacture aluminium bars, rods and other products for use by other industries." Non-ferrous metals include producers of metals and primary metal products other than iron, aluminium, and steel. Finally, Iron & Steel include manufacturers and stockholders of primary iron and steel products such as pipes, wires, sheets and

[1] Definition of Industry Classification Benchmark "The Industry Classification Benchmark (ICB) is a definitive system categorizing over 70,000 companies and 75,000 securities worldwide, enabling the comparison of companies across four levels of classification and national boundaries". *www.icbenchmark.com*

bars, encompassing all processes. The third group is particularly well represented among the large firms. The role of large steel groups in the transition of the Chinese economic model is explicitly stated, as they act as a support in the development of strategic emerging industries (The State Council, 2012). As the secretary of the Chinese Steel & Iron Industry states it "… *In developing the seven such industries designated by China, namely, energy conservation & environmental protection, new-generation information technology, biotechnology, high-end equipment manufacturing, new energy, new materials and new energy vehicles, the iron and steel industry of China is expected to fulfil a new mission…: to produce and provide high-quality and new-material-based iron and steel products necessary for such strategic emerging industries."* This requires, in turn, these firms to innovate and to provide high quality iron and steel products *"it is necessary for iron and steel companies to enhance their research and to develop high-performance products featuring high strength, corrosion resistance, long life and light weight, and improve their technological competence related to such products"* (Zhang, 2012)

The relatively low degree of industrial diversification of Chinese firms was mentioned and explained in the previous sections, and this is what we observe. The category 'Conglomerates and diversified industrials' include the 42 large Chinese firms that adopted diversification as part of their growth strategy. Conglomerates extend their activities across manufacturing and non-manufacturing sectors through several entities. This includes firms that operate in real estate, finance, services, etc. in addition to manufacturing activities. Firms in general industrials, the second subcategory, are engaged in the production of different products that belong to different industries, and require different skills. Firms fall into this category when they are engaged in three or more classes of business. Private firms are more likely to adopt diversification strategies than state firms. 45 percent of Chinese "conglomerates" are private firms. And one is tempted to link this to the relative absence of diversification as a central strategy of centrally state-owned firms.

The fourth significant group of firms is made of the 29 large firms in the construction and material sectors. The sectors include two categories "Building materials & fixtures": producers of materials used in the construction and refurbishment of buildings and structures, including cement and other aggregates, and the Heavy construction sectors: companies engaged in the construction of buildings. Altogether, they represent 9 percent of the total population. This percentage reflects the need for infrastructures of an emerging nation like China, and the role of building and construction in the economy (wastes of resources). The construction sector acts as a driver for other industries. It accounted in 2011 for 54.4 percent of the total iron and steel consumption (Zhang, 2012). Ownership is quite balanced, as well as the geographic repartition. There are 8 centrally state-

owned firms, 9 private firms, and 12 locally state-owned firms, which are in fourteen different localities (provinces or municipalities). The largest location is Beijing, which is related to the importance of centrally state-owned firms in this region. The construction industry is particularly fragmented. There were in 1999 8000 independent cement manufacturers (against 1500 at a global scale).

Finally, a special mention must be made of large firms, which are under the prerogative of the Chinese state. This encompasses strategic sectors like aerospace and defense. Aerospace includes the manufacturers, assemblers, and distributors of aircraft and aircraft parts primarily used in commercial or private air transport. Defenseincludes producers of component and equipment for the defense industry, including military aircraft, radar equipment, and weapons. In addition, there are monopolies (salt, gold, etc.). All of them are centrally state-owned firms.

5. Conclusion

The population of the 325 largest Chinese firms we have presented is characterized by its diversity. The category "Large Chinese firms" includes very diverse entities, eachrelatively specialized and presenting a complex mix of private and state ownership. Their trajectories can be explained by dynamics associated with the economic and political transformations since the Third Plenary session of the 11th Central Committee of the China Communist Party in 1978. Firms did not emerge out of nowhere, though. The preceding period between 1949 and 1978, which laid the foundations by setting up a soviet-style planned economy with plants and research institutes as part of the industrial production structure, has conditioned their emergence and influenced their specializations and localizations.

The vice-premier Wu Bangguo emphasized in 1997 the importance of supporting large competitive firms by emphasizing international comparisons, with the United States of America, and with other Asian countries, Japan, and Korea. ... *international confrontations show that if a country has several large companies or groups it will be assured of maintaining a certain market share and a position in the international economic order. America, for example, relies on General Motors, Boeing, Du Pont and a batch of other multinational companies. Japan relies on six large enterprise groups and Korea relies on ten commercial groupings. In the same way now and in the next century, our nation's position in the international economic order will be to a large extent determined by the position of our nation's large enterprises and groups*" Wu Bangguo, Vice-premier of China (1998).[1] The composition of our sample of 325large firms suggests that the idea that China's economy relies on "several large firms" needs to be nuanced. Altogether, the

[1] Borrowed from Nolan (Nolan, 2001b, p. 17)

population of large firms we selectedemploys about 16 million people, which is indeed a limited proportion of the total employment (around 700 million).

Chapter 6: **The integration of Research & Development by large Chinese firms**

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1. Introduction

The aim of this chapter is to discuss investment trends within large Chinese firms in R&D**.** The "catch-up model" predicts that when firms get close to the technological level of the leading firms, R&D becomes the primary technological learning mode and becomes increasingly technologically complex (Amsden and Tschang, 2003). This should be reflected in firms increasing the resources they allocate to R&D, and, in turn, in an increase in R&D investments.

This is what is observed in China. There is a common recognition, along with WIPO's Chief Economist Carsten Fink, that "China is a country where you've seen a lot of investment in R&D, as well as in the education and science system with the long term view that this will harvest growth dividends in the future" (Xinhua, 2015). The general increase in R&D spending by firms is visible. Chinese firms used to represent a small share of national R&D expenditures, but this is no longer true. In 2010, Chinese firms accounted for 73 percent of the national R&D expenditures, from 43 percent in 1997. R&D expenditures in the business sector havegrown to outperform that of the European Union, and they represent 1.82 percent of GDP in China against 1.29 percent in Europe (Hollanders and Van Cruysen, 2014).[1]

What does that mean? What does it tell about the place of Chinese firms in the world economy? The first section discusses the emergence of large Chinese R&D firms among the global population of R&D firms. In the second section, we look at whether this trend is representative of national dynamics: the size of China generates a situation where the fact that there are Chinese

[1] We can also make the following observation. Existing firms are driving the trend. In 2012, there were officially 7840 high-tech enterprises with R&D, and large and medium enterprises, as officially classified (10 percent of firms), account for two-thirds of corporate R&D spending (Source: National Bureau of Statistics).

R&D firms among global R&D firms does not necessarily imply that R&D is a significant pattern among Chinese firms themselves. Finally, in the third section, we compare Chinese firms to global firms in terms of R&D intensity.

2. The emergence of Chinese R&D players

2.1. Chinese firms represent a growing proportion of global R&D firms

2.1.1. Preliminary remarks on R&D data

Global R&D firms are multinational corporations with important levels of R&D. The term "global R&D" emphasizes the fact that R&D is a source of competitive advantage, but R&D activities may not be globalized (Laurens et al., 2015). The 1400 world largest R&D spenders between 2004 and 2014 witnessed dramatic change regarding the participation of Chinese firms during the period considered. The evolution of the number of Chinese firms among the top R&D spenders across years indicate the increase of Chinese's R&D. Part of the increase might have come unnoticed because some Chinese firms are not incorporated in China. In the EU scoreboard, for instance, firms are classified by their country of legal incorporation, which might not be the country where they were created and where they operate. This creates erroneous interpretations. Many Chinese firms are incorporated in Bermuda and The Cayman Islands. Explanations for this choice include fiscal reasons, legal constraints on the Shanghai and Shenzhen Stock Exchanges, political motivations, and gaining access to other stock's exchanges "skills". The choice of listing in Bermuda and Cayman rather than other locations is explained by the fact that Initial Public Offeringsin Hong Kong have for long only been authorized for firms incorporated in Hong Kong, Mainland China, Bermuda, and Cayman Islands (source: Hong Kong Stock Exchange).[1]

The topic of incorporation of firms is beyond the scope of our research, but we integrate these firms that originate from China in our analysis because not counting for these firms distorts the picture of R&D spending, and leads to vastly underestimate the real contribution of Chinese firms. Indeed, among global R&D firms, most of those incorporated in the two islands originate in China. In 2013, Chinese firms represented 77 percent of firms incorporated in the Cayman Islands and 53 percent of firms in Bermuda in the ranking. Overall, this represents a significant proportion: 23 percent of Chinese firms in the 2014 ranking are incorporated in one of these two nations (or 28 percent of Chinese firms in the 1400 top spenders).

On the contrary, other factors lead to overestimating the R&D expenditure levels of some firms. A firm can be counted several times because it has several listed entities that declare R&D

[1] This reason might also what led to include in the scoreboard both the parent company, and the subsidiary under the same categorization for the industrial sector "Pharma & Biotech"

expenditures. This does not create distortions, when entities are at a similar level in the corporate hierarchical structure (Tata Motor, Tata Steel, etc.) *i.e.* when there is not one that depends on the other. In the other case, the pyramidal structure of large groups sometimes leads to countingR&D expenditures twice in the European Union's Innovation Scoreboard. For instance, the Chinese conglomerate Fosun appears twice: once as Shanghai Fosun Pharma and once as Fosun International. Fosun International declares 60 million euros in R&D and Shanghai Fosun 53 million euros. However, Fosun International is the controlling shareholder of Shanghai Fosun and holds 48 percent of its shares, and integrates it into its consolidation scope(Dec 2014).[1] Thus, R&D expenditures are counted twice (the 60 million euros include the 53 million euros). The description of research activities in the 2014 annual report of Fosun International confirms this: Shanghai Fosun Pharma represents the core of its R&D activities. We try to avoid such problems when possible, and the distortion that is generated remains marginal when looking at historical trends.

2.1.2. Historical increase in China's contribution

The historical evolution of the number of Chinese firms among the largest global leaders in R&D is summarized in the table below. The number of Chinese firms among global R&D spending leaders increased significantly between 2005 and 2013, from 9 firms in 2005 to 94 firms in 2013. China was ranked the 19th nation in 2005 in terms of R&D focused firm numbers. From 2010 to 2011, with a rise from 37 to 72 firms, China moved from the 8th position to the 5th position. It is the 4thregarding the number of national R&D focused firms in 2014.

The increase was continuous, with Chinese firms newly joining the ranking each year, except for the year 2006. 2007 and 2010 were two years of particularly strong growth (respectively +140 percent in 2007 and + 95 percent in 2010). Over the same period, minimal average R&D spending has increased more slowly from 27 million euros in 2005 to 39 million euros in 2013.

Table 6-1: 2005 – 2014. Historical presence of Chinese global firms among R&D leaders

	Chinese firms in the world top 1400 R&D firm	Repartition by industry (more than 10%)
2013	94 Chinese firms Incl. 2 in Hong Kong, 22 Cayman Island 3 Bermuda +22 percent since 2012	Auto& Parts (14%); Industrial Engineering (14%); Construction & Materials (13%); Technology Hardware & Equipment (12%); Software & Computer Services (12%); Electronic & Electrical Equipment (10%)
2012	78 Chinese firms Incl. 3 in Hong Kong, 23 Cayman Island 1 Bermuda +8 percent since 2011	Industrial Engineering (17%); Automobiles & Parts (16%); Technology Hardware & Equipment (15%); Construction & Materials (12%); Software & Computer Services (11%);

[1] The scope of consolidation refers to the subsidiaries whose operations are reported in the consolidated income statement of the holding company.

2011	72 Chinese firms Incl. 2 in Hong Kong, 16 in Cayman Island +95 percent since 2010	Industrial Engineering (20%); Automobiles & Parts (13%); Construction & Materials (13%); Technology Hardware & Equipment (11%); Software & Computer Services (10%);
2010	37 Chinese firms Incl. 5 in Hong Kong, 12 in Cayman Island +23 percent since 2009	Construction & Materials (13%); Semiconductors (10%); Internet (13%); Telecommunications equipment (13%); Automobiles & Parts (10%);
2009	30 Chinese firms Incl. 6 in Hong Kong, 3 in Cayman Island +43 percent since 2008	Automobiles & Parts (17%); Construction & Materials (13%); Industrial machinery (10%) Internet (10%); Oil & gas producers (10%); Telecommunications equipment (10%);
2008	30 Chinese firms Incl. 5 in Hong Kong, 12 in Cayman Island +75 percent since 2007	Automobiles & Parts (14%); Construction & Materials (14%); Oil & gas producers (14%); Industrial machinery (14%)
2007	30 Chinese firms Incl. 5 in Hong Kong, 12 in Cayman Island +150 percent since 2006	Oil & gas producers (25%); Automobiles & Parts (17%); Telecommunications equipment (17%);
2006	5 Chinese firms Incl. 1 in Hong Kong -44 percent since 2005	Oil & gas producers (40%); Telecommunications equipment (20%); Semiconductors (20%); Computer hardware (20%);
2005	9 Chinese firms Incl. 1 in Hong Kong, 2 in Cayman Island	Oil & gas producers (33%); Telecommunications equipment (22%); Semiconductors (11%); Computer hardware (11%); Electronic equipment (11%); Fixed line telecommunications (11%);

2.2. Is global R&D representative of national trends?

The increase in the number of Chinese firms doing R&D is unique among emerging nations. This is illustrated by the comparison with Brazil, and India. Another country, Russia, is sometimes categorized along with Brazil, India, and China (under the acronym of BRIC). We do not integrate Russia in the comparison because the "emerging" nature of Russia is subject to discussion. In any case, we can however easily discard the Russian case, because there are very few Russian firms doing R&D at a global level. Between 2005 and 2013, only between 1 and 4 Russian firms are among the world 1400 R&D spenders.[1]

[1] Gazprom (Oil & Gas), Lukoil (Oil & Gas), Rosneft (Oil equipment, services, and distribution, Scientific Production (Aerospace & Defence) – Source: World 2000 firms ranked by R&D, 2013

Table 6-2: 2005 - 2014. Contribution of China, India, and Brazil to global R&D firms

	CHINA	INDIA	BRAZIL
2013	94 Chinese firms	13 firms	6 firms
2012	78 Chinese firms	15 firms	7 firms
2011	72 Chinese firms	13 firms	7 firms
2010		17 firms	9 firms
2009	30 Chinese firms	17 firms	8 firms
2008	30 Chinese firms		3 firms
2007	30 Chinese firms		3 firms
2006	5 Chinese firms		3 firms
2005	9 Chinese firms	4 firms	3 firms

In 2013, for each Indian firm among the 1400 largest R&D spenders, there are eleven Chinese firms, and the ratio is even higher for Brazilian firms. The difference with China was not pronounced at the beginning of the decade: the gap appeared between Chinese firms, and Indian and Brazilian firms, between 2005 and 2013. In 2013, 13 Indian firms and 6 Brazilian firms were among the top 1400 largest R&D spenders, respectively three and two times their 2005 levels, which is small compare to Chinese firms whose number was multiplied by 10.

Based on these trends, China is not only a unique case among emerging countries, but is also "in advance" compared to what is expected on the basis of historical precedents. It was observed that when industrialised nations reached a certain level of economic development, the national R&D intensity abruptly increased from 1 percent to about 2-3 percent. This occurs when the average GDP by PPP per capita is around $8000[1]. However, China's S&T take-off started at a GDP per capita around $3600 in 2007 (Gao and Jefferson, 2007)[2], with a national R&D intensity of approximately 1,4 percent. This "advance" is explained by three main factors: the average level of education, the proximity with dynamic economic regions in Asia, and China's market size that creates internal opportunities (Gao and Jefferson, 2007). In addition, it might be argued that it is because Chinese figures are artificially inflated. Indeed, part of the trend is exaggerated, and distorted by the quality of R&D data. Chinese firms tend to declare many activities as R&D costs for a fiscal reason. In addition, the increase of its R&D activities since 2006 is partially caused by the introduction of new accounting standards. It is, however, unlikely to account entirely for this trend.

The importance of Chinese firms in terms of global R&D expenditures also reflects the way the Chinese economy is organized. To become R&D firms, firms need to be in an environment

[1] Depending on the year considered, small and medium firms represent between 0 percent and 33 percent of the Chinese firms in the top 1400 spenders. In 2013, on the 25 firms with less than 10 000 employees (or 26 percent of firms): 6 are subsidiaries of larger groups (in industrial engineering, automobiles & parts, fixed lined telecommunications and in construction). 8 firms are in the software & computer services industry (and are not included in the scope of the dissertation), 1 in the video games industry, and 3 seem to be start-ups in technology hardware & equipment.

[2] Including 199 firms headquartered in China, to which we added Chinese firms incorporated in Cayman Island (48 firms) and 10 Chinese firms in Bermuda

where they can grow and develop their activities. The Chinese environment allowed, despite the importance of the state economy, the emergence of a diversity of corporate actors. The progressive integration of R&D activities by different types of Chinese firms explains the increasing proportion of Chinese firms among global R&D focused firms. While the growth in the number of Chinese firms was associated with a diversification of their profiles, there was no major change in Brazilian and Indian firms. In 2006, Brazilian firms which do R&D were three national firms, in resource industries (Vale, Petrobras) and aerospace (Embraer), among which two are former state-owned firms (in which the Brazilian state is still a shareholder), and one state-ownedfirm (Table 6-3, p. 116). This is quite a common pattern for firms from developing nations. By contrast, Indian firms have another profile. In 2006, the four Indian firms listed among the top R&D firms were either subsidiaries of a larger conglomerate or smaller firms in R&D intensive sectors such as computer services and pharmaceuticals.

At the time, all large Chinese firms capable of investing a large amount in R&D had a similar profile. In 2006, the five largest ones included Semiconductor Manufacturing, Lenovo, ZTE, China Petroleum & Chemical, and PetroChina. Those firms are state-owned enterprises or firms that derive from governmental organizations. Employing on average 221 000 employees, they were larger than Indian firms (30 000 employees) or Brazilian firms (36 000 employees). Since 2006, the situation (partly) stagnated for Indian and Brazilian ones. Kay et al., for instance, noted how two grand types of large players could be seen in Brazilian nanotechnology: national firms, and foreign firms (Kay et al., 2009).

This was not true for China, where there was a change in the profiles of firms. From 2005 to 2007, the trend was driven by large central state-owned firms (PetroChina, Sinopec & CNOOC in oil & gas, China Telecom…). Progressively, more modest large firms started doing R&D as well. The average size of Chinese firms that are part of the largest R&D spenders regularly decreases from 140 586 employees in 2005 to 48 972 employees in 2013. This decrease is not caused by the progression of small high-tech firms or by a decrease in the employment level of firms that already had R&D (which are mostly “giant” firms), but by the progression of mid-sized and large firms in R&D. The average size of firms that employ less than 10 000 employees has remained stable during the period, with an average of 5037 employees.[1] In contrast, among large firms, new large firms managed to increase their R&D efforts, the average size of large Chinese firms ranked among global R&D spenders decreases from 222 000 employees in 2005 to 65 000 employees in 2013. We can conclude that the newly R&D players have a different profile than those at the beginning of the period. The ability of the Chinese environment to allow firms to grow appears as an explicative factor for the growth in the participation of China in global corporate R&D. It shows that the

[1] Provided by the 2014 scoreboard

increase in the intensity of R&D of large firms was no longer limited to the giant state-owned firms.

Table 6-3**:** The largest R&D spenders in firms from emerging nations in 2006

Firms	**Industry (ICB)**	**Detail**
EMBRAER (Br)	Aerospace & Defence	Founded as a state-owned firm, privatized in 1994 19 265 employees 86 million € in R&D (3% of net sales)
Vale Do Rio Doce (Br)	Mining	Founded as a state-owned firm, privatized in 1997 52645 employees 365 million euros (2,4% of net sales)
Petroleo Brasiliero (Br) - Petrobras	Oil & gas producers	State-owned firm 62266 employees 551 million (1% of net sales)
Semiconductor Manufacturing (Cn)	Semiconductors	Central state owned firm 10 048 employees 71 million euros in R&D (6,4% of net sales)
Lenovo (Cn)	Computer hardware	Private firm (originate in the Chinese Academy of Science) 25100 employees 172 million euros in R&D (1,6% of net sales)
ZTE (Cn)	Telecommunications equipment	Private firm 39266 employees 275 million euros in R&D (12,3% of net sales)
China Petroleum & Chemical (Cn) - Sinopec	Oil & gas producers	Central state-owned enterprise 340886 employees 282 million euros in R&D (0,3% of net sales)
PetroChina (Cn)	Oil & gas producers	Central state-owned enterprise 446290 employees 414 million euros in R&D (0,6% of net sales)
Kpit Cummins & Chemical (In)	Computer services	Private firm founded in 1990 3256 employees 49 million euros in R&D (62,5% of net sales)
Dr Reddy's Laboratories (In)	Pharmaceuticals	Private firm founded in 1994 9000 employees 42 million euros in R&D (3,8% of net sales)
Ranbaxy Laboratories (In)	Pharmaceuticals	Private firm now part of the Indian group Sun Pharma 11343 employees 68 million euros in R&D (6,5% of net sales)
Tata Motors (In)	Automobile & Parts	Subsidiary of the private conglomerate TATA 32610 employees 137 million euros in R&D (2,5% of net sales)

Source: author

Another trend is observable: Chinese firms have entered global R&D rankings from the bottom-up of the ranking. In 2013, 10 percent of the 2500 firms that invest the most in R&D was Chinese, with R&D investments ranging from 15 million to 3.6 billion euros[1]. While China is in 4th position among the top 1400 R&D focused firms, it performs better and is in 3rd position if we extend to the 2500 first R&D spenders, after the United States and Japan (respectively 387 and 260 firms).[2] In contrast, China holds the 6th position among the top 500 world R&D firms, showing that

[1] Huawei Technologies

[2] In addition to these three categories of criticisms, another element, that we mentioned briefly, is the change in the

firms can increase and maintain their level of R&D efforts. Finally, it is the 11th nation in the top 100 spenders with two firms: Huawei Technologies and PetroChina.

On average, large Chinese firms are smaller and less profitable than other global firms; this partly explains that they are at the bottom of the ranking. Chinese firms are in the "second tier" and the "third tier" of global R&D firms. The fact that China ranks 4th globally with the highest number of firms among the largest spenders contrasts with a "catch-up" situation. With rare exceptions (Huawei, PetroChina, China railway, ZTE, see bow describing ZTE activities below), Chinese R&D firms' R&D is below leading multinationals. We can illustrate that with the case of firms in the automotive sector. All nations included, large companies in the automobile sector, which is intensive in R&D, employ more than 70 000 employees, for €1.07 billion euros in R&D and profits of 1.53 billion euros (data for the 70 world R&D firms in the automobile and employing more than 10 000 employees). Large Chinese firms in the same sector employ on average 30 636 employees, spend €101 million in R&D and generate 173 million euros in profits. They are therefore smaller, and less intensive in R&D compared to the number of employees. Figures reflect striking differences. The largest Chinese automaker, Dongfeng (110 000 employees) invested 194 million euros in R&D in 2013, against 12 billion euros for Volkswagen (572 000 employees).

2.3. Persisting doubts on Chinese R&D

In 1981, the Shanghai People's Daily, reflecting the prevailing irony and defiance on Chinese ambitions in R&D at the time, wrote: "*Many of these so-called institutes have been dubbed the 'three no centres' – no research subjects, no funds, and no personnel. Others have been dubbed the 'three diminutive centres' – one room, one seal, and one empty shelf. Others have been called the "three machine centres' – one mimeograph, one stapler, and one telephone."* (Simon, 1981 p. 24, quoted by Fischer, 1983). In 2014, the general level of China's technology and the quality of data considerably improved, but there a persisting defiance regarding the quality of R&D by Chinese firms, defiance particularly common among Chinese scholars. In 2009, Simon & Cao recognized persisting worries on the quality of S&T data, despite a substantial improvement in the last period. Nevertheless, they justified the use of Chinese data as an indispensable base for the analysis (Simon and Cao, 2009).

This leads us to pay attention to the meaning of Chinese S&T data. R&D data reflects a transition towards innovation, but to what extent the official figures reflect the reality is uncertain.

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accounting standard in China. China issued new Accounting Standards in 2006: the new Chinese Accounting Standards N°6 made significant changes about the accounting treatment of R&D expenditures. According to the previous Accounting standard of China, there was no account like R&D costs or R&D investments. In response of the legal change, that aimed to harmonize Chinese standards with IFRS, firms progressively started to declare R&D costs in their income statement. This led to underestimate R&D costs in the preceding years, and to create a sudden increase in reported R&D expenditures.

What is behind the increase in R&D spending has led to questioning the reality of the trend (Fischer and Von Zedtwitz, 2004; Walsh, 2007).

There are three primary critics that can be addressed about the validity of R&D figures in China.[1] The first one is the reliability of collected data on scientific and technological activities. Figures for R&D are inflated, but it is difficult to measure to which extent and to which degree it invalidates the analysis. The second category is research quality (qualification of researchers and engineers). Finally, the third category regroups questions concerning the relevance of R&D activities for effective innovations, emphasizing the ambiguous impact of state-led research programs (Chen and Naughton, 2011).

Part of these critics directly or indirectly take their source in China's incentive system for R&D. Since R&D became a political – and quantified – objective, firms are encouraged to do R&D. This includes incentives directly linked to the level of R&D (tax credit), and general incentives through mechanisms such as lowering the applicable corporate tax rate for approved high-tech firms with intensive R&D.

In addition, firms are the beneficiaries of direct grants for their R&D projects, in the framework of national or local innovation programs. The grant system is not exempt of corruption. In 2015, Guangdong's provincial science department's deputy party secretary was investigated in the context of a case that includes more than 50 officials in Foshan City to take bribes from firms and research in exchange for R&D subsidies. It is estimated that they pocketed about 30 percent of the subsidies ("Research and embezzlement," 2014).

2.4. Conclusion

China has emerged in global R&D dynamics and has taken off in science and technology. The take-off, as well as the surge of Chinese firms in global R&D, has raised questions about the nature of R&D activities and caught the attention of both competitors and various analysts. This is only one piece of the puzzle. The big challenge for China is not the emergence of large Chinese R&D focused firms, but rather the general transition of its economic structure toward innovation. This would guarantee China a participating role in global R&D dynamics. China is still a relatively poor nation, and some regions are underdeveloped. Nominal GDP per capita is $7589 in 2013 (IMF) against $36 268 for the European Union. Therefore, the commitment of large firms to R&D occurs in an economic context characterized by economic disparities across regions, and sectors. The dynamics behind the emergence of large Chinese firms as global R&D spenders can be either R&D commitment by a few centralized corporate actors, or be balanced across large Chinese firms.

[1] Huawei

The deployment of ZTE R&D strategies

ZTE was created in 1985 as "Zhongxing Semiconductor Co Ltd." by Hou Weiqi, and sponsored by the N°691 factory. The trajectory of its emergence follows the second path: new entrants after 1999. Its English name was then changed to Shenzhen ZTE Corporation, and finally ZTE Corporation. It is now listed on the Hong Kong and Shenzhen stock markets. ZTE works as an OEM and has more recently developed its own brand. It operates in three sectors: telecommunication equipment (4G stations, LTE), the mobile market (smartphones) and services.

The importance of technological innovation for the firm is claimed and is demonstrated through various channels. Two corporate publications in English: ZTE Technologies, and ZTE Communications. The R&D strategy of ZTE is reflected in the number of patents it applies for. ZTE ranks first in 2011 as the world largest PCT applicant (with 2826 international applications in 2011). ZTE includes in this strategy nanotechnology research, with 64 priority invention patents between 2000 and 2008. ZTE collaborates with universities.

The firm's R&D activities are organized around different centres. ZTE announces 27 100 R&D personnel in 2013 (annual report 2014), which would represent 35,9 percent of the company, just followed by manufacturing (20 percent). However, the level of qualifications indicates that a considerable proportion of this R&D activities is development. 416 personnel have a doctorate in the firm, all divisions included. The general level of ZTE reflects the qualifications: 69 percent of the personnel in 2013 had, at least, a bachelor's degree. The dominant model has changed progressively, with a growing market share of the high-end smartphones (39 percent in the first half 2015).

The historical research centre is in Nanjing, where ZTE set up an R&D centre in 1993. At the moment of writing, the firm has 14 R&D centres around the world, of which the Nanjing R&D centre is one of the largest. ZTE's Nanjing R&D centre houses the main R&D departments of the Network Division, the Data Division, as well as the Central Academy and ZTESoft. ZTEsoft is a joint venture established in 2003 for the development of business operations support systems. The Nanjing R&D centre covers all aspects of R&D and also develops R&D for key projects of China's national technology development (863 Plan). The firm expanded its R&D abroad from 1998, starting in the United States. The firm inaugurated a dedicated R&D tower in Shenzhen in 2005 (Shenzhen R&D ZTE building).

3. Exploring R&D investments by large Chinese firms

3.1. The breadth of large Chinese firms' R&D activities under question

How many large Chinese firms are well engaged in R&D activities? Answering that question is less trivial than it seems. The reason is that it is not possible to give a single clear-cut answer for each firm. R&D activities are visible through R&D inputs, i.e. financial or human resources used to research and develop new products, with R&D expenditures commonly used as an indicator of activities undertaken. Figures of R&D spending by a firm come from its income statement. The data thus refers to the accounting entity and can either be at the level of a subsidiary or the consolidated figure obtained at the level of the parent company. It results that in the case of large firms organized as business groups, R&D expenditures are not available for the entire firm. To get a transversal approach to R&D in China, we look at listed firms because these are the ones for which we have the most reliable data in terms of quality. Based on the information they provide; we also calculate the R&D intensity of the activities undertaken by subsidiaries. R&D intensity gives an indication of the importance of R&D in the scope of activities of a firm. It is calculated directly from the income statement as the ratio of R&D costs to net sales.[1]

Based on 2013 and 2014 figures, many firms spend low –or insignificant amounts in research in China. Among the 4117 firms listed in Shenzhen and Shanghai (source: ORBIS), 3492 firms filled the field "R&D expenditures" for the last available year (either in 2013 or 2014), but 1563 firms declared less than $1000. Only 1735 listed firms declared more than 1 million dollars in R&D expenditures. Some of these firms are independent, are part of a smaller group or belong to a foreign group, and are not in the scope of our research. However, others are subsidiaries of the 325 large firms we selected or one of them. We focus on the latter population of firms to get an overview of the patterns of R&D investment by these firms. This means that we identify them among these 1735 listed firms. We complete with information directly provided by a very specific number of non-listed actors.

In this way, we obtain a list of the large firms which have at least one subsidiary engaged in R&D activities. This gives us a picture of corporate R&D levels within Chinese firms. We observe is that declaring R&D activities is quite common. More than half of the large Chinese firms (60 percent) invest over one million dollars in R&D directly (at the level of the parent company), or through one or several entities. This figure includes large Chinese firms, which we know are doing

[1] Net sales consist of the operating revenues of a firm (or 'revenues'). They appear in the income statement as sales or net sales. R&D costs or R&D expenditures gather operating expenses associated with research and development activities of a firm. It appears as R&D costs in English, and 研发费用 / 科研费用 in Chinese.

R&D because they have a visible patenting activity, but which do not provide R&D expenditures. However, the threshold of one million dollars is low and does not necessarily reflect advanced research activities.

3.2. Distribution of R&D activities among Chinese large firms

When we look closer at this corporate landscape, and notably when we focus on the 60percent of firms with identified R&D activities, it is possible to observe several patterns according to the way R&D activities are distributed among different entities of a group. Firms follow different patterns of investments, which is dependent on the way they are structured (Table 6-4).

Table 6-4: Summary of data available in R&D

Category	Description	Number of firms	Remarks
Business groups	Firms made of several entities	44 firms with 2 or more listed firms with R&D expenditures (13 percent)	Centrally state-owned firms Heterogeneity among the firms
Listed groups	Firms listed as a group. Consolidated income statement available.	157 firms with available data on R&D intensity of the firm or one subsidiary (41 percent)	Private firms Various degree of R&D intensity Few firms: well-known champions
Other firms	Unlisted group with valid information on R&D		
	Firms for which we have no solid data on R&D spending. Includes firms with visible R&D (patents) and without (no sign of technology)	138 (41 percent)	Local firms and private firms Generally indicate low R&D implications

Source: author

For listed groups, the situation is simple. R&D intensity is given for 157 firms. Among them, 136 firms directly invest in research or have a subsidiary that spent more than 1 million USD in R&D in 2013. The remaining 11 firms are non-listed firms for which reliable data were available. The profile of these firms is diversified: 59 local state-owned firms and 61 private firms. Most private and locally state-owned firms only have one subsidiary. There are 5 locally state-owned firms and 2 private firms investing in R&D through more than 2 of their subsidiaries, which presents a contrast with figures of centrally state-owned firms.

However, in the case of large business groups, different entities of a firm can do R&D in parallel. In 2013, 44 firms were in this case, with two or more of their listed subsidiaries with R&D activities. This pattern is common among centrally state-owned firms. Firms which have more than 3 listed subsidiaries with R&D activities all depend on the central government. In turn, we observe that most centrally state-owned firms do R&D via at least one subsidiary: 64 firms out of a total of

79 centrally state-owned firms have at least one of their subsidiaries with more than 1 million dollars in R&D, and more than half of these firms invest through 2 subsidiaries or more (34 firms).

Firms with the highest number of subsidiaries in R&D originally belong to sectors that are more intensive in R&D (aerospace &defense, and electronics). The Chinese group with the highest number of subsidiaries in R&D is Aviation Industry Corporation of China (AVIC). 18 of the 20 listed firms under AVIC we identified spend more than 1 million dollars in R&D.

Table 6-5**:** Intra-group variation and differentiated R&D commitments

Group	**Subsidiaries**	**R&D intensity**
aviation industry corporation of china (avic)	18	0,58 percent (aircraft manufacturing) to 48 percent (glass)
China Electronics Corporation (CEC)	9	From 0,20 percent (computer, communication and other equipment manufacturing) to 19,89 percent (software and information technology services
China North Industries Group Corporation	7	From 0.16 (oil & gas) to 4.45 (auto & parts)
china electronics technology group corporation	6	From 0,82 percent to 10,39 percent (both software and information technology services) Manufacturing only: 1,56 percent and 5,61 percent (computer, communication and other equipment manufacturing)
china minmetals corporation	6	0,17 to 1,23 (nonferrous metal foundries and press)
china national machinery industry corporation (sinomach)	6	0,11 percent (civil engineering work construction) to 3,62 percent (special equipment machinery)
China South Industries Group Corporation	6	1,19 percent (other traffic equipment manufacturing) to 5,03 percent
China Aerospace Science and Industry Corporation	5	From 0,98 percent (computer, communication and other equipment manufacturing) to 9,69 percent (computer, communication and other equipment manufacturing)
china national materials group corporation (sinoma)	5	0,53 percent to 5,78 percent (both in non-metal mineral products)
china petrochemical corporation (sinopec)	5	From 0,6 percent (oil processing and refining) to 3,43 percent (special equipment manufacturing)
china faw group corporation	4	From 0,81 percent (automobile manufacturing) to 6,96 percent (information and software technology service)
china national building materials group corporation	4	1,31 percent to 2,87 percent (both in non-metal mineral products)
china national chemical corporation (chemchina)	4	0,90 percent to 3,22 percent in chemical materials and products
china resources	4	0,87 to 2,77 percent (medicine manufacturing)
Harbin Electric Corporation	4	0,82 percent (electric equipment and parts) to 5,08 percent (special equipment manufacturing)

Source: author

Each individual entity does not allocate the similar proportion of its sales to research. The aircraft manufacturerAVIC which is present in different industries presents the largest variation, from 0,2 percent to 40 percent. This partly reflects the trajectories of centrally state-owned firms. Large centrally state-owned firms grew through the extension of existing facilities and restructuration of state assets. Most firms, however, operate in one main industrial sector. The

central state-owned firm AVIC is a typical example. Its core business is the aeronautic sector (more than 50 percent of its revenue in the 2013 annual report), it has specialized branches that progressively extended their knowledge base towards neighbouring technological fields. For instance, Avic Sanxin, manufactures specialized glass, targeting the aircraft manufacturing industry, before diversifying the product line to other industries.

To illustrate this argument, we detail the case of China South Industries Corporation, the group to which belongs Chang'An automobile. China South Industries Group Corporation was founded in 1999 on the basis of the former 5th Machinery Industry, Ministry of Ordnance Industry, and Committee of Machinery Industry[1]. It defines itself as "*defence-related science, technology and industry and one of the oversized military industry groups integrating military with civilian purpose*s." China South Industries is composed of about 64 large and medium industrial enterprises, most of which belong to the automotive and parts sectors, and the firm employs 191 000 persons in total. Chang'an Automobile, Tianwei Group, Jialing group and Jianshe group are four listed subsidiaries of the group.[2]

At central level of China South Industries, there is a department of science and technology (Department of Science Technology and Information), while research centres belong to the subsidiaries. Overall, according to the corporate website, the group supervises 13 research institutes. Three firms Chang'An, Jialing, and Jianshe belong to the same sector "Automobile and Parts." Each division, however, puts different emphasis on R&D. Chang'An Automobile invests more in R&D than the other entities together: more than 1 billion RMB in R&D for Chang'An and only 18 million RMB for Jialing. In addition, Chang'An Automobile not only puts more resources in technological development than the other entities of China South Industries, but it also adapted its research organization. This is indicated by the restructuration of the original research institute into a modern R&D organization. In 1995, the General Engineering Research Institute of Chang'An Automobile was among the first validated technical enterprises (which mostly were former public research institutes). It extended its activities to Shanghai in 2004 (automobile integration, engineering design), to Europe in 2006 (styling design, body, interior & exterior parts), to Japan in 2008, to the UK (powertrain system research), to Beijing (research on advanced vehicle technology, new energy), to Harbin in 2010 (product development), and to Jiangxi and to Detroit in 2011 (chassis). This reflects the development of a network of R&D departments with specialized competences. In contrast, the other subsidiaries seemingly put less efforts in extending their

[1] In addition, it also is the controlling shareholder of Lida Optical & Electronical.

competences. Jianshe relies on its technical centre that is in operation since 1991. Jialing possesses the Institute of engineering technology and relies on its cooperation with Honda since 1981.

Table 6-6: R&D by subsidiaries of China South Industries Group Corp. (2013)

Subsidiaries	Employees	Industry	R&D (000Y)	R&D organization
Chongqing Jianshe Motorcycle	2 479	Motorcycle Automotive components (1889)	26 436 1,48 percent	A technical centre (1991)
		Motorcycles, engines (1875)		Institute of engineering technology established in 1994 ("product plot, prospect design, creative formation, reverse engineering, and CAD&CAE to engineering development and trial-making and experiment."
China Jialing Industrial	2 794		17 886 1,19 percent	Works with: Technical cooperation with Honda since 1981
Chongqing Chang'An Automobile	30 877	Automobile maker	1 105 926 4,3 percent	Chang'an Automobile Engineering Institute (1995) Extended to form an R&D structure with facilities in 9 locations (5 countries: Chongqing, Beijing, Shanghai, Turin, Yokohama, Nottingham, Detroit, Jiangxi, Harbin)

Source: companies' websites, calculation and compilation by author

3.3. Conclusion

This section had two primary goals. The first one: emphasizing the difficulty there is to characterize R&D activities of one firm with a unique approach. The second one was to introduce the variations that exist among the subsidiaries of one group. Interpreting a group-level R&D intensity might lead to strongly underestimate the performance of firms in certain sectors (and to overestimate it in others). This is well illustrated by the case of China South Industries.

4. A comparison between Chinese firms and their global competitors

4.1. How do we measure successful catch-up?

How to determine that a firm reaches the technological frontier if its different entities adopt different catch-up and technological strategies, as it seems this is the case? To further illustrate this difficulty, we elaborate on anexample. We already introduced Fosun China, a private conglomerate, which employs around 34 000 employees. Fosun is a private firm that was founded in 1992 and is headquartered in Beijing. It is organized around two main domains: finance (insurance, investment,

asset management, banking and other) and industrial operations, among which pharmaceuticals ("health") and steel. The firm invests mainly in R&D in the pharmaceutical sector, under Fosun Pharma. The R&D intensity at the level of the whole group Fosun is 1 percent (on the basis of consolidated figures) while the R&D intensity of its subsidiary reaches 4,4 percent. Both percentages are below the standards of its main industry "Pharmaceuticals & Biotech", as we shall develop, but they strongly differ with one another and reflect a different image of the firm.

In this case, how to position Fosun regarding its competitors? Fosun Pharma – even though it belongs to the top 1400 global R&D spenders in 2013 – invests little in R&D in comparison to a global average R&D intensity of 12 percent in pharmaceuticals & biotech. This is, however, above R&D intensity given on the basis of consolidated figures given for the whole group Fosun International. It is also a better proxy of concrete operations, and as such should be the one used for comparison.

A second element complicates the comparison. Fosun Pharma is in the industry of generic pharmaceuticals: "At the end of the reporting period [2014], Fosun Pharma had 125 pipeline drug, generic drug, generic biopharmaceutical drug and vaccine projects" (Annual Report, 2014). Accordingly, an R&D intensity of 4,4 percent places Fosun Pharma in the same range than the US-based firm Perrigo: Perrigo invests 4,5 percent of its net sales in R&D and is specialized in generic medicine. In that perspective, the conglomerate Fosun invests as much as its competitors. Of course, R&D intensity is only an indicator among others: the US firm makes more profit and more than twice in sales with fewer employees. However, the interpretation somewhat differs. In this case, what appears is not so much the lack of capabilities of Fosun, but the absence of Chinese firms on the upstream side of the pharmaceutical market. This is consistent with all studies on Chinese pharmaceuticals.

4.2. R&D performance by Chinese firms across industries

The previous example shows the need to pay attention to intra-group dynamics of R&D, and to use subsidiary-level R&D data rather than group-level data. Therefore, this is what we do, and we compare R&D intensity of each Chinese subsidiary to international benchmarks of R&D spending[1].

The table below shows how the subsidiaries of large firms are positioned by looking at each industry. For each industry, we indicate the sectoral R&D intensity and the average R&D intensity for large firms only (more than 10 000 employees). For Chinese firms, we indicate the average

R&D intensity, as well as the minimal and maximal values of R&D intensity. In the left column, we indicate how many Chinese entities invest a proportion of their sales in research and development that is superior to the average benchmark. The maximum R&D intensity and the proportion of firms above global average give an accurate point of comparison for these Chinese entities.

In addition, we indicated the minimum and average R&D intensity but this informationis difficult to interpret. Minimum R&D intensity is directly determined by the threshold we chose of R&D expenditures superior to a low threshold of one million dollars, and therefore, does not say much. This choice also impacts on the average value. We kept this information as it gives an idea of the repartition of the R&D intensity among firms in one same sector, thus emphasizing the diversity of situations.

When they do R&D, large Chinese firms are less intensive in R&D than the average of firms with an average of 2,4 percent of their net sales invested in R&D. There are, however, contrasting situations regarding the R&D intensity of the sectors in which they operate. In low R&D intensity sectors, there are Chinese entities above average in every industry, and all Chinese average R&D intensity is superior or equal to global average (oil and gas, paper, mining, industrial metals and mining, construction, and materials). In the medium-low R&D intensity (from 1 to 2 percent) industries, there are entities above average in one industry (food production). Similarly, Chinese average R&D intensity is superior to the average of the food production industry. In the medium-high (between 2 percent and 5 percent), some firms invest more in R&D than the average. For instance, 38 percent of large Chinese firms in the chemical sector invest more in R&D than the average level of R&D expenditures by global firms in chemicals.

Chinese firms are above global average in 3 industries (Household goods & home Construction, industrial engineering, and general industrials). Finally, in industries with high R&D intensity (superior to 5 percent), there is only one firm that invests more than the global average in one industry (Huawei), and the Chinese average is always inferior to the global average of R&D intensity.

Table 6-7:R&D intensity: Comparison of Chinese entities with global benchmarks

		Benchmark		**Chinese firms**	**Repartition**
		R&D intensity			
	Industry	Ind.	Large		
Low R&D intensity (inferior to 1 %)	Oil & Gas producers	0,40 %	0,40 %	4 entities Average R&D intensity: 0,40 % Min: 0,06 % Max: 0,76 %	2 companies above average (50 %)
	Forestry & Paper	1,40 %	0,80 %	4 entities Average R&D intensity: 1,47 % Min: 0,23 % Max: 3,38 %	2 entities above global average (50 %)
	Mining	6,50 %	0,80 %	13 entities	3 companies

				Average R&D intensity: 0,80 % Min: 0,00 % Max: 4,18 %	above global average (23 %)
	Industrial metals & Mining	1,40 %	1,00 %	36 entities Average R&D intensity: 1,02 % Min: 0,03 % Max: 3,56 %	14 entities above average (39 %)
	Construction & Materials	1,90 %	1,50 %	21 entities Average R&D intensity: 8,70 % Min: 0,11 % Max: 99,98 %	10 entities above global average (43 %)
Medium-low R&D intensity (from 1 to 2 %)	Electricity	1,00 %	0,60 %	4 entities Average R&D intensity: 1.75 % Min: 0,09 % Max: 5 %	2 companies above global average (50 %)
	Food producers	2,00 %	1,20 %	9 entities Average R&D intensity: 0,64 % Min: 0,003 % Max: 3,23 %	2 companies above global average (22 %)
	Beverages	1,10 %	3,70 %	2 entities Average R&D intensity: 0,03 % Min: 0,03 % Max: 0,04 %	No company above global average
Medium-high between 2 % and 5 %	Chemicals	3,90 %	1,70 %	19 entities Average R&D intensity: 1,16 % Min: 0,01 % Max: 5,09 %	5 companies above global average (26 %)
	Household goods & home Construction	3,00 %	1,80 %	2 entities Average R&D intensity: 3,52 % Min: 0,93 % Max: 6,10 %	1 company above global average (50 %)
	Personal goods	2,90 %	2,30 %	8 entities Average R&D intensity: 1,77 % Min: 0,28 % Max: 4,15 %	3 companies above global average (38 %)
	Industrial engineering	3,90 %	2,70 %	42 entities Average R&D intensity: 3,02 % Min: 0,02 % Max :12,13 %	25 companies above global average (60 %)
	General Industrials	3,80 %	3,20 %	2 entities Average R&D intensity: 3,62 % Min: 1,09 % Max: 6,15 %	1 company above average (50 %)
	Electronic & Electrical Equipment	7,40 %	3,90 %	21 entities Average R&D intensity: 3,28 % Min: 0,25 % Max: 8,51 %	9 companies above global average (43 %)
	Alternative energy	5,30 %	4 % [2]	[5] entities Average R&D intensity: 2,54 % Min: 0,81 % Max: 5,96 %	1 company above global average (20 %)
	Automobile & Parts	4,30 %	5,10 %	34 entities Average R&D intensity: 2,37 % Min: 0,18 % Max: 5,86 %	3 entities above global average (9 %)
High R&D intensity - superior to 5 %	Aerospace & Defence	5,30 %	5,50 %	9 entities Average R&D intensity: 1,89 % Min: 0,57 % Max: 4,64 %	No company above global average, one third of companies with more than 3 %
	Leisure Goods	9.3 %	6,70 %	1 entity R&D intensity: 3,29 %	No company above global average
	Technology hardware & Equipment	16,50 %	9,80 %	32 entities Average R&D intensity: 5,06 % Min: 0,20 % Max: 16,60 %	5 companies above global average (16 %)
	Pharmaceuticals & Biotechnology	11,60 %	10,90 %	13 entities Average R&D intensity: 1,67 % Min: 0,01 % Max: 4,41%	No company above global average

General Average		4.4 %	3.4 %	2.4 %	30 %[1]

Source: EU Industrial Scoreboard 2014, author's own calculations

Distinctive patterns are therefore associated with industrial sectors. Chinese firms tend to invest above the global average in industries with low R&D intensity (oil & gas, forestry & papers, mining, industrial metal & mining & construction & materials). Quite the contrary, the R&D performance of Chinese firms is below for all industries which require substantial R&D efforts. In these industries, the Chinese average R&D intensity is inferior by 6.2 percent points to the global average. In pharmaceuticals & biotech, the average R&D intensity among Chinese firms reaches 1.8 percent against 11.6 percent for global large firms in the 2014 Industrial R&D scoreboard.

A second trend is the spread of the R&D intensity across firms within similar industries. There is for each industry an average difference of 9 percent points between the minimum and the maximum R&D intensity, reflecting that large Chinese firms in the same industry can invest different proportions of their revenues in R&D activities. The figure goes down to 4,8 percent when we exclude the extreme values, i.e. firms with a particularly high R&D intensity (superior to 40 percent). This means that firms have different strategic motivations, incentives or financial resources for R&D. Accordingly, in most industries, there is at least one firm that performs better in terms of R&D intensity than the global average of R&D for large firms. There are four exceptions to that. In beverages, leisure goods, aerospace &defence, and pharmaceuticals & biotechnology, there is no firm that invests more than the global average in R&D, suggesting a relatively low intensity of R&D activities. This is particularly true in demanding industries. Three of these four industries where Chinese firms are all below average are in the high R&D intensity category. This is consistent with the preceding comment: firms do less R&D investment, and there are fewer "champions" in R&D demanding industries. It is only in 'technology & hardware equipment' that Chinese firms manage to do better than the average.

In conclusion, large Chinese firms invest relatively more in R&D in sectors less intensive in R&D than in sectors where important R&D efforts are necessary to be competitive. There are however some exceptions, and in other industries, there are entities that outperform the rest of the world's firms. In R&D intensive sectors, there are only a few "champions," other firms having strategies oriented towards manufacturing. This might be explained by the fact that in these industries, there is a larger gap to catch-up. In industries less demanding in R&D, such as resource-based industries and construction, large Chinese firms invest a greater proportion of their sales than

[1]This number reflects the weight of the low- intensive R&D

their world counterparts.

5. The respective role of private and state firms in China's R&D

There are opposed views on the role of private firms. On the one hand, the literature emphasizes the role that private firms play in R&D. State firms tend to do less R&D than private firms and to be less effective in doing so. In the case of China, this is emphasized by the twin governance structure in state-owned enterprises with the political governance (the Chinese communist party) along with the legal governance system (Wang, 2014), which explains why many strategic corporate decisions tend not to be R&D oriented. There is, in addition, a common belief that state-owned firms are the main beneficiaries of R&D subsidies, thus "wasting" financial resources allocated for R&D.

A previous study on the effect of R&D subsidies for the period 2001 – 2006 reveals a more nuanced picture: private firms and minority state-owned firms actually have higher chances to receive grants than majority owned state firms (Boeing, 2014). A determinant factor for a firm to receive R&D subsidies appears to be minority state shares. The author explains this result by the prominent role of local governments in innovation policies and the fact that these governments are more likely to distribute resources to firms in which they held shares (Boeing, 2014). We cannot see this trend in our data as firms are classified according to their controlling shareholders, and therefore no distinction is made between private firms with or without state participation.

However, what we describe is the respective propensity of the firms to engage in R&D, and the relative amounts they allocate to research and development. In our data, centrally state-owned firms and locally state-owned firms are numerous to invest: we find 163 subsidiaries of centrally state-owned firms, 66 of locally state-owned firms and 61 of private firms that invested more than 1 million euros. The greater number of entities under centrally state-owned firms reflects the fact that they are larger than other firms.

Private groups are smaller than state firms and in particular than centrally state-owned firms, with a size closer to that of local firms. They are in proportion investing more in R&D. On average, R&D intensity of private firms reaches 2,5 percent, which is superior to that of centrally state-owned firms: 2,40 percent (3,7 percent including outliers with a ratio superior to 50 percent), and to locally state-owned firms, with 1,81 percent of the net sales in R&D expenditures. Private firms do not make a uniform group, though. Their performance is driven by firms in technology hardware & equipment, and in particular by Huawei Technologies (13 percent).

The commitment of private firms to R&D is coherent with other sources. Indeed, private firms see R&D as strategic to upgrade their technological level. The Chinese Chamber of

Commerce, based on a survey of the top 500 private firms in 2013 indicates: “Data show that in 2013 there are 389 companies to upgrade and develop a detailed plan, accounting for up to 77.8 percent, an increase of 30 over last year, of which 83.8 percent of the enterprises that significantly accelerate the pace of transformation and upgrading. Upgrade has become the consensus of large-scale private enterprises. Research shows that the adjustment of enterprise development strategy and planning, increase talent introduction and training, improve the ratio of R & D investment, and downstream industry chain upward, is the top 500 private enterprises to upgrade the "four-wheel drive." (All-China Federation Of Industry & Commerce, 2014).

The poor performance of locally state-owned firms needs to be nuanced. These firms are particularly active in low R&D intensive sectors (exploitation of resources, mining, industrial and metal mining). This is the case of many companies in the industrial mining and metal sector: 25 of the 45 firms in that sector are owned by local governments, which represents 56 percent of the firms (against 40 percent of locally state-owned firms for the whole dataset).

The allocation of resource for R&D is not randomly distributed, and investment in R&D is accompanied by the creation of facilities (for these firms that emerged as manufacturers) and by the re-organization and extension of old ones (for state firms). China’s R&D responds to strategic needs that integrate the history of Chinese firms, their financing constraints, and industrial factors, as well as political incentives. This is true at the industry level – some firms invest more in R&D than others. This is also visible at the intra-group level for the largest state firms: these groups dedicate their R&D efforts towards specific entities.

6. Conclusion

A few years ago, Chinese firms’ R&D was a marginal topic for both foreign or Chinese scholars, with a few early exceptions on R&D in planned economy (Fischer, 1983; Fischer and Farr, 1985). Interest in the specific dynamics of formal R&D Chinese firms is more recent (Williamson and Yin, 2014). The topic became popular during the 2000s under the influence of two dynamics: the establishment of R&D centres by multinationals in China, and the growing quality of Chinese sciences and technologies. In addition to the role of foreign firms, the S&T take off of China in the first decade of the 2000s, was accompanied by the increase of R&D efforts by Chinese firms themselves. Many firms managed to reach international R&D expenditure level, as is indicated by the growing participation of Chinese large firms to international R&D ranking. However, a large base of firms with low R&D investment is likely to be oriented towards development rather than research.

Understanding R&D activities of Chinese firms has become critical for their competitors and for Chinese leaders, and the topic raised the interest of governmental agencies and consulting firms (DGTPE, 2009; Strategy&, 2014, 2013), as well as the interest of innovation scholars. The analysis of R&D inputs (spending, personnel employed in R&D activities) and research outputs (patents, publications) indicated an increase in the level of R&D in China, and that corporate R&D represented a growing share of research along with universities (Van Noorden, 2014; Wisdon and Keeley, 2007). Several dimensions attached to R&D such as R&D incentive system, innovation programs, are quite documented in the perspective of the analysis of China's innovation system. There are however uncertainties and gaps to fill. R&D in Chinese firms are not well understood and are the object of very contrasting analysis[1]. Among case studies of large firms, the most studied of all, Huawei Technologies, might as well be an exception other firms want to emulate than representative of them.

In this chapter, our contribution was to draw attention on the difficult task of analysing global R&D dynamics, even at the level of one group only. Based on quantitative data, it appears important to look at industrial sectors that, on average, are less intensive in R&D. We shall add that R&D covers a variety of firms' activities that go from pure science, basic research, applied research to exploratory development all the way to advanced development (Amsden and Tschang, 2003). Most large Chinese firms that master advanced manufacturing processes, are (at least) engaged inthe development and production of prototypes for manufacture, declaring part of the development costs as R&D costs. Whether they extend their knowledge towards basic research is the subject of the next chapters.

[1] It is a general concern of all non-Chinese actors that we met in China, many of them recognize their inability to understand current trends within Chinese firms 'we know things are happening, but we do not know what". In contrast, Chinese actors emphasize the weaknesses of the R&D by the same firms.

Chapter 7: **The integration of nanotechnology into the knowledge base of large Chinese firms**

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1. Introduction

This chapter discusses the extent to which large Chinese firms invest in nanotechnology R&D. The level reached by China's scientific institutions and by China's general environment justifies the attention we pay to the diffusion of such nanotechnology-related knowledge in Chinese firms. Our data further justifies this claim. In fact, China possesses the largest numbers of nano-patent applications in the 2000s with 51 268 nano-patent applications registered on the China's State Intellectual Property Office between 2001 and 2009 whereas few countries lead nanotechnology development: The United States, Japan, Germany, South Korea, and China.[1]In addition, the total contribution of the Chinese applicants (including firms, universities, public research institutes and individuals) increased faster than those of the other nations: we have found that, in 2006, China became the country with the greatest number of nano-patent applications (8669 priority invention patent applications), overcoming the United States by contributing to 22 percent of the world applications.[2]

This observation raises questions about how the large Chinese firms participate in the process of knowledge creation and skill development. To deal with this question, we look at

[1] The selection was restricted to patents applications posterior to 2001, when China aligned its patents standard on other intellectual property systems. The IFRIS patent database counts 382 027 applications for priority invention patents. Including all types of applicants: individuals, firms, universities, public research institutions and notably the institutes of the Chinese Academy of Sciences, hospitals, military, etc. The figure also includes foreign firms. See Chapter 4.

[2] Unless otherwise specified, all our patent data refer to priority invention patents. See Chapter 4.

whether the 325 largest Chinese firms have integrated nanotechnology into their knowledge base.

The chapter is divided into three sections. The first section is a historical introduction that describes how the development of capabilities by Chinese firms in the last thirty years has coincided with the emergence of nanotechnology; We point out here that China is better positioned to seize the opportunity of nanotechnology compared to previous technological waves (mechanicaltechnologies, the internet, biotechnology). The second section focuses on the patterns of the nanotechnology patenting activity adopted by the large industrial firms. Finally, the third partof this chapter compares the case of China to two other emerging countries: India and Brazil.

2. Nanotechnology research in China

2.1. Articulating the early stage of nanotechnology with China's catch-up stages

This section puts in perspective the dynamics of the Chinese firms with the context of emerging nanotechnology since the 1980s. In the past forty years, China has changed from being a closed economy into being a middle-high income country and, since 2010 the second world economy by nominal GDP. The articulation of these two historical dynamics – nanotechnology's and China's – could explain how nanotechnology starts to be a "window of opportunity" for the Chinese firms, following the China's technological catch-up.

Two distinct stages can be observed in the observed period: the early days of nanotechnology in China from the 1980s to the late 20th century (1981 – 2000) and the rapid emergence of China and development of skills (2001 – 2008). The first period starts in the early 1980s and ends in the late 1990s with the entry of China into the World Trade Organization. The 1980s are indeed considered as the decade of the birth of nanotechnology with the invention of the Scanning Tunnelling Microscope in 1981[1](Binnig et al., 1982) which made possible exploration and research at the nanoscale. The two decades are marked by an early interest in China for nanoscience and nanotechnology, which takes part of a broader interest in promoting sciences in the perspective of national development. However, contributions to global trends remain limited. The shift occurred at the turn of the millennium when the reduction of the gap between Chinese and other scientific nations became visible and the constraints the World Trade Organization imposed to China fostered the transformation of the Chinese institutions.

[1] The Scanning Tunneling Microscope (STM) was invented by Gerd Binnig and Heinrich Rohrer (IBM Zurich in Switzerland), which, in 1986, gave them the Nobel Prize in physics.

2.2. The end of the twentieth century: emerging nanotechnology in China

2.2.1. The absence of large firms doing nanotechnology research

In the 1980s, when IBM's research teams were working on the cutting-edge scanning tunnelling and atomic force microscopes, the gap between leading firms and large Chinese latecomers was huge, with a substantial gap in technological and organizational capabilities. China's economic growth was driven by low-added value production and foreign investment, and technological learning essentially happened through interactions with their foreign customers.In the perspective of the catch-up framework introduced in Chapter 2, Chinese firms were still at the first staged, the phased of "technology acquisition" and "technological assimilation"(Kim, 1997).

At that time, there were few large Chinese firms, and all of them were national firms. These firms were created before1978, originating in a Soviet-style industrial planning and still exist now of writing. We wish to bring attention to an element: 2013's large firms originate in the restructuring of firms existing prior1978 or are new entrants in the reform and opening period. Because it was in the 1990s that many of the latter, including local state and private firms, were founded or formally created, more than half of 2013's largest industrial firms did not exist in the 1990s. Private firms, which already existed, had a modest size, and their development is recent. For instance, the food-processing company, Sichuan Gaojin Food, among the largest private employers in 2015 (175 000 employees), was founded in 1996[1]

During the period, China was at the beginning of a period of market transition that was still not associated with a diversification of the profiles of large firms.[2]State-owned firms composed the totality of the large firms. It is, thus, no surprise to see that they were the first to do research including nanometric dimensions in the 1990s. Their weak patenting activity hardly reflects a real involvement in emerging technologies, though (92 patent applications over the decade all types of firms included).[3]

Nevertheless, the patenting activity of these firms at that time is explained by the fact that they were part of the planned system of research and production, and as such had access to public research infrastructures.[4] Research including nanometric dimension was done within research units or organizations under the Ministry of Petroleum Industry, and the Ministry of Metallurgy (or their

[1] Sichuan Gaojin Food Co., Ltd.
[2] Economic development was rather driven by collective and smaller firms.
[3] Including priority and non-priority patents
[4]Because the system was restructured at the end of the nineties, part of the patents preceded the incorporation of research teams into a firm.

equivalents).[1] It aimed at improving processes in the petrochemical and steel production industries. Firms with the largest number of nano-patent applications included the oil and gas firm Sinopec, and the steel makers Baosteel, and Angang Steel, that were respectively restructured from the Ministry of the Petroleum Industry, and under the control of the *Ministry* of Metallurgy until 1998.[2] Besides research done within the scope of these firms, central research institutes under the same ministries were also among the early contributors to nanotechnology research. Large central research institutes are independent and directly placed under the ministry. The Central Iron & Steel Research Institute (CISRI) under the Ministry of Metallurgy, based in Beijing, appears to be the largest applicant.

In the previous paragraphs, we used the term "research including nanometric dimension" instead of "nanotechnology research" on purpose. Labelling research from these institutes as "nanotechnology research" would suggest higher research quality that what the data can tell us. Indeed, China's patent system suffered from many lacks until 2000, and patent data quality cannot be trusted.[3]In addition, the scientific and technological infrastructure was known to be poor. Public institutes and research institutes linked to state-owned firms had outdated research infrastructures, lacked qualified engineers and scientists, and the level of scientific production lagged far behind that of leading countries (Fischer and Von Zedtwitz, 2004; Kostoff et al., 2006).

2.2.2. Production of nano-powders and nano-particles

What do these patents reflect? We suppose that early nanotechnology patenting in China reflects activities aimed at improving nanopowders' and nanoparticles' production process, which did not present important technological complexity. Our data, as well as alternative sources, support this idea. First, the production of nanopowder was the main industrial activity related to nanotechnology development. In his review of the state of nanotechnology in China, Prof. Bai Chunli, a Chinese nanoscientist, probably one of the most knowledgeable persons on Chinese

[1]In 1955, the Ministry of Petroleum Industry (MPI), under the authority of the State Council was given primary responsibility for the development of China's oil industry. In 1978, the Ministry of Petroleum Industry (MPI) was re-established and became a separate body from the Ministry of Chemical Industry, which was responsible for the downstream segment of the oil industry. Another set of institutional changes followed in 1980 as the State Energy Commission was established to handle the Ministries of Petroleum and Chemical Industries and the Ministry of Electrical Power.

[2] Boundaries between these large firms are therefore difficult to determine. In particular, some of Sinopec's assets were swapped with those of PetroChina. More specifically, the two firms swapped part of their subsidiaries in an attempt to rationalize the division between south and north China, in the context of 1998's restructuring of the national oil industry. Petrochina (CNPC) acquired 19 companies from China Petrochemical Corporation (Sinopec), while Sinopec acquired 12 of CNPC's companies. The existence of such arrangement makes determining firm's boundaries complex.(Lewis, 2007)

[3] With the exception of the present section, we only consider patent applications posterior to 2000 or 2001 in the dissertation.

nanotechnology, identified 20 production lines with ton-capacity to produce and prepare nanopowders (Bai, 2001). He gives an estimate of 100 enterprises in nanotechnology for the year 2000. The nature of the firms he refers to, is however not clear. An alternative estimate by the Chinese Academy of Sciences gives a figure of 300 enterprises in nanoscience in 2002 (Xinhua, 2002).

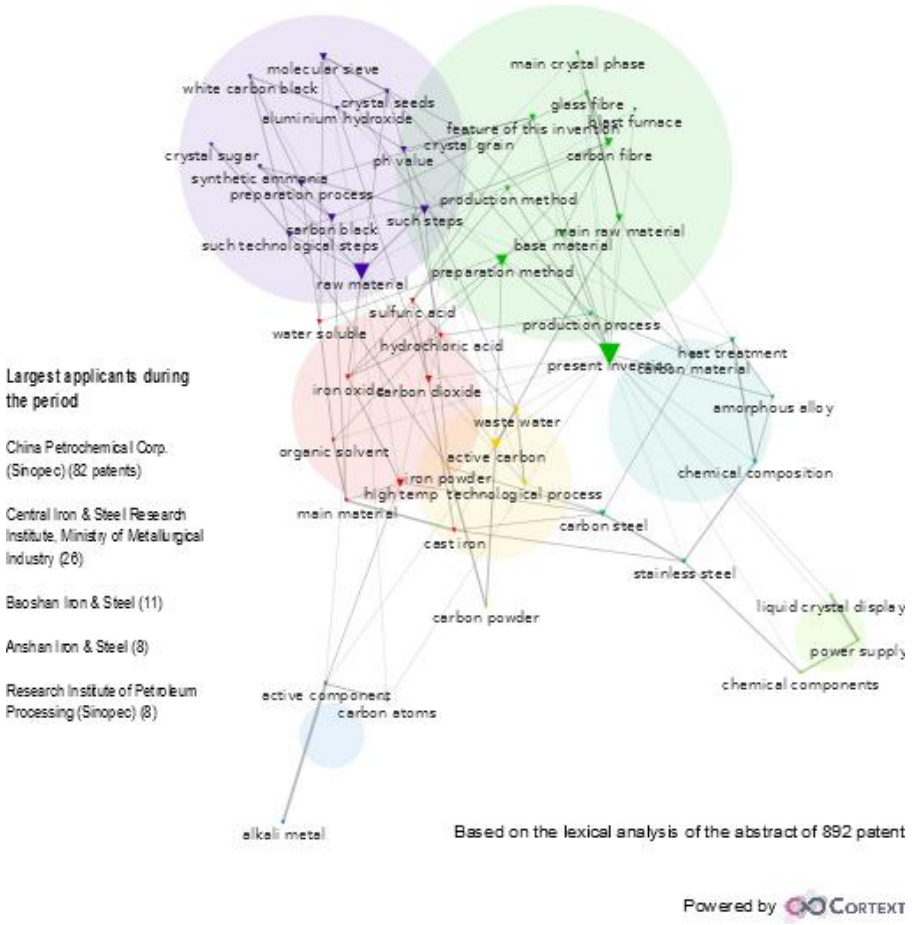
The content of patents reflects efforts for improving materials' production process, as this is further suggested by a lexical analysis of the content of the patented inventions (

Figure 7-1).[1] This analysis is built on the analysis of the keywords that most often appear in patents' English abstracts before 2001. What appears is the absence of specialized technological vocabulary related to nanotechnology. Keywords are concentrated around a few concepts: production methods; acid, technological process, and belong to a non-specialized vocabulary of metallurgy (steel, and aluminium production) or linked to the preparation and production process of materials like carbon, and it is quite difficult to find a clear structuration of a field on this basis.

Carbon nanotubes do not appear, while they are one of the Chinese strengths and one of the building blocks of nanotechnology. "*Carbon nanotubes (CNTs) are extended tubes of rolled grapheme sheets, single-walled and multi-walled types. CNTs have assumed an important role in the context of nanomaterials, because of their novel chemical, physical and electrical properties. They are mechanically very strong as stiff as diamond, flexible about their axis and can conduct electricity extremely well. All of these remarkable properties give CNTs a range of potential applications: for example, in reinforced composites, sensors, nanoelectronics and display devices, etc"* (Miyazaki and Islam, 2007). As previously mentioned, in the 1990s, nanomaterials and nanoparticles, and in particular carbon nanotubes, were already considered as a major strength of China's nanotechnology (Bai, 2001, 2005), but the absence of reference to them in the abstracts of corporate patents suggests that this was limited to research in non-corporate institutions. The absence of nanodevice related terms is less surprising, as investigations in this field were relatively weak and lacked originality (Bai, 2001).

[1] The analysis was performed by the author using tools developed by the digital platform of IFRIS, Cortext. http://www.cortext.net/

Figure 7-1: Thematic map. Nanotechnology research in China 1990 -1998



2.2.3. China's early interest for nanoscale instrumentation

Another early trend was the interest by China in instrumentation (microscopy). According to Prof. Bai Chunli, this played a major role in fostering theinterest of the scientist community for nanotechnology. "*Early explorations by Chinese scientists using scanning tunneling microscopes (STMs) and other types of SPMs helped build excitement about nanoscience and nanotechnology and led to visions of new techniques for revealing nanostructures and the novel properties that these structures can lead to.*" (Bai, 2005). It should be notedthatProf. Bai Chunli, is also the president of the Chinese Academy of Science since 2011. He was among the early pioneers in scanning probe microscopy as he started researching on scanning tunnelling microscope in the mid-1980s.[1] His remarkis consistent with posterior observations. China took an active part in the definition of standards for microscopy instrumentation, and Kostoff et al. noticed that by 2005China produced about 25 percent more papers in nanotechnology instrumentationthan the USA, whereas

[1]Website of Chinese Academy of Sciences, Institute of Chemistry - http://english.ic.cas.cn/pe/acad/200907/t20090717_23951.html. Accessed on 15/07/2016

the USA produced 30 percent more than China all nano-fields, reflecting the thematic orientation of China(Kostoff et al., 2007).[1]

2.2.4. An early interest for nanoscience by scientists and the Government

Despite the relative absence of research in nanotechnology before 2000, the question of supporting the development of nanoscience and, to some lesser extent, nanotechnology, was taken seriously. In particular, China's scientific community and the Government showed an early interest for nanoscience(Bai, 2005; Huang and Wu, 2012).Chinese institutions contributed to the organization of international scientific events. This includes the organization of several academic international conferences in China. China hosted the 7th*International Conference on Nanometer Science and Technology* in 1993, with Prof. Bai Chunli as the Chairman of the Program Committee and Secretary General. We can also mention the 4th*International Conference of Nanometer Scale Science and Technology* in 1996(Bai, 2005; Huang and Wu, 2012).[2]

This is also visible in the antecedents to China's national nanotechnology program. The Ministry of Science and Technology (or its predecessor the *State Science and Technology Commission*) funded nearly 1000 projects, and another 1000 small-scale grants were approved by the National Natural Science Foundation between 1990 to 2002 (Huang and Wu, 2012; Niosi and Reid, 2007).

2.3. The construction of skills in nanoscience since 2001

2.3.1. A general framework that supports nanotechnology development

The turn of the twenty-first century witnessed a change in China, but also in other nations, where nanotechnology received governmental support. Most national governments prioritized nanotechnology as a component of their innovation policies by doing a dedicated national program which took form at the beginning of the decade: the US National Nanotechnology Initiative was launched in January 2001. Among other nanotechnology contributors, Korea launched its national nanotechnology initiative in 2001(Ahn, 2012).[3]Japan selected nanotechnology and materials as one of four fields for priority promotion in the Second and Third Basic Plans for Science and Technology (2001-2005, 2006-2010) (Center for Research and Development Strategy, Japan Science and Technology Agency, 2016). Germany is an exception, as the country did not adopt a national nanotechnology initiative until 2006 (Clunan and Rodine-Hardy, 2014) .

[1] 2015 database
[2] Bai Chunli: Member of International Program Committee
[3] Countries which launched their national programs in 2001 include South Korea, Singapore, Romania, Mexico, Japan, Israel, Ireland, Estonia, China (Clunan and Rodine-Hardy, 2014, p. 34)

Nanotechnology has also grown in importance in China at the same time, where it has been part of the development strategy of the country. Indeed, the support to nanotechnology has been part of a general effort to improve the level of sciences, as well as to promote emerging sciences as part of China's economic development. Nanotechnology, along with others emerging sciences and technologies, was considered as an opportunity and priority. President Jiang Zemin emphasized it for instance during the 5th plenary session of the fifteenth party central committee in October 2000: *We should concentrate our efforts to make breakthroughs on such fields as genome science, information science, nano-science, life science, and geosciences.*[1]

Formalization of China's nanotechnology initiatives occurred at the same period. The National Steering Committee for Nanoscience and Nanotechnologywas set up in 2000by the Ministry of Science and Technology, the State Development and Planning Commission, the Ministry of Education, the Chinese Academy of Sciences, the Chinese Academy of Engineering, and the National Natural Science Foundation of China, all six organizations dependent on the State Council.China launched its national strategy for nanotechnology, drafted by the committee, in 2001, the following year.[2]

Another important factor that shapes the development of nanotechnology in China is the role of standardization. China is among the few countries involved in the elaboration of standards in nanotechnology, and the most active emerging country. Standardization is crucial for technological leadership and, the adoption of formal standards reflects the support to the leadership strategy of China. Standards played a role in Korea's innovation transition, notably in the information and communication industry (Choung et al., 2011a)

China was the first country to issue national standards for nanotechnology in 2005. The country initiated the process in 2003, covering various nanomaterial types and measures. In 2005, the Standardization Administration of China (SAC) established the National Technical Committee on Nanotechnology (SAC/TC279), which was located at theNational centre for Nanoscience and Nanotechnology(Guston, 2010).This led China to actively participate in the elaboration of standards of the International Organization for Standardization, ISO technical Committee 229, responsible for developing international guidelines for nanotechnology (Bhattacharya et al., 2011), notably through the coordination of the working group on nanomaterial specification for professionals (the WG4) (Delemarle, 2012). This working group was created in 2008 in response to previous suggestions of the Standardization Administration of China in 2007 for new TC 229 activities (Bhattacharya et al.,

[1](NIBC 2006, p. 14 in (Kay et al., 2009).
[2] http://www.most.gov.cn/fggw/zfwj/zfwj2001/200512/t20051214_55037.htm

2011). Large firms also participated in these working groups (e.g. Baosteel) (interview # 2).

Finally, a general factor in favour of the development of nanotechnology is the support to military-related research, because of the vast range of potential applications of nanotechnology for military purpose (Altmann, 2004). At first, by contrast with Russia, and to some degree India, which insists more on potential military applications, China appears to be much more focused on the economic growth potential of nanotech than on its military applications (Clunan and Rodine-Hardy, 2014, p. 33). This shall however be interpreted at the light of the dual research system adopted by China, and reinforced under Hu Jintao which promotes civil-military integrations of research as a way to leverage national science and technological resources, in particular in strategic emerging technologies(Lafferty et al., 2013).

2.3.2. The growing contribution of Chinese institutions to nanoscience

i. The increased visibility of Chinese nanotechnology

Interest in nanoscience and nanotechnology is visible since the publication of a first review of the state of the art in 2001 already mentioned (Bai, 2001). It can be added to this element the increased perception of the Chinese society on nanotechnology, and efforts made on “nano-education” (Wu et al., 2014). There was a hype both in the industry and in the publicfor whom nanotechnology was at first popular. Many “nano” products were commercialized, with “nano” considered as a sign of advanced technology even though some products did not include any nanoscale related dimension. Moreover, this happens, contrary to other countries while the general public appears quite knowledgeable (Hu, 2012): according to a survey mentioned by the author, a majority of people have an understanding of what nanotechnology recovers (ibid).

ii. The increase in the Chinese scientific publications

Globally, the rapid growth of scientific publications began about 1990 (Zucker and Darby, 2005). While China first was not among the countries to be scrutinized, the breadth of the contribution of China to nanotechnology development shed light on it, in particular in scientific publications in materials and nanostructures (Kostoff et al., 2007).

In the mid-2000s, scholars looking at global nanotechnology trends noticed the high level of China’s R&D investments (Lux Research, 2008), or its contribution to scientific publications (Kostoff et al., 2007; Larédo et al., 2010; Miyazaki and Islam, 2007; Zucker and Darby, 2005), which led to dedicated research on the country (Guan and Ma, 2007; Tang and Shapira, 2011; Zhou and Leydesdorff, 2006). Since then, a myriad of innovation studies or scientometric research, based

on different samples of scientific publications, converge to indicate a surge in the number of Chinese scientific publications.

Part of the trend comes from low-impact scientific publications (Kostoff et al., 2007). However, the increase of China's participation in international collaborations and publication in high quality journals in nanotechnology indicates its capacity. Zhou & Leydesdorff analyze China's performance in nanotechnology based on the number of Chinese publications in international and domestic journals, categorized in two sets of journals: in 3 core nanotechnology journals ('Journal of Nanoscience and Nanotechnology', 'Nano Letters', and 'Nanotechnology'), and in 85 nano-relevant journals (e.g, Journal of Chemistry). Their results reflect an increase in the level of China' science. While authors from the United-States and from the UK published in 'Nanotechnology' (the unique specialized journal at that time) since the beginning in1994, Chinese authors started to be visible in core nanotechnology journals only in 2000, and their number has continued to grow exponentially. In 2004, China was the second largest contributor of the three core nanotechnology journals (Zhou and Leydesdorff, 2006).

Alternative sources give similar trends. In 1998, Huang and Wu calculate that 1875 publications were coming from China, against 4423 from Japan, and 9468 from the United States (Huang and Wu, 2012). On the basis of the same sample of publications, China's proportion of publications grew from 6 percent in 1998 to 23 percent in 2008, with an annual growth rate of 92 percent.[1] Guan and Ma perform an analysis on the participation of China to nano-publications on the period 1985 - 2004.[2] They found that China became the second contributor in 2002. According to their data, China does research before 2000, but the Chinese number of publications grew faster than in other nations, and doubled every 2.1 years during the period 1995-2004 (Guan and Ma, 2007). In addition, Chinese authors contributed in a greater proportion to the world's "nano-relevant" publications (8,3 percent) than to all publications (6.5 percent) (ibid).

These trends were driven by the Chinese Academy of Sciences, and to some lesser, extent by universities. Public research institutes were the most prolific institutions in nano-related scientific publications between 1985 and 2004 (Guan and Ma, 2007).

iii. From nanoscience to nanotechnology

Scientific publications reflect the significant contribution of China to the development of nanosciences. There is however contrastedevidence regarding the degree of technological advances

[1] Data source: MERIT Database of Worldwide Nanotechnology Scientific Publications
[2] As a method to delineate nanotechnology, the authors searched in scientific papers keywords containing "nano" prefix (with some exceptions)

in nanotechnology.[1] Traditionally, patents are considered closer to technological developmentsand the market than to publications. China's contribution to patent applications in nanotechnology is lower than its contribution to scientific publications. In addition, patenting in nanotechnology is initiated by academic research in universities and public research institutions, and it is weakly linked to the technology demand and the high-tech industries(Huang and Wu, 2012).

We shall detail the contribution of firms in the next section.

2.3.3. The relative contribution of Chinese firms to nanotechnology development

i. Modalities of support to the industrialization of nanotechnology

Early, the Chinese Government recognized the strategic dimension of nanotechnology for industrial development. The national strategy in nanotechnology, decided at the central level, is deployed at the provincial and sub-provincial levels by local officials.

Two main approaches were adopted to support nanotechnology development by firms. The first approach consists in supporting the start-up ecology, with a focus on young innovative firms. Such policies include various types of interventions, which encompass seed funding, subsidies, or broader support to the development of clusters by proposing attractive conditions and talent programs: a major example of the latteris the support for the creation of a nanotechnology cluster in Suzhou[2].

The second approach, which also targets large firms, aims to support the construction of skills by fostering the development of nanotechnology R&D. This support to industrialization is notably part of the role attributed to the national centres for nanotechnology: The Nanotech Industrialization Base of China located in Tianjin and founded by Ministry of Science and Technology in 2000, Shanghai Nanotechnology Promotion Centre, the National Centre for Nanoscience and Technology created in 2003 and located in the Institute of Chemistry of the Chinese Academy of Sciences in Beijing,as well as the National Centre for Nanoengineering created the same year (Guston, 2010). The Shanghai Nanotechnology Promotion Centre, under the Shanghai Municipal Science & Technology Commission, was set up in 2001 to coordinate R&D projects and to promote "nanotech industrialization" in the area. In addition to support small firms in getting funds, through an incubator for start-ups**,** and through its association with Shanghai

[1]Given the size of the country, one can name a series of technological successes, for instance the development of a nano-enabled space suit in the space industry (Clunan and Rodine-Hardy, 2014, p. 15).

[2] Suzhou Industrial Park integrates research institutes, universities and firms, and is one of the innovation park that focus on biotechnology and nanotechnology. It benefits from the support ofthe local, provincial (Jiangsu Province) and central governments. In 2013, the technological park Biobay housed 42 firms in "nanotechnology-related materials nanotechnology, optoelectronics, biomedicine, micro and nano system manufacturing, and energy-saving and the environment" (Cao et al., 2013, pp. 59–61)

Nanotech Association (interview # 3), the Shanghai Nanotechnology Promotion Centre organizes as well the training of participants in the use of infrastructures and materials.

ii. Going beyond the nanotechnology commercialization challenge

Previous studies have emphasized the weaknesses of the contribution of Chinese firms to nanotechnology development. For instance during the period 1985-2004, firms represented 0,5 percent of Chinese nano-publications, a proportion which is below the level of other nations(Guan and Ma, 2007).[1] This modest contribution of firms in national dynamics is also visible globally. In fact, in 2006 China was ranked 5th in corporate R&D investment, which represented 3 percent of the global private R&D investments in nanotechnology in the world (Lux Research, 2008).

This might lead to think that the nanotechnology-related research in the corporate sector lags behind other research institutions(Cao et al., 2013). This idea, which is true, shall however be nuanced. The fact that public institutions drive the trend, does not mean that firms are absent. Indeed, since 2000 a growing number of firms have developed research in nanotechnology. During the period 2001 - 2008, the relative contribution of firmsto the total has remained stable, with a proportion varying between 29 percent and 35 percent of total Chinese nanotechnology patents.

Another element that was evidenced as a barrier to nanotechnology development is the decoupling between scientific institutions and industries (Huang and Wu, 2012; Shapira and Wang, 2009). The situation is explained by a differential of competences between the industry and the research institutions (Huang and Wu, 2012), and by the geographical distance (Motoyama et al., 2014). Looking at this question more closely, we observe that the commercialization of nanotechnology is associated with two distinct challenges. The first one is linked to the promotion of new firms and start-ups in nanotech (Shapira and Wang, 2009). However, the technological regime associated with nanotechnology does not promote the creation of new industry, and the start-ups rather follow a 'business to research' model (Larédo et al., 2010), by providing services or intermediary goods such as nanoparticles used for research. This idea is shared by actors themselves who consider the notion of "nanotechnology industrialization" as misleading (interview # 2). It results that the development of start-ups act as a support for the diffusion of nanotechnology within industries.

The second challenge is the diffusion of nanosciences and nanotechnology in the industry. A major channel of nanotechnology diffusion (or knowledge acquisition from the firm perspective) is through the training and hiring of qualified human resources to work within research departments of firms(Lee and Allen, 1982). The availability of qualified engineers and technicians has a direct

[1] Authors do not provide detailed figures at the exception of the Chinese percentage.

impact on nanotechnology industrialization. In that perspective, the predominance of scientific institutions, universities in particular, is less problematic, as in certain conditions, their presence means the presence of qualified personnel for firms. Above 3000 researchers from different institutes, universities, and enterprises across China were involved in nanotechnology research before 2005(Bai, 2005).[1] An alternativestatistical sourcefrom the Chinese Academy of Sciences,gives a higher figure and counts 7000 scientists in nanoscience in 2002 (Xinhua, 2002).

2.4. Conclusion of the historical perspective on nanotechnology development

The first section summarised the evolution of nanotechnology in China, and the development of nanoscience since 2000. It gives the image of a state-led development, with scientific publications as well as patent applications driven by public research institutions. The engagement of public research institutions in nanotechnologyis associated with the training of nano-engineers. This modality of emergence of nanotechnology in China, articulated with the history of firms,justifies takingseriously the question of the acquisition of nanotechnology knowledge by large firms. This question has rarelybeen addressed in the Chinese context. We observe one particular study on energy storage-related nanotechnology applications for which authors identified the largest applicants (Kay and Youtie, 2013). Their patent data show the repartition of corporate patents in nano energy storage. Four firms including BYD, the Taiwanese firm HongFuJin (Foxconn)and two medium-sized firms represent 41 percent of the total. The importance of BYD and Foxconn reflects the role played by the large firms in a specific field.[2]

3. **Knowledge acquisition of nanotechnology by large firms in China**

3.1. Half of large Chinese firms have nanotechnology patents

The results we obtained from our analysis show that many firmshave been willing to develop new knowledge in nano-related area. This concerns about half of large Chinese firms: 48 percent of the large industrial Chinese firms applied for nano-patents between 2001 and 2009. Specifically, 157 firms out of the 325 firms applied for at least one nano-patentfor a total of 3708 invention priority nano-patents.[3]The number of patents taken by these 157 firms represents a small proportion of the totality of patents applied in China, but shows the integration of the nanoscale dimensionin the knowledge base of a substantial number of actors.

Forty-eight percent of firms can be interpreted asa high proportion of firms. Indeed, it shall

[1] The author does not precise the exact period. 2005 is the publication date of its article.
[2]Georgia Tech Global Nano Database
[3] Unless explicitly stated, we use the term of ‘patent’ for ‘priority invention patent’

be reminded that the 325 large industrial firms forming part of the observed population are neither selected on the basis of innovation criteria such as patents, R&D or new products nor on any alternative indicators of economic or financial performances. In addition, the trend is notable for at least half of them. Indeed, there are important variations in the depth of nanotechnology research among these firms with nanotechnology patenting. Half of them have a “low” (only one patent application) or limited (between two to four patents) commitment to nanotechnology research. However, the other half’s contribution is more important, as it concerns firmsthat have applied for five patent applications and more. This shows that the repartition of firms among these four categories is balanced. 28 firms (18 percent) have only one patent application, which reflects a low investment in nanotechnology research. Another group of 47 firms (30 percent) falls in the category of “limited” number of patents, which implies that around half of the large firms has moderately integrated nanoscale dimension in their research activities (48 percent). By contrast, the remaining 52 percent of the studied firms have a significant patenting activity, 47 firms have between five and fourteen patent applications, or a substantial patent activity, 35 firms have at least fifteen patent applications.

In addition, the characteristics of the largest applicants (Table 7-1) show that some firms have a substantial nanotechnology patenting activity. They, together, contribute to a great proportion of nanotechnology patents. Eight firms, representing 2.5 percent of the large industrial firms, account for 59 percent of all patent applications. The most productive firms include, by decreasing number of patent applications: the firm Sinopec (916 patents), the firm Aluminum Corp (317 patents), the firm BYD (202 patents), the firm PetroChina (187 patents), the firm Datang Telecom (186 patents), the Baosteel Group (168 patents), the firm BOE (115 patents), and Huawei Technologies (113 patents). They are among the largest firms, with an average size of 195 000 employees higher than the average size of all patenting firms (79 929 employees). The smallest firms of the group are the locally state-owned firm BOE Technology which employs 35 165 persons, and Datang Telecom with 23 305 employees. The six other firms employ more than 100 000 employees.

Table 7-1: Eight largest filer of patents in nanotechnology 2001 - 2009

Rk	Firm	Industry sector	Number of *patent applications*	Yr	Employees	Ownership
1	Sinopec	Oil & Gas producers	916	2000	268 953	Central State Owned
2	aluminum corporation of china (chinalco)	Industrial metals & Mining	317	2001	192 272	Central State Owned
3	BYD company limited	Electronic & Electrical Equipment	202	1995	159 000	Privately Owned

4	china national petroleum corporation (Petrochina)	Oil & Gas producers	188	1999	544 083	Central State Owned
5	Datang Telecom Technology & Industry Group	Technology hardware& Equipment	186	1994	23 305	Central State Owned
6	Baosteel group corporation	Industrial metals& Mining	168	1978	195 307	Central State Owned
7	BOE technology group co Ltd	Electronic & Electrical Equipment	115	1993	35 615	Local State Owned
8	Huawei	Technology hardware & Equipment	113	1988	150 000	Privately Owned

Source: author

3.2. China's trends are similar to world's trends

This section focuses on the importance of China's nanotechnology research and comparesChina to the leading countries that participate in the "nanotechnology race" such as the United-States (Dong et al., 2016; Gao et al., 2016; Kostoff, 2012; Liu and Guan, 2016), or Germany (Preschitschek and Bresser, 2010).How do China's trends compare to global trends? The fact that about half of large Chinese firms have applied for patents in nanotechnology needs to be put in perspective with dynamics of nanotechnology research within research laboratories of technological leaders of the world economy.[1]

Technological leaders *ie* multinationals and firms with important level of R&D investments from advanced economies were already engaged in nanotechnology research by 2008. Among these firms, some were particularly active. During the period 1980 – 2004, in addition tobe at the origin of nanotechnology instrumentation, IBM was the most prolific applicant; it was followed by Genentech, Motorola, Micron Technology, and Xerox (Shea et al., 2011).

In addition, the trend is notable by its breadth. The majority of R&D firms had engaged in nanotechnology research by 2008 (Larédo et al., 2010).[2] The trend was notable: 88 percent of firms applied for at least two nano-patents in chemicals, 68 percent in electronics and electrical**,** 74 percent in the oil,gas and electricity sector,and 69 percent in automotive & transport. This trend is also visible in industries less demanding in R&D: 76 percent of firms in the construction & materials sector, and 47 percent of firms in industrial engineering have applied for nanotechnology

[1]The landscape of the large industrial firms is given by existing rankings based on S&T indicators such as R&D expenditures (European Innovation Scoreboard), patents, or a combination of both (Corporate Innovation Board).
[2] These figures include firms with more than two patent applications

patents. An average of 64 percent of global R&D firms had applied for patents through industries by 2008. This goes to show the engagement in nanotechnology research among industries in all countries.[1]

The importance of nanotechnology research by established firms is also visible in the case of China, where 48 percent of established large Chinese firms had applied for patent by 2009. How Chinese firms compare with other firms vary. Indeed, the comparison between China and the rest of the world (Table 7-2) suggests two distinctive cases: industries in which Chinese tends to be less engaged in nanotechnology research than technological leaders (among which automobile, chemicals, construction and materials) and industries in which Chinese firms are particularly engaged. The differences observed in oil and gas, aerospace and defence industries are not conclusive because they are state monopolies with a very limited number of actors.

Table 7-2: Proportion of large firms with nanotechnology research

Industry	Number of firms in DTI R&D scoreboard[2]	Of which have two nano-patent applications	Proportion of large Chinese firms with nano-patent applications
Chemicals	96 firms	88 percent (84 firms)	56 percent (9 firms)
Electronics & electrical equipment	103	68 percent (70 firms)	56 percent (14 firms)
Oil & gas, electricity	53	74 percent (39 firms)	100 percent (3 firms) oil & gaz Electricity
Automobile & transport	86	69 percent (59 firms)	29 percent (9 firms)
Tech hardware & equipment	225	66 percent (150 firms)	76 percent (13 firms)
Construction & materials	55	76 percent (42 firms)	34 percent (10 firms)
Aerospace & defense	35	56 percent (24 firms)	100 percent (4 firms)
Pharmaceuticals & biotech	153	48 percent (73 firms)	86 percent (6 firms)
Alternative energy	NR	NR	50 percent (1 firms)
General industrials	38	76 percent (24 firms)	48 percent (11 firms)
Industrial engineering	70	47 percent (33 firms)	71 percent (23 firms)
Household goods & personal goods	40	53 percent (21 firms)	11 percent (2 firms) Personal goods Household goods & home construction
Food producer (incl beverage)	32	50 percent (16 firms)	Incl. food producer: 31 percent (5 firms) beverage: 60 percent (3 firms)
Conglomerate	NR	NR	
ALL	**986**	**635 (64 percent)**	**48 percent (157)**

Source: author's calculations, (Larédo et al., 2010)

[1] In a practical way, these percentages offer an indicative world "benchmark" by quantifying industrial orientations towards nanotechnology research. The relatively low patenting activity of large Chinese firms compared to the global average cannot be interpreted directly though because of the selection criteria that differs from one population~~s~~ of firms to another. It is expected to find a higher proportion of nanotechnology research among the population of global R&D firm, which was selected based on their level of R&D expenditures.Inversely, the figures obtained for global R&D firms only count those with more than two patent applications and do not include only large firms. This creates a selection bias as some small firms that invest already important sums in R&D (pharmaceuticals & biotech sectors) are also included.

[2] Source: DTI scoreboard and Nanobench/ Nanotrenchart project, 2009 (Larédo et al., 2010)

3.3. A diversified group of firms in nanotechnology research

3.3.1. The persisting driving force of national firms

About the composition of the 157 firms who have patents in nanotechnology, two observations can be made. The first observation relates to the variety regarding ownership. Our results indicate 69 centrally-owned state firms, 57 locally-owned state firms and 30 private firms that have applied for nano-patents This suggests that corporate nanotechnology research has been driven by the three categories of firms. In addition, the historical evolution of the entries of these firms into nanotechnology research (Figure 7-2) suggests a relative stability in their respective contribution to nanotechnology patents over the years.

A second observation relates to the importance of the contribution of state-owned firms to the trend. This partly reflects the composititon of the group of 325 firms. Indeed, private firms are underrepresented among the large firms group in China compared to the weight of the private sector in the economy. They represent 32 percent of the whole group of firms (see p. 97).

The fact that they constitute only 19 percent of firms with nanotechnology research reflect a lesser engagement of private firms into research. This lower proportion reflects different patterns. Indeed, some private firms were early engaged. Seven of them have realized nanotechnology research by 2001.[1] Among them, we find two firms that have close links with some public research institutions. This is the case of Lenovo (PC maker)**.** Indeed, Lenovo started as a spin-off company from the Chinese Academy of Science.[2] The company Tsinghua Tongfang is also attached to a public research institution, Tsinghua University (China's Ministry of Education).

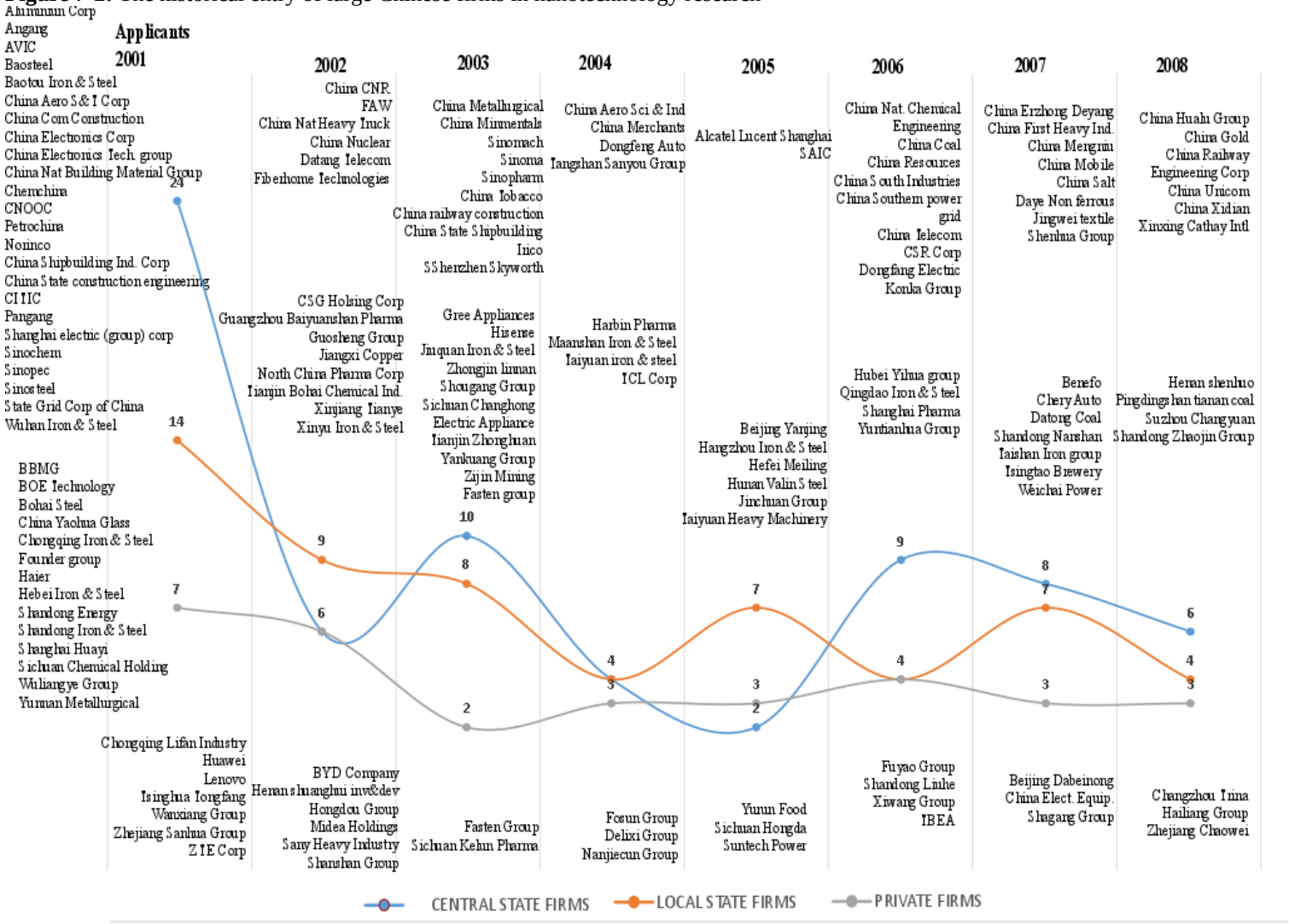
The contribution of state firms is largely imputable to centrally-owned firms: one out of four depends on the Central Government. Centrally state-owned firms have been the most productive patentors: and they contribute to 72 percent of the large firms' patent applications (2673 patent applications). Whereas, the local and private firms represent each 14 percent of the total of all patent applications. This suggests, therefore, that they apply to a greater number of patents than the others. It should be nuanced though. First, itis partly caused by the large contribution of the firm Sinopec, which represents by itself about a fourth of the total (916 patents). Nevertheless, Sinopec only explains part of the trend. Figure 7-2 illustrates the persistence of nanotechnology activity among centrally state-owned firms throughout the considered period, as well as the regular entry of state firms among new entrants in nanotechnology. Throughout the observed period, there is a

[1] Chongqing Lifan Industry (founded in 1992, automobile and parts), Huawei, Lenovo (1984), Technology hardware & Equipment), Tsinghua Tongfang (1997, Technology hardware & Equipment), Wanxiang Group (1969, automobile and parts), Zhejiang Sanhua Group, ZTE Corporation.

[2] that is still maintaining its shares in the company through a holding

modest variation towards the private firms and locally state-owned firms. 42 percent of the local state-owned firms have registered a patenting activity, but they represent a lesser proportion of the total.

Figure 7-2: The historical entry of large Chinese firms in nanotechnology research



3.3.2. Three groups of industries

The table below illustrates the sectoral impact of nanotechnology variation among industries (

Table 7-3). By considering two dimensions: -the proportion of firms which have nanotechnology patenting compared to all firms in one industrial sector, -and the overall sectoral contribution to patent applications realized by large firms,we can distinguish three patterns of nanotechnology research: leading sectors which contribute to the overall trend (and in which a majority of firms is engaged in nanotechnology patents), leading secondary sectors (in which a high proportion of firms does research but with a lower contribution to the total), and other sectors with both a moderate proportion of firms who do research and a low contribution to the total.

Table 7-3: Categorization of industries by their patenting

	Industry	Nb	Nb	%	Total_N	Sector
Leading sectors - Contribution to the overall trend - Pervasiveness across sectors	Oil & Gas producers	3	3	100%	1144	31%
	Technology hardware &	14	17	82%	440	12%
	Industrial metals &	27	43	63%	818	22%
	Electronic & Electrical	14	25	56%	461	12%
Leading secondary sectors - Nanotechnology is pervasive - Modest contribution to patenting	Aerospace & Defence	4	4	100%	124	3%
	Leasure goods	1	1	100%	2	0%
	Pharmaceuticals &	6	7	86%	27	1%
	Industrial engineering	17	21	81%	128	3%
	Beverages	3	5	60%	14	0%
	Chemicals	9	16	56%	120	3%
	Alternative energy	1	2	50%	2	0%
	General Industrials	11	23	48%	88	2%
Other sectors - Significant investment in nanotechnology - Modest contribution to national trend	Construction & Materials	10	29	34%	83	2%
	Mining	8	26	31%	20	1%
	Conglomerate	6	19	32%	37	1%
	Automobile & Parts	8	28	29%	22	1%
	Food producers	5	16	31%	29	1%
	Household goods &	4	9	44%	54	1%
	Electricity	3	9	33%	30	1%
	Tobacco	1	2	50%	45	1%
Absent or marginal sectors in nanotechnology	Personal goods	2	18	11%	20	1%
	Forestry & Paper		2	0%		0%

i. Leading sectors: Oil & Gas, Technological hardware and equipment, industrial metal and mining, and electronic and electrical equipment

A few industrial sectors are characterized by a high proportion of firms which have nanotechnology patenting, and a significant overall sectoral contribution to patent applications realized by large firms. Four industrial sectors, - oil and gas, - technological hardware and equipment, - industrial metals and mining, - and electronic and electrical equipment, make 77 percent of all patent applications by the group of large firms. These are also sectors in which firms are on average well engaged in nanotechnology research.

The first sector, oil andgas, is a central state monopoly with three main firms under the State Asset Supervision and Administration Commission. These three main firms are PetroChina and Sinopec, which both operate onshore, and China National Offshore Oil Corporation, which operates offshore. They are global Fortune companies and, altogether, contribute to 31 percent of the total patent applications by large firms, this trend being largely due to the high contribution of Sinopec (916 patent applications). The importance of this sector in China's patenting echoes to what is observed in other emerging economies.Sinopec and PetroChina are among China's largest contributors (Table 2-1, p. 147). The producer of oil and gas Sinopec is by far, the largest patent applicant (916 patent applications) representing almost one-fourth of all nano-patent applications by firms. Similarly, Brazil's Petrobras is the largest patent filer in nanotechnology of the country (Table 7-5, p. 163). Indian Oil is also present among the firms that patent the most in India (even though its contribution remains modest, see p. 160). They also reflect the importance of nanotechnology-related research in oil and gas industries: *Oil & gas producers have been an early adopter of nanotechnology. Fundamentally, the industry has been part of nanotechnology since the beginning because oil reserves are really just emulsions of oil, gas, and water that create nanoscale particles. More recently, however, nanoscale research and commercialization has transitioned to leveraging nanotechnology to improve their extraction processes* (Ferris and Micromem Applied Sensor Technologies Inc., 2014).

Half of the eight largest applicants are central state-owned firms in resource-related industries: either in the production and transformation of oil and gas sector (Petrochina, Sinopec)or the metallurgical sector, aluminum and steel industries (Baosteel and Aluminum Corp).The importance of these national firms into nanotechnology patenting reflects two elements. They reflect both features of economic development and the weight of these industries in the economy. Industrial production requires energy and natural resources, that are strategic resources for the

government and kept under its control. It shall be noted that these four firms above-mentioned had filed patent applications before 2001 (a period essentially characterized by improvement of the production processes of nanoparticles and nanopowders).

The firms that compose the metallurgical sector display very different features. Locally-owned state firms are the most active, which is associated to a high number of firms. 63 percent of firms in the mining and metal industries have applied for patents in nanotechnology: this represents 27 firms of the total of 43 large firms in these sectors.

Two other sectors among the leading industrial sectorsincludehardware & equipment sector (notably the telecommunication equipment companies), and electronic & electrical equipment sector, both high in R&D activities. Four of the eight largest applicants were in these two categories. Two firms are telecommunication equipment firms: Datang Telecom, and Huawei Technologies.[1]Finally, two firms belong to the electronic & electrical equipment sector, both founded in the 1990s: the Beijing-based locally state-owned firm BOE Technology in the liquid crystal displays industry and BYD Company a private firm in the electric battery. [2][3]

ii. Secondary leading industrial sectors

A second group is gathering industries that display significant nanotechnology pervasiveness *i.e.* a proportion of firms with nanotechnology above the general average, but with a smaller sectoral contribution to the total. These industries are - Aerospace and Defence, - Leasure Goods, Pharmaceuticals and Biotechnology, Industrial engineering, Beverages, Chemicals, Alternative energy and general industrials. Globally, these sectors contribute to 12 percent of all the patent applications.

This includes sectors intensive or highly intensive in R&D. Fourcentrally state-owned firms compose China's Aerospace and Defense sector: China Aerospace Science and Technology Corp, Aviation Industry Corp of China, China North Industries Group Corp and China Aerospace Science and Industry. The four of them have already applied for patents.

The cases of China's chemicals and pharmaceutical & biotechnology sectors are also

[1]大唐电信(datang dianxin) Not to be confused with China Datang Corporation (中国大唐集团公司 zhongguo datang jituan gongsi) which is also a central state-owned enterprise, but in the power generation industry. Datang Telecom is controlled by its parent company, the China Academy of Telecommunications technology (CATT). It is known for its contribution to the 3G technology standard TD-SCDMA(Gao, 2014). While Huawei patents on the behalf of the group, the situation differs for Datang Telecom. Most patent applications under Datang Telecom, were made by the Shanghai-based firm Semiconductor Manufacturing International Corp. (SMIC) in which Datang Telecom has controlling shares since 2011.

[2]1993 for BOE Technology and 1995 for BYD

[3]Liquid crystals are a substance that bends and refracts light waves as they pass through them. With the addition of external electric charges, the property of light changes creating the various shades of color and shadow you see on the display (source BOE)

interesting as there are potential applications of nanotechnology in these industries. 86 percent of firms in pharmaceuticals &biotech, and 56 percent of firms in chemicals have already integrated nanoscale dimension in their research. However, the intensity of their participation remains modest. This is relatively surprising regarding the fact that the chemicals sectors are among the most dynamic in nanotechnology (88% of patents among technological leaders in that category, see section 3.2).

iii. Industries: Laggards and absent of the trend

In some others industries, nanotechnology research is still less diffused. There are two distinctive cases according the nature of industries concerned.Some industries are traditionnally less demanding in research, and they have been associated to lower pervasiveness of nanotechnology at the global level. For instance, there are no Chinese firms highlyengaged in nanotechnology among the following industries: food production, personal goods, forestry & paper, but this is explained by the fact that these industries are traditionally less intensive in R&D. Large firms in the (forestry) and paper industry invest on average 0,8 percent of their sales in R&D.

In contrast, the modesty of nanotechnology investment in sectors where firms from advanced economies have important nanotechnology research reflects the lag of Chinese firms. The automobile industry is traditionally demanding in R&D. The OECD uses to categorize the automobile industry as a medium to high R&D intensity, Here, the China's automobile sector is showed to underperform in R&D (we found only the average of 2,3 percent of R&D intensity, see Table 6-4, p. 123). 69 percent of global firms in automobile and transport had nanotechnology patents. This is the case of a small proportion of 29 percent of Chinese firms. In addition, none of these firms make a noticeable contribution.

3.4. Conclusion

There are few if none corporate communications on nanotechnology research by large firms, exception made of the Shanghai-based steel producer Baosteel. We also found that a few other firms mention the use of nano-enhanced products: Shanghai Electric, and Hisense. In the press, articles that refer to nanotechnology mention either governmental programs where nanotechnology is perceived as an opportunity for technological breakthroughs, or research related activities in universities and research institutions. A research on Factiva, gathering all "*Nanotechnology Weekly*" between 2009 and 2015 illustrates this absence of communication. 152 news articles in this Journal include the terms "China" and "firm" (or equivalently company, enterprise, business), against 33

143 articles that include both the terms: “China” and “nanotechnology”.[1]

However, their patents suggest they have engaged in nanotechnology research. The results we obtained first suggest the importance of nanotechnology research among the 325 large industrial firms. A proportion of 48 percent of the 325 large industrial Chinese firms have included nanoscale dimension in their research, among which the half do it in a high proportion (5 patents and more). Based on the previous descriptions we made of the industries and firms that compose the trend, we can make two observations. The first one is the existence of several firms with a substantial level of nanotechnology patenting.The identity of the largest applicants in nanotechnology does not create surprise and it is quite consistent with what we know of China’s large firms. A second observation relates to the variety underlying the trend, regarding industries and ownership, as well as its breadth

4. China as a unique case among emerging economies

4.1. Introduction

The contribution of large Chinese firms to nanotechnologycoupled with the importance of China’s R&D, leads to questioning China’s status compared to the rest, and to the large emerging countries such as India and Brazil. This comparative approach is common. A series of research has compared nanotechnology in China to other developing countries such as Brazil, India,and Russia (Klochikhin, 2013; Liu et al., 2009).

Comparing China to Russia would offer an enlightening perspective. In fact, both China and Russia are former communist countries that have followed an alternative transition paths towards market economies (Buck et al., 2001). In parallel, the nanotechnology development in China versus Russia was the object of a series of research (Klochikhin, 2013). Here, we do not integrate Russia in our discussion, but we can make a few comments. Firstly, Russian patent applications in nanotechnology reflecta low implication into technological development. There were 3231 invention nano-related patents registered at the Russian Office between 2001 and 2008. Secondly, this observation contrasts with the relatively high level of Russian nanoscience and nano-scientists, and their participation to international collaborations(Karaulova et al., 2014). The absence of technological development is true at least on the civil side, but the Russian nanotechnology is characterized by a stronger emphasis given to the military developments than in China (Clunan and Rodine-Hardy, 2014).

In this section, we perform detailed analysis only on the cases of Brazil and India.

[1] Factiva is a global news database featuring nearly 33,000 sources, including licensed publications, influential websites, blogs, images and videos.

4.2. Absence of Indian firms from nanotechnology patenting

4.2.1. Weak patenting activity in India

Compared to China, the relatively modest investment of Indian firms in R&D underlines their lesser capacity to invest and to develop skills in nanotechnology than Chinese firms. Indeed, a limited patenting activity suggests that there is a modest number of Indian firms with nano-related R&D. Wholly, the Indian institutions applied for 567 patent applications between 2000 – 2008, and almost the half of these patents was applied by individuals (which are generally not included in quantitative analysis as they are too difficult to interpret).[1]The number of 567 patent applications contrasts sharply with the Chineseone where 51 258 nano invention were patented in the same period (between 2001-2008)This number is coherent with previous researches that notice the weak implications of India in nanotechnology patents (Bhattacharya and Shilpa, 2011).

However, there has been in India, a continued national government support to the nanotechnology development. The first national nanotechnology initiative in India was decided in 2001 with a short-term horizon: The Nanoscience and Technology Initiative (NSTM) running between 2001 and 2006. Later in 2007, NSTM program was engaged by the Indian Department of Science and Technology during five years with an annual allocation of around $5 million.

The Indian firms are not absent from the nanotechnology research landscape (

[1]IFRIS NanoPat that covers the whole period till 2008

Table 7-4). In fact,nanotechnology patenting is dominated by firms. There is one exception, which is also the largest institutional applicant in India. The *Council of Scientific and Industrial Research* is an independent organ mainly funded by the Indian government and ruling about 217 nano-related patent applications.

Furthermore, 22 Indian institutions out of the 25 top applicants in nanotechnology are mainly private firms, owning to the pharmaceutical and biotech sector (list provided by the table below). In total, the Indian firms represent 31 percent of the total patent applications activity, with 228 nanotechnology patents registered at the Indian Office of Property Intellectuals (OPI) between 2000 and 2008 (Patstat 2009).

Table 7-4: Top Indian patent applicants in nano (all years, more than 5 patents)

Rank	**Name**	**Nb**	Detail	Sector	R&D scoreboard
1	Council of Scientific & Industrial Research	217	Autonomous R&D organization mainly funded by the Ministry of Science and Technology		
2	Ranbaxy Laboratories Limited	32	*Acquired by Sun Pharma in 2014*	Pharma & Biotech	
3	Dr. Reddy's Laboratories Ltd.	27	Private Indian firm	Pharma & Biotech	525th largest R&D spender in 2014 (145 million €)
4	Biocon Limited	14	Private Indian firm	Pharma & Biotech	
5	Reliance Life Sciences Pvt. Ltd.	14	Belong to conglomerate Reliance Industries	Pharma & Biotech	535th (143 M€)
6	Indian Oil Corporation Limited	12	State-owned firms	Oil & gas	
7	Sun Pharmaceuticals Industries Ltd.	12	Private Indian firm	Pharma & Biotech	660th (110 M€)
8	Cipla Limited	10	Private Indian firm	Pharma & Biotech	1038th (60 M€)
9	Eli Lilly and company	10	American firm	Pharma & Biotech	
10	Panacea Biotec Ltd.	8	Private Indian firm	Pharma & Biotech	
11	Dr. Reddy's Research Foundation	8	*Belong to Dr. Reddy Industries*	Pharma & Biotech	
12	Lupin Limited	8	Private Indian firm	Pharma & Biotech	686th (105 M€)
13	Indian Petrochemicals Corporation Limited	7	Private Indian firm	Chemicals	
14	Nicholas Piramal India Limited	7	Private Indian firm	Pharma & Biotech	1523rd (35 M€)
15	Lakshmi Machine Works Limited	7	Private Indian firm	Industrial engineering	
16	Birla Research Institute for Applied Sciences	7	Privately-funded institute in 1969		
17	Cadila Healthcare Limited	7	Private Indian firm	Pharma & Biotech	1175th (50 M€)
18	Hetero Drugs Limited	7	Private Indian firm	Pharma & Biotech	
19	Glenmark Pharmaceuticals Limited	6	Private Indian firm	Pharma & Biotech	2405th (17 M€)
20	Sahajanand Medical Technologies PVT. Ltd	6	Private Indian firm	Health Care Equipment & Services	
21	Galaxy Surfactants LTD	6	Private Indian firm	Chemicals	
22	Torrent Pharmaceuticals Ltd	5	Private Indian firm	Pharma & Biotech	
23	USV Limited	5	Private Indian firm	Pharma & Biotech	
24	National Research Development Corporation	5	Government enterprise under the Department of Scientific and Industrial Research (Ministry of S&T) for technology transfer		
25	Bharat Serums & Vaccines Ltd.	5	Belong to conglomerate Bharat	Pharma & Biotech	

Source: compilation of various sources by the author

This low level of patenting activity by Indian firms can found several explanations. First, the

number of firms with internal R&D activities is relatively low: only 24 Indian firms were ranked among the top 2500 R&D firms in 2013, including small firms.Besides, many India's R&D firms are operating in industrial sector where the nanotechnology has limited applications. Indeed, among the large 16 Indian firms ranked among the top 2500 R&D firms in 2013, only five of them have patents in nanotechnology (about one-third of the group) and six of them belong to the Software & Computer Services sector.[1]A second explanation to the low nanotechnology activity in India is coming from the research organization modalities among the large Indian firms that might externalize part of their research activities.[2] Finally, and alternative explanation might related to India's national specificities regarding patents.[3]

4.2.2. Nanotechnology and Patterns of industrial specialization across India

Accurately, the diffusion of Indian nanotechnology patenting is limited. This fact is associated with the notable absence of industrial diversification in India among firms with nanotechnology patents. According to the list of the most prolific nano-patent firms,they belong mainly to the same sector activities. For instance 17 Indian firms belong to the Pharmaceuticals & biotechnology sector- a sector in which Indian firms are historical actors under the leadership of Ranbaxy Laboratories, Dr. Reddy and Cipla (Kale, 2012). Few others firms belong to some distinct industrial sectors: Indian Oil Corp Ltd a one state-owned oil and gas firm, Galaxy surfactants a chemical firm, Sahajanand Medical Technologies specialised on healthcare equipment and services, and Lakshmi Machine Works Limited an industrial engineering company.

Innovative Indian firms and their strategies have been as well studied and recognized to have reached the stage of innovating behind the technological frontier (Kale, 2012). Concerning the Indian firms that are the most studied regarding their innovation capacity, we identify the following firms, Ranbaxy the pharma Dr. Reddy and TATA subsidiaries, notably in the automobile sector. The WIPO (World Intellectual Property Office) says about Dr Reddy the following: The Indian firm, Dr Reddy appears to be a classic case of intellectual property and has successful caught up "Dr. Reddy himself so well describes, "Ours is a story about bringing affordable medicines to people in India, then moving on to compete in the advanced markets of the world, and finally, to drug discovery." This transformation and the company's R&D carried out by DRF, gave the company financial success on one hand and made a strong social impact on the other. Acting as a primary link, IPRs helped the company become the innovator that it is today."(wipo, 2010).

[1] There are 24 Indian firms, whose size is known for 17 of them. 16 with more than 10 000 employees.
[2] Large conglomerates invest in separate research institutes or in collaboration with universities
[3],For instance in the pharmaceutical sector in particular, Indian firms did not need to patent before 2005 (Chaudhuri, 2005).

This suggests that national differences in patenting trend are not explained by individual performances of firms, but by national dynamics of firms

4.3. Brazilian firms: a less pronounced trend than in China

Concerning the diffusion of nanotechnology, Brazil offers a different example than India. Brazil presents a distinctive interest. Besides that it is the 5th world largest country**,** with an area of 8,4-million square kilometers**,** Brazil leads nanotechnology development in Latin America area. According to (Kay and Shapira, 2009), the Brazil had contributed in 2006 to about half of all Latin American scientific publications. Brazil designed its own nanotechnology policies in the 2000s**,-** a few years after China. From fact, the Brazilian government has adopted a national nanotechnology program between 2004-2005, when nanotechnology was declared one of the eleven areas for strategic government investment (Clunan and Rodine-Hardy, 2014, p. 35).

Furthermore, Brazilian nanotechnology is providing an interesting comparative view with China. Indeed, to some extent, the Brazilian case is presenting some similarities with China. Firstly, public research organizations and universities are driving nanotechnology patenting trend. In the top five of Brazilian applicants, three of them are universities (the *State University of Campinas*[1], *University of Mina Gerais, University of Sao Paolo*) and one is a governmental institution (São Paulo Research Foundation). This reflects both the traditional emphasis of Brazil on basic research for economic development (Niosi and Reid, 2007), and the driving role of Brazilian universities in nanotechnology (Kay et al., 2009). The National Nuclear Energy Commission and the National Council for Scientific and Technological Development are also productive contributors. Another aspect similar to China is the role of foreign firms in nanotechnology patents.

In parallel, the specificities of the Brazilian case is the degree of deployment of nanotechnology research among other actors. The weak patenting power of the Brazilian firms has already been identified. In a previous bibliometric analysis based on Georgia Tech's nanotechnology database, Kay et al. have found that 95 percent of the 157 nanotechnology patents, belong to universities, and counted less than 80 firms in Brazil pursuing the development of the nanotechnology (Kay et al., 2009). In our data, 22 percent of the observed institutions are Brazilian, and the total number of their nano-patent is estimated around 3493 applications.[2]

The table below (Table 7-5) reproduces the list of firms with more than 10 patents in nanotechnology.The firm Petrobras is the largest applicant with 190 patent applications in nanotechnology. In addition, formerly state-owned firms are also well represented in our data such

[1]Universidade Estadual de Campinas – Unicamp. A public research university in Sao Paolo.
[2] the figure includes both foreign firms and Brazilian firms

as Vale and Usiminasin mining and steel industry. The repartition of firms across industrial sectors seems to indicate less specialization than in the case of Indian firms. In contrast, greaterimportance is given to the primary sector (agriculture, resources) and related industries. This is further suggested by the fact that Brazilian R&D firms do develop knowledge in nanotechnology. In 2013 among the 2500 global R&D spenders, seven firms out of the nine Brazilian firms have applied in the past decade for at least one patent related to nanotechnology.[1]

Table 7-5: Top Brazilian patent applicants in nanotechnology (all years)

Rank	Name	Nb	Detail	Sector	R&D scoreboard[2]
1	Petrobras[3]	190	State Brazilian firm	Oil & Gas	135th (833,6 million euros)
2	dana industrial ltda	69	Private Brazilian firm	Auto & Parts	
3	Vale doriodoce	50	Privatized national firm (1997)	Mining	174th (880 million euros)
4	Embrapa - EmpresaBrasileira de Pesquisaagropecuaria	45	Research Agency under Ministry of Agriculture[4]	Agriculture research	
5	Semeato s.a. industria e comercio	44	Private Brazilian firm	Agricultural machinery	
6	Empresa Brasileira de Compressores s. a. – embraco	43	Brazilian firm	Refrigeration compressors	
7	Usinassiderurgicas de minas Gerais s. a. - Usiminas	39	Privatized national firm (1991)	Mining & Metals	
8	Maquinasagricolasjacto s.a..	29	Private Brazilian firm	Agricultural equipment	
9	Brasilata s.a. embalagensmetalicas	19	Private Brazilian firm	Packing Industry	
10	Duratex s.a.	18	Private Brazilian firm	Paper & Forest	
11	Centrais eletricas do norte do brasil s.a. - eletronorte	14	Belong to Electrobras	Electricity	
12	Tigre s.a.. - tubos e conexoes	12	Private Brazilian firm	PVC products	
13	Produquimica industria e comercio s.a.	11	Private Brazilian firm	Chemicals	
15	CristaliaprodutosquimicosfarmaceuticosLtda	11	Private Brazilian firm	Pharma	
16	Itautec philco s.a.. - grupo itautec philco	10	Belong to Itausa (conglomerate)	IT & software	1831th (26 million euros)
17	Isoeste ind. e com. de isolantes termicos ltda	10	Private Brazilian firm	thermal insulation	

Source: compilation of various sources by the author

4.4. The specific model of China and large Chinese firms

The comparison of nanotechnology research between Chinese large firms with Indian and

[1] The other two firms operate in the food industry (BRF), and in the software industry (TOTVS).
[2] Year 2013, 2014 ranking
[3] petroleo brasileiro s.a
[4] The Brazilian Agricultural Research Corporation (Embrapa) was founded on April 26, 1973, and is under the aegis of the Brazilian Ministry of Agriculture, Livestock, and Food Supply.

Brazilian ones emphasized the specificities case of China. We find that the nanotechnology patenting activity in China is coherent with the nature of its industrial corporate landscape. What is remarkable in the comparison between China on the one hand, and Brazil and India on the other hand (Table 7-6), is both the diversity and the number of large firms applying for patents in nanotechnology in China compared to the other nations. Regarding the diversity: China's case presents variety, in terms of ownership, and industries. The capacity of the Chinese institutional environment to allow Chinese firms to grow in significant number was noticed in the early 2000s (Nolan, 2001b). China's large firms managed to emerge and to become global R&D firms.

By contrast, there are fewer large firms in nanotechnology in India and Brazil in nanotechnology research. This is partly explained by national specificities in the industrial structure. For instance, India has a specialized profile for many Indian private firms are in the pharmaceutical and biotech industry. In Brazil, the large domestic firms with nanotechnology patents present more variety, but there are less numerous than in China. It also results from a lesser investment in Research in Development. This is consistent with our observations in the previous chapter about the investments of these countries' firms in R&D. The result is that the large Chinese firms have invested more in nanotechnology research than India and Brazil.

Consequently, the differences are not individual strategic approaches**,** but in the number of the firms engaged in the patenting process. Put differently; the difference is not due to the technological capabilities of individual firms, but to the dynamics of catch-up process among national firms. This puts the emphasis on the fact that patenting dynamics are national and not only linked to individual firm performances.

Table 7-6: Summary of the main features of nanotechnology in China, India and Brazil

	CHINA	INDIA	BRAZIL
Main national programs to support nanotechnology development	Nanotech R&D as one of twelve megaprojects 2006 - 2020	2001: Nanoscience and technology Initiative 2007: Nanoscience and Nanotechnology Missions	2003: Program for the development of nanoscience&nanotechnology 2005: National Nanotechnology Program
Research model	Universities (state-key labs) Government institutes	Research foundations Institutes Government-supported institutes	Universities Government institutes
Nanotech system		$145 million over 5 years	2012: 17 nanotech networks 8 national labs 2500 researchers, 3000 graduate students
Target	Technological breakthrough Commercialization	None	Technology transfer Basic research
Public expenditures		$145 million over 5 years (Dep of S&T)	$5 million a year between 2004 – 2008 by the Ministry of Science, Technology and Culture
Public Nanotechnology R&D 2006 (Lux Research), in millions of US dollars, using currency exchange rates	220	Less than 60	Less than 60
Contribution to patenting nanotechnology research	High	Low	Medium
Largest contributors to nanotechnology development		Council of Scientific & Industrial Research	Petrobras (SOE) University Campinas
Domestic firms with more than 10 patent applications	~ 40 large firms	~ 7 firms	~ 15 firms
Challenges	Integration of skills in the firms' strategy	Growth and diversification of large firms that engage in R&D	Growth and diversification of large firms that engage in R&D

Source: compilation of various sources by the author

5. Conclusion

This chapter was concerned with the deployment of nanotechnology research among 325 large industrial Chinese firms. The challenge for China's nanotechnology development is double. At stake is the transformation of the Chinese industrial model, which is based on the development of capabilities of a broad range of firms, as well as the competitiveness of the Chinese industrial firms on a global level. It is worth reminding here that about the half of the large Chinese firms have

applied for patents in nanotechnology by 2008. Among which one-fourth had a nanotechnology patenting activity that might be considered as significant or important.

This means that China was better positioned to seize opportunities in nanotechnology than it was during the previous technological waves. We illustrated this by putting two historical dynamics in perspective: the dynamics of technological learning of Chinese firms and the emergence of nanotechnology.

This trajectory appears unique among emerging economies. The comparison of China with Brazil and India shows that the large Chinese firms distinguish themselves from other firms in emerging countries. Chinese large firms have entered the global rankings in terms of R&D expenditures, and in terms of research in nanotechnology. Such a differential can be explained in several ways. The first explanation is the difference in terms of technological capabilities between Chinese, Indian and Brazilian firms. Indeed, this explanation seems limited. There are no elements in individual case studies on Indian and Chinese firms that would be conclusive in this sense.

A second explanationis suggested by the comparison of the identity of these countries' largest shareholders. The comparison puts in evidence two primary features: the combination of the industrial diversification of large Chinese firms and of the great number of large firms is unique among emerging countries. This suggests that national differences in nanotechnology patenting activities cannot be explained only by the performance of individual firms, but essentially by the industrial structure of China.

Additionally, the large Chinese firms present a profile closer to the "Western"model" of firmsthan what is observedin emerging countries. This echoes to the introduction we made of China's firms in Chapter 5. Large Chinese firms operate in a broad scope of industries and have more varied ownership. Despite the existence of centrally state-owned firms, the model of large Chinese firms is neither a model of a planned economy characterized by the existence in each industry of one or two nationalchampions, nor a model dominated by conglomerates like in other Asian countries such Korea and Japan.

These firms are also similar to "Western" global firms in the sense that they invest in developing knowledge in new technologies by doing research. The breadth of nanotechnology patenting among large Chinese firms may underline the questions about the future development of their capabilities. This question requires further examinations of the dynamics associated with these patenting activities.

Chapter 8: **Differentiated pathways in the way firms develop nanotechnology**

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1. Introduction

The fact that a significant proportion of large Chinese firms file nanotechnology patents indicates the integration of nanotechnology research in their strategies. We described the general features of these firms filing nanotechnology patents in the preceding chapter (Chapter 7, p. 149). We noted the major contribution of centrally-owned state firms and a few industries to the overall trend (Oil & Gas, Technological hardware and equipment, industrial metal and mining, and electronic and electrical equipment). However, another prominent element that appears, particularly when comparing the case of China with India and Brazil, is the variety of Chinese firms that engage in nanotechnology research, in terms of industries and ownership.

This, in turn, questions what nanotechnology research uncovers. Because of the diversity of trajectories associated with Chinese firms, the way firms engage in nanotechnology research activities are not likely to follow a single trajectory. What can we tell about this topic? This chapter aims to contribute to that question and looks at the different modes of engagement in nanotechnology research. More specifically, our chapter pursues two objectives. The first one is to show that Chinese firms follow trajectories that cannot uniquely be understood through the lenses of ownership or industrial specialization, and that more complex dynamics are at work. The second objective is to elaborate on these elements and to introduce a categorizationof the firms according to their research profile.

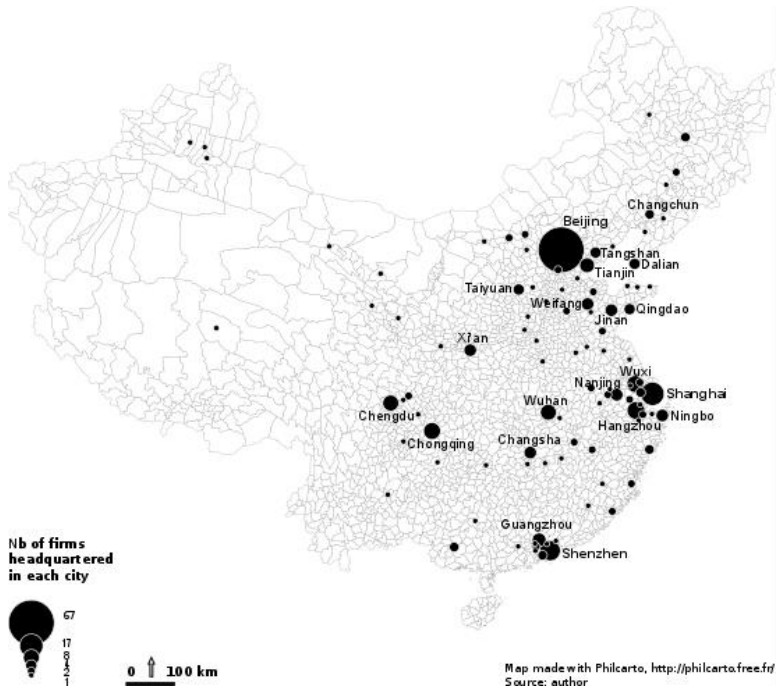
2. Structuring elements of nanotechnology research in large Chinese firms

2.1. Introduction

What elements might explain the trajectories of Chinese firms in nanotechnology research?The importance of China's investments in R&D (Chapter 6), and the capacity of a substantial proportion of Chinese firms to patent in nanotechnology (Chapter 7) questions underlying dynamics at the firm level. At stake is the capacity of firms to benefit from investment in research.

Both national historical specificities and local environments of firms condition these dynamics. There are three dimensions attached to that question. The first relates to the availability of human resources for nanotechnology research in China. How do firms find the personnel they need? Indeed, the development of a firm's knowledge base requires the hiring of new researchers specialized in the field (Lee and Allen, 1982). This is of crucial importance as nanotechnology is demanding in terms of qualifications, and requires access to ad-hoc technological infrastructures (Robinson et al., 2007). In that regard, the localization of firms tremendously matters. This is even more important considering the geography of China is characterized by important regional disparities in innovative activities and in human resources. The country has sharp disparities and "empty" regions in terms of public research. China's geography of innovation is typical of an emerging country (Crescenzi et al., 2012). Patents, reflecting innovative activities, are highly concentrated in three centres (Shanghai, Beijing, Shenzhen) with barely any patenting activities outside the latter, which contrasts with advanced economies where the concentration in centres co-exists with a broader dispersion of patenting activities in the territory (Crescenzi et al., 2012).

Map 8-1: Localization of the headquarters of large industrial firms



This must be put in perspective with the emergence of Chinese firms outside these centres. A second dimension pertains to the first one and is the localization of a significant proportion of firms outside the main centres(reproduced from p. 100). Out of the 325 firms we selected, 110 firms have their headquarters outside the three most

dynamic regions (p. 99).[1] This trend is due in large part to the role of local governments in the emergence of firms during the transition to the market economy (Oi, 1995).

Among them, 45 firms have applied for nanotechnology patents. This raises a series of questions about those firms' capability to find resources to do research in their environment. It also illustrates the necessity to account for the geographic dimension of their activities.

A third dimension is related to China's historical legacy. We mentioned the importance of the legacy of central planning prior to 1978 in shaping today's firms (chapter 5, p. 93 "Histories and trajectories of today's large Chinese firms"). Another feature we hitherto barely mentioned is that it has also conditioned corporate research. Indeed, China's emphasis on high-technology is not new. Barry Naughton mentions that China'sR&D intensity reached 1.7 percent in 1964 (as measured by the outlays in the proportion of science and technology of GDP) and averaged 1.5 percent between the late 1950s and 1978 (Naughton, 2007, p. 353). The key S&T institutions were developed based on the model of the Soviet Union in the context of a vast movement of technology transfer during the 1950s (ibid., p. 355). The existence of previous research units is likely to influence the contemporary way these organizations engage in research activities.

These dimensions are key elements to understand the dynamics of Chinese firms filing nanotechnology patents. We, therefore, introduce them. First, we focus on the factors that are likely to impact the way firms find and mobilize resources, and organize this discussion around two elements. The first element is the geography: the way firms do nanotechnology research is determined by the distribution of competences in nanotechnology in the Chinese territory. The second element is China's historical legacy: one major feature of China is the existence of a prior research system, linked to state planning. This system is mobilized by large firms and, thus, structures the way a part of these large firms do research.

2.2. The role of universities and public research institutions

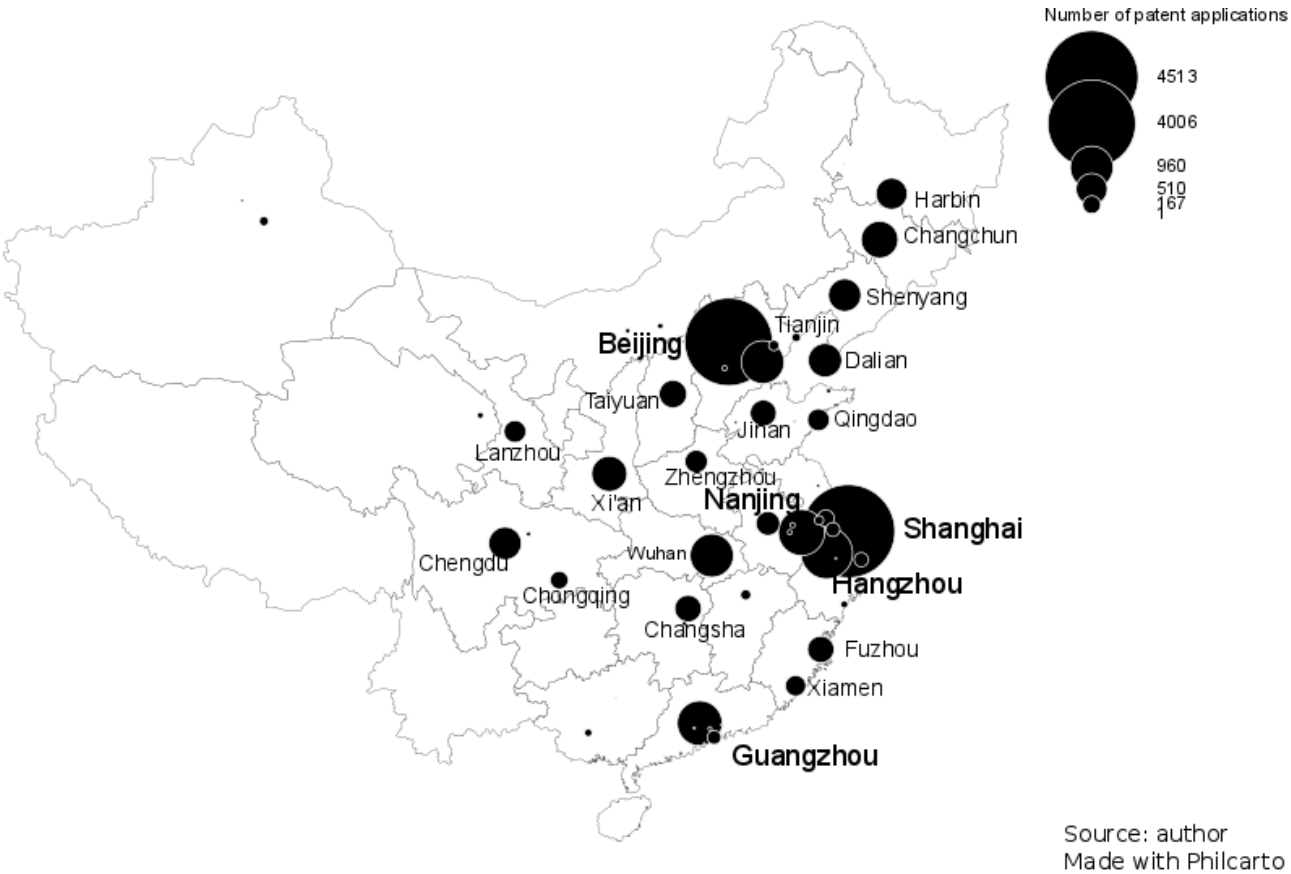
The role of localization for innovation has been widely studied and is encapsulated in concepts such as clusters or technological agglomerations. The importance of being localized close to knowledge centres is associated with a series of elements: availability of qualified human resources, collaborations, and knowledge spin-off, or access to technological structures (Robinson et al., 2007).

In this section we will look at public research in nanotechnology. The presence of

[1] Bohai RimRegion(Beijing-Tianjin area), the Yangzte Delta River Area (Shanghai and its surroundings, and the Pearl River Delta area (Guangdong Province)

universities and research institutions involved in nano-related areas indicates education and training activities of qualified engineers. In that regard, the localization in a region with public research is a major determinant of a firm's ability to do nanotechnology research by providing qualified personnel.

One way to assess the intensity ofnanotechnology research in one city is to look at the inventive activities, as measured by nanotechnology patents, of non-corporate research institutions. Indeed, the dynamism of a region in terms of research and the orientation of its activities are reflected in indicators such as scientific publications, and patents taken by public research institutes and universities. Mapping public research (Map 8-2, p. 170) shows that competences in nanotechnology are unequally distributed in the territory.[1] There is a concentration of scientific and technological activities linked to public institutions in a limited number of cities. We find 29 cities where public institutions applied for more than 100 patents, among which five cities count more than 1000 patents: Shanghai, Beijing, Hangzhou, Nanjing, and Guangzhou.[2]



Map 8-2 : Geographic repartition of nanotechnology patenting by public institutions

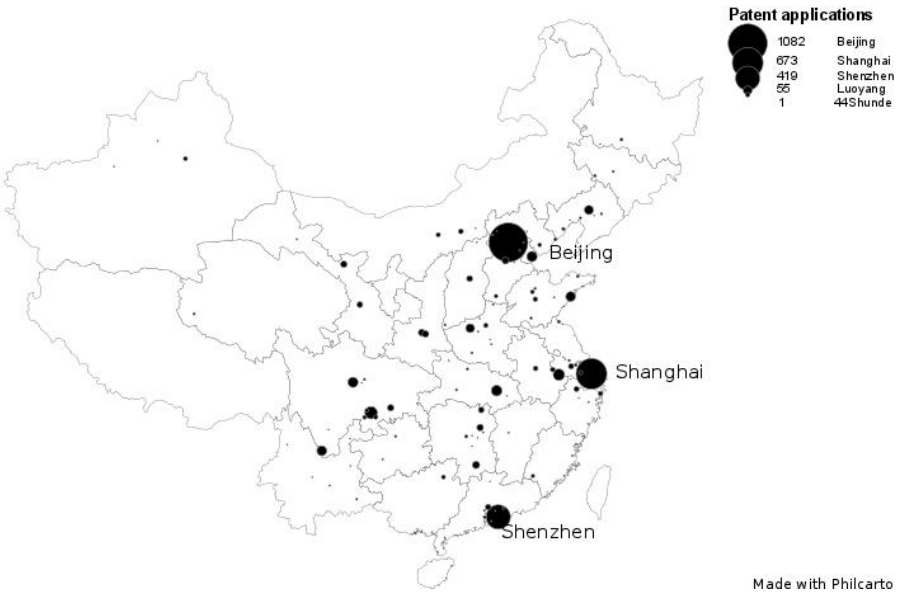
[1]We base the measure of patenting activities on the declaration made by applicants as they filed their patent applications, and count the number of patents whose applicants are localized in each city.

[2] All maps in this chapter were done by the author. The maps were done with the software Philcarto (developed by Philippe Waniez) and available at http://philcarto.free.fr/

This is coherent with the country's geography of innovative activities, and with previous observations about patterns of concentration in nanotechnology in China (Bironneau, 2012; Motoyama et al., 2014; Tang and Shapira, 2011). The Chinese situation is not unique; nanotechnology is concentrated in about 200 areas in the world (Larédo et al., 2009, 2010).

The main issue in the Chinese context is the extent to which the geographic repartition of public research corresponds to the repartition of industrial activities, especially in regions that are outside the main nanotechnology centres. To have an idea of the articulation of public research with corporate nanotechnology research, we cross this information on public research with information on the localization of firms' nanotechnology research and of firms' headquarters. The repartition of corporate nanotechnology research (map 8-3) give a precise image of the localization of teams that do research in nanotechnology.[1]

The articulation of these dimensions shows three situations coexist in Chinese nanotechnology research.



Map 8-3: Localisation of corporate nanotechnology research (2001-2008)

[1]We have considered the localization of the different firms' competence centres in nanotechnology *i.e.* we did not input all patents of a firm to its headquarters, but counted independently patent applications done by the same company in divisions or subsidiaries localized in different cities. As in the rest of the chapter, our analysis is based on the use of geolocalized patents. Interpreting the distribution of nanotechnology research among firms based on patent data is a tricky issue. The application process itself varies depending on firms, their corporate IP strategies, and the routines followed by the research teams and support departments involved.Therefore, the address that appears in the patent applications is not necessarily the place of invention. Instead, firms often have departments specifically in charge of filing patent applications on behalf of research teams. The Intellectual Property Department, often attached to the technical centre, oversees patent applications.

2.2.1. Firms localized in driving regions: benefiting from the general environment

Driving regions are characterized by the co-location of both public research and firms. Shanghai and Beijing are characterized by the presence of top universities and public research institutes, and house the largest number of headquarters of largefirms (Table 8-1): 17 large firms are headquartered in Shanghai, and 67 in Beijing. These areas, unsurprisingly, offer the most favorable environment for nanotechnology patenting activities: 51 groups headquartered in Beijing do nanotechnology research, and this is the case of 10 Shanghainese groups.

On the basis of these figures, Beijing has a prevalent role. However, it must be emphasized that its weight in the total contribution of corporate patents might have to be relativized. As many headquarters are localized in Beijing, it is possible that in some cases, firms apply on behalf of their subsidiaries localized in other cities. This is particularly likely to be the case because centrally state-owned firms are likely to centralize their patent applications in their headquarters in Beijing. In addition, the contribution of Shanghai shall be interpreted in light of its driving role in the Yangtze Delta areas. Shanghai is close to two other cities which are particularly active in nanotechnology research, as they are among the five cities with the highest number of patents: Nanjing and Hangzhou (Table 8-1).

The situation of Shenzhen presents a more contrasted profile. Shenzhen houses nine firms including BYD Company, Huawei, ZTE Corp, Aviation Industry Corp,etc. As this is visible in Map 8-3, Shenzhen is among the largest contributors to corporate nanotechnology by large firms (419 patent applications) after Shanghai and Beijing. In contrast, the modest contribution in nanotechnology patenting (101 patents between 2001 and 2008) indicates the relatively low intensity of public research. This relative weakness is compensated by the integration in the Pearl River Delta Region, and the proximity to Guangzhou (and Hong Kong). This is not specific to nanotechnology, though, and has been characteristic of Guangdong Province where corporate R&D research is not linked to the presence of research institutions (Jastrabsky and Arvanitis, 2005).

Table 8-1: Profiles of the driving regions in nanotechnology research

Geographic Areas	**Firms**	**Public Research (patents applications by universities and research institutions)**[1]
Shanghai	17 headquarters – 10 firms with nanotechnology patents	Top institutions: shanghai jiaotong university (943); Fudan University; 597); Donghua University (390); Shanghai University (371); Tongji University (339) 4513 (78 percent Univ / 22 percent Gov)
Beijing	67 headquarters – 51 firms with nanotechnology patents	Top institutions: Tsinghuauniversity (1010); Beijing university of science and technology 358); institute of chemistry, cas (317); Beijing university of chemical technology (299); institute of physics, cas (208) 4006 (67 percent Univ / 33 percent Gov)
Hangzhou (Zhejiang)	10 headquarters-– 2 with nanotechnology patents	Top institutions: Zhejiang University (1082) 1389 (97 percent univ)
Nanjing (Jiangsu)	4 headquarters – 2 with nanotechnology patents	Top institutions: Nanjing university (393); southeast university (269), Nanjing university of technology (100) 1120 (96 percent univ)
Guangzhou (Guangdong)	6 headquarters – 2 with nanotechnology patents	Top institutions: South-China University of Technology (288); Sun Yat-Sen University (259) 1057 (83 percent univ, 17 percent gov)

Source: author

2.2.2. Explaining corporate nanotechnology research in cities less intensive in public research: the role of local specialization

A few firms who filed nanotechnology patents, directly or through subsidiaries, are in cities with barely any public nanotechnology research (

[1] Top 5 institutions and institutions with more than 100 patent applications

Table 8-2). What implications does this have for the firms' access to resources?

Let us limit our scope to cities where large firms applied for at least 20 patent applications, and look in detail what these cases uncover. 13 firms do part or the totality of their research in these cities. They include Fushun City, in Liaoning Province (108 patents, 2 firms), Zibo in Guangdong Province (60 patents, 4 firms), Luoyang in Henan Province (55 patents, 7 firms), Guiyang in Guizhou province (38 patents, 3 firms), Xianyang in Shanxi Province (33 patents, 3 firms), Yueyang City in Hunan Province (23 patents, 1 firm).

Localization of research in these areas follows various patterns, in which past choices and resources are determinant factors. The first relates to the historical development of central state firms. The localization of large firms' research institutes and subsidiaries reflects historical choices of localization based on political, strategic, or military reasons(localization in inland areas). For instance, the localisation of seven firms in Luoyang (Henan) is explained by the fact that the city was one of the industrial base for the first 5-year plan, and part of the "third front" project, and by the persisting presence of the People's Liberation Army (Tsai, 2004, p. 181): Luoyang was chosen for its localization as it lies in a river basin surrounded by mountains, which makes it "a safe place".[1]Second, the presence of natural resources has also been determinant (coal, petroleum, nonferrous metals, etc.). In addition, localization can also be linked to the history of acquisitions of firms. Such is the case of Shandong Energy Group, a local state-ownedenterprise, that grew out of Zibo Mining, and further changed the localization of its headquarters from Zibo to Jinan, the provincial capital, but have kept facilities there. An alternative case is a state firm headquartered in Beijing, whose production base is localized: this is the case of the group IRICO, and suggests a proximity from production to research activities.

These cases illustrate that each localization has its own individual story. In addition, the fact that they file nanotechnology patents suggests they have found resources to do so. The apparent disconnection between corporate research and public research and universities raises questions about the way they access nanotechnology skills. It suggests, in particular, the crucial role of the local links.

The geographic proximity to a city with a more dynamic environment mightbe an element of explanation. This is the case of Fushun, which is close to Shenyang, or Xianyang, close to Xi'an.

Another pattern is regional specialization. In this case, firms might benefit from an

[1] The "third front" refers to an industrial development program for the western and internal provinces that started in 1964. "As the worst of the post-Leap crisis ended, Mao pushed for the construction of the "Third Front." The Third Front was a massive construction program focused on China's inland provinces… The objective was to create an entire industrial base that would provide China with strategic independence. By building factories in remote and mountainous interior regions, Mao hoped to ensure that China's industrial base would not be vulnerable to American or Soviet military pressure." (Naughton, 2007, p. 74)

ecosystem and have collaborations with a local university active in their field, even though there is not much research in the city. For instance, Fushun City (localized at about 40 kilometres of Shenyang) is home to the Liaoning University of Petroleum and Chemical Technology. We have identified two subsidiaries of large firms which do research there: Sinopec Fushun Research Institute of Petroleum, and a subsidiary of Aluminium Corp of China: Fushun Aluminun Co Ltd. While the university has applied for 10 patents (which constitutes the patenting activity of the city and remains quite limited) it is a university in the same field of specialization than Sinopec.This could explain the availability of research resources in the refining technologies. Indeed, the existence of links between institutions is further indicated by collaborative activities between them. More specifically, the existence of collaborations is further indicated by the existence of a joint venture with Liaoning Provincial People's Government, Petrochina, Sinopec and China National Offshore Oil Corporation (CNOOC).[1]

The importance of local specialization is also visible in Zibo (Shandong Province), where the historical orientation of the city towards industrial ceramics explains the patenting activity of Shandong research and design institute of industrial ceramics, and Sinoma advanced materials. The city has a history of "8500 years" in porcelain (China.org, a portal site established by the *Chinese* government), and is a cluster in ceramic(Yang and Qi, 2011).[2]

[1] China Petroleum & Chemical Corporation
[2] http://www.china.org.cn/english/2001/Mar/9542.htm Accessed on 25/10/2016

Table 8-2: Research institutes of large firms outside innovative centres

City	Firms doing research in the city	Public Research	Remarks
Fushun City	Sinopec: Sinopec Fushun Research Institute of Petroleum Aluminium Corp of China: Fushun Aluminun Co Ltd	liaoning university of petroleum and chemical technology (10 patents)	Lioaning Province, close to Shenyang Proximity to Liaoning University of Petroleum Area formerly rich in coal. "The capital of Coal"
Zibo City	Sinopec: Sinopecqilu petrochemical corporation Sinoma[1]: Shandong research and design institute of industrial ceramics &sinoma advanced materials Aluminiun Corp of China: Shandong aluminium company Shandong Energy Group: Zibo Mining	Shandonguniversity of technology (24 patents)	Shandong Province Abundant in petroleum and natural gas, and coal Industry: ceramics
Luoyang City	Sinopec: china petrochemical group Luoyang petrochemical engineering corporation &Luoyang institute of petrochemical equipment Sinosteel; Luoyang institute of refractories research of sinosteel corporation or Loyang refractory Sinoma; china luoyang float glass group co., ltd. China Shipbuilding Industry Corp: no.725 int CITIC: citic heavy machinery co ltd China Unicom: china unicom AVIC: china aviation optical-electrical technology co ltd	henan university of science and technology (14 patents)	Henan Province "Third Front" Project
Guiyang City	Aluminium Corp: Guiyang Aluminium & Magnesium design and research institute China Minmetals corp: Guizhou Minmetals Xinxing Cathay: Jihua 23537 shoe	Guizhou university (31 patents)	Provincial capital of Guizhou Province
Xianyang City	Petrochina China Shipbuilding Industry: n°12 institute Irico Group Corp: several subsidiaries	northwest a&f university (56)	Main production base for Irico Group (HQ in Beijing) Close to Xi'an
Yue yang City	Sinopec: baling petrochemical ;changling petrochemical	None	Hunan Province

Source: author

This pattern is, however, specific to state firms, and specifically to centrally state-owned firms, under the State Asset Supervision and Administration Commission (SASAC). Among firms localized in these cities, one firm only is administrated by the government of Shandong. Therefore, only state firms, and especially centrally-owned firms, are localized outside the main innovative centres, unless they originate and have their headquarters there (which is also a frequent case).

Most local and private firms set up their research centres in the city of their headquarters, or, in cities that present a more dynamic environment. This is the case of TCL, for instance. The firm originated in 1981 in Huizhou, part of the Pearl River Delta region, and that grew as a

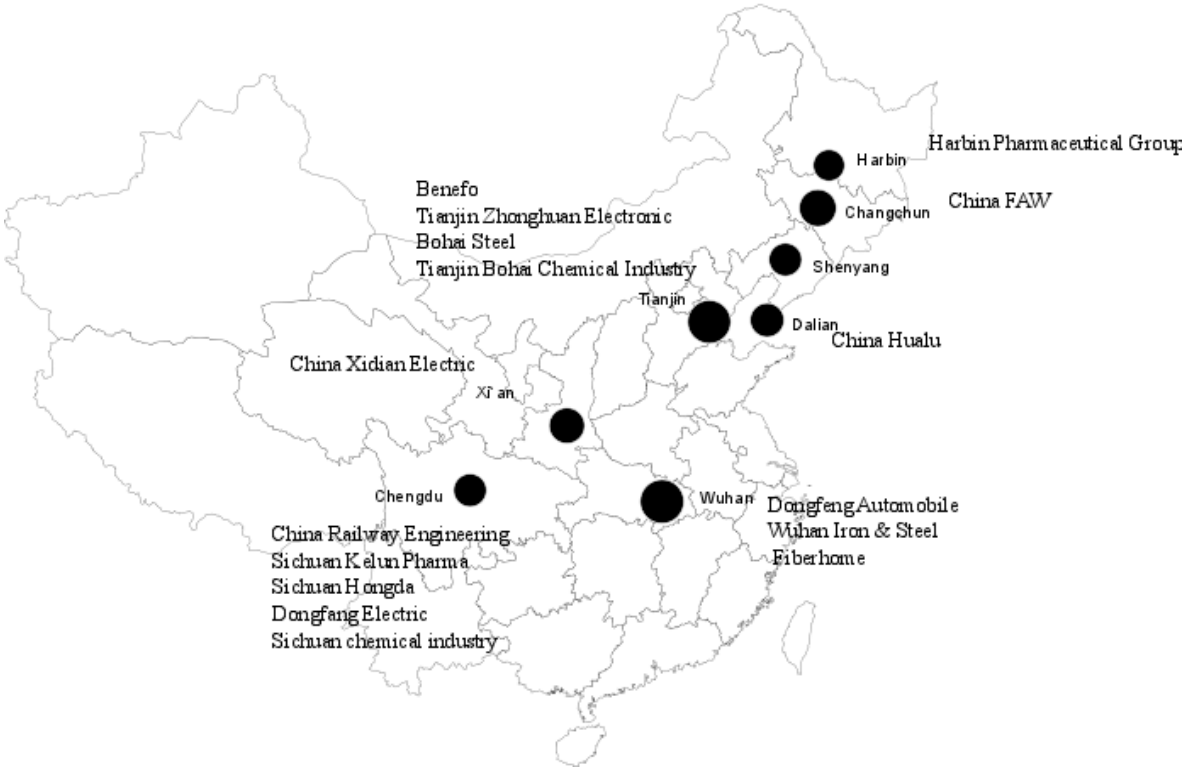
[1] China national materials group corporation (sinoma)

manufacturing company in consumer electronics, set up R&D in ten Chinese areas including Shenzhen city (where we find nanotechnology patents).

The case of these cities with few apparent public nanotechnology research seems to illustrate that being localized outside the most innovative centres can be compensated with the existence of local links, notably to local universities, and is part of a logic of specialization of the city.

2.2.3. Localization in secondary centres in public nanotechnology research

Besides the driving regions in nanotechnology, a few cities distinguish themselves by their contribution to scientific development in nanotechnology, as measured by the number of patents. These cities (Map 8-4) include Wuhan, Tianjin, Changchun, Xi'an, Chengdu, Dalian, Harbin, Shenyang. One of them, Tianjin constitutes a specific case because it is part of the Bohai Rim Area that surrounds Beijing, but others are not localized in the most active regions in nanotechnology.



Map 8-4: Secondary centres in public nanotechnology research (500 - 1000 applications)

The number of large firms that do nanotechnology research (Map 8-4: Secondary centres in public nanotechnology research (500 - 1000 applications)) shows three cities that are particularly active, as measured by the number of firms.

These cities are characterized by the co-localization of public research with a greater participation of large firms in nanotechnology patenting. This is the case in Chengdu, in Sichuan

Province, Wuhan, in Hunan Province, and Tianjin Municipality, whose characteristics are given in the table below (table 8-3).

Interestingly, this refers to three different historical and geographic situations: we mentioned Tianjin in the close environment of Beijing. The second one, Wuhan is an important second-tier city, that has been a historically secondary economic centre, and is characterized by the presence of several universities (3 universities have filed more than 100 patent applications). Finally, Chengdu is in a western region of China, Sichuan. The fact that 5 large firms have nanotechnology research in Chengdu there suggests the creation, even if it is limited in number, of a cluster of innovative activities. Indeed, Chengdu, the provincial capital (since 1994) is one of the Western city that was paid continuousattention to in the perspective of rebalancing the country's economic disparities towards the western region(Qin, 2015).

The existence of these two cases illustrates the possibility for firms to develop outside the main centres, but in proportions that remain very modest. We could, to some extent, add Xi'an in this category. While Xi'an houses one firm with nanotechnology research, it is close to Xianyang where three firms do nanotechnology research.

Table 8-3: Profiles of secondary centres in nanotechnology research

Geographic Areas	**Firms**	**Public Research (patents applications by universities and research institutions)**
Wuhan (Hubei Province)	8 headquarters – 3 with nanotechnology patents	Top institutions: Wuhan University of technology (241), Wuhan University (235), Huazhong University of Science and Technology (143) 986 patent applications in total
Tianjin Municipality	7 headquarters – 4 firms with nanotechnology	Top institutions: Tianjin University (464); Nankai University (242) 960 patent applications in total
Chengdu (Sichuan Province)	8 headquarters – 6 firms with nanotechnology	Top institutions: Sichuan University (317) 559 patent applications in total

Source: author

In contrast, in other cities in that category, the absence of patent applications by large firms reflects the lack of absorptive capacity and/or lack of incentives by firms to engage in emerging technologies, at least during the period considered. This is the case of cities such as Shenyang and to some lesser extents, Changchun, Dalian, Harbin.

2.3. Mobilizing existing research infrastructures within firms

As mentioned in the introduction of this chapter, we consider two dimensions to be central to understand contemporary dynamics linked to nanotechnology research by large firms: the firms' localisation close to public research centres, and the fact that China has been engaged in science and technologies since the 1950s.

This second aspect, the structure of the previous research system is visible in the patent applications of large firms in the 2000s. Indeed, the contribution of formerly public research institutes to nanotechnology research on behalf of large firms questions the impact they have had on the way firms structure their research activities. The trend is considerable. Between 2001 and 2008, 68 of these research institutes and 17 design and research institutes applied for nanotechnology patents, accounting for about one-third of nanotechnology patenting activities (31 percent).

This is associated with the weight of centrally state-owned firms in the total of patent applications (see p. 150). The former research structure acts as a major source of research for central state firms. Almost half of centrally state-owned enterprise (44 percent) that do research on nanotechnology rely, at least partly, on these facilities which represent 42 patents of their patent applications. Indeed, the activity of these research institutes explains the contribution of centrally state-owned firms to the total number of patents in nanotechnology. It shows that the considerable number of nanotechnologypatents filed by central state firms is not due to these large firms' size, but to their access to productive (in terms of patents) research facilities. This is, for example, the case of Sinopec, which does a large proportion of its nanotechnology research in a limited number of institutes (see p. 191). These are large and comprehensive research centres ranging from several hundreds to thousands of persons, with about 200 Ph.D. in the largest ones that we could identify. They provide skills, resources and infrastructures for doing research on nanotechnology, and have privileged access to governmental spending.

As we will observe later, the role of research institutes is not limited to centrally state-owned firms, however. Some locally state-owned firms and private firmshave also integrated them into their organization, but their contribution to the total of nanotechnology patents is modest. In our data, research institutes respectively represent 7 percent and 2 percent of nanotechnology patenting by locally state-owned firms and by private firms.

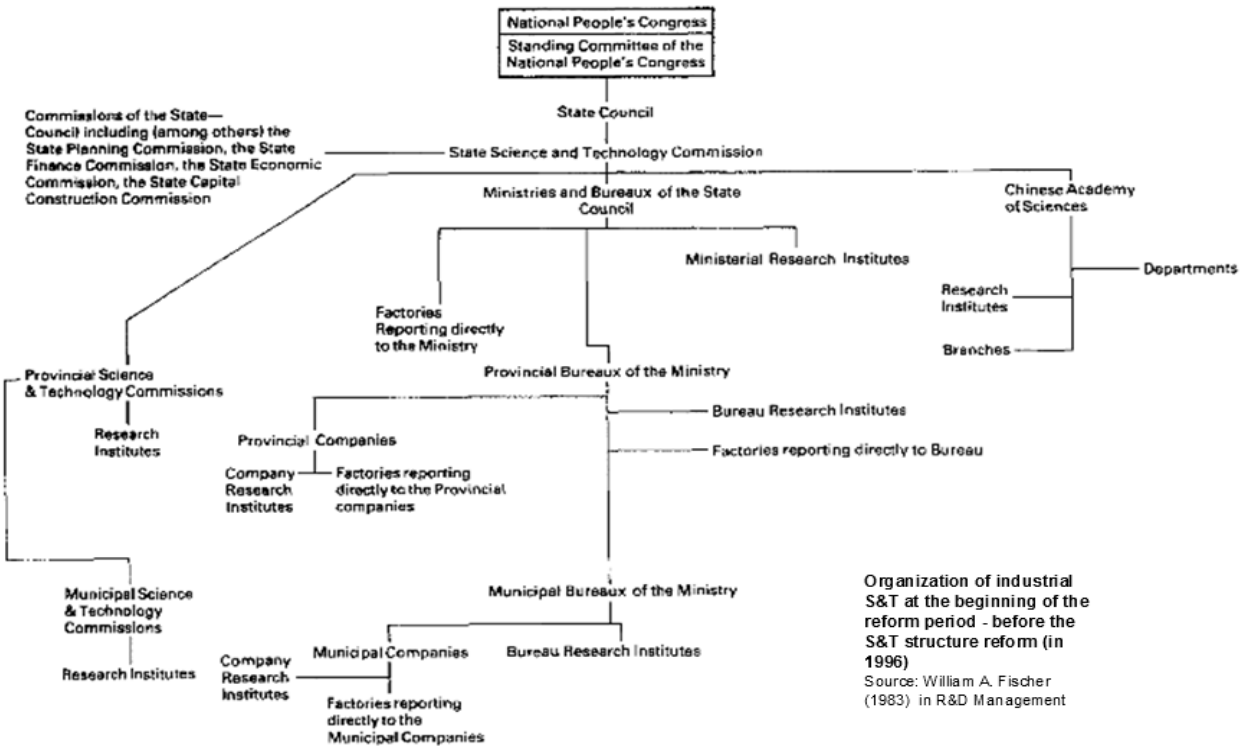
What is the history of these institutes? They partly inherit their current organizational forms from the Science &Technology structure established under Mao and restructured in the 1990s (Tang, 2003). According to Liu & White, in the 1950s, during the first plan, the country created more than 400 research units first focused on reversed engineering and that then evolved into three groups: one with more emphasis on basic research under the Chinese Academy of Science, one that aimed at training and research within universities and, finally, industry-specific institutes for the development of production technologies(Liu and White, 2001, p. 1097). The organizational structure of the production and research system is reproduced below (Figure 8-1). The figure reproduces the formal organization as it existed in the 1980s, and is similar in form to what was

prevalent during the previous period.

We shall highlight two elements. The first one is that research institutes are attached at different governmental levels, and to different functions (basic or applied research). Some were research units under ministries or alike (national research institutes), under provincial and municipal bureaus, or associated with factories within state-owned firms. The dominant model was that of a mission oriented lab. Naughton describes them in these terms: "*Leaders in China set a few key tasks, and planners then coordinated flexible multidisciplinary and multiskilled research groups—with plenty of money—to pursue those key goals"* (Naughton, 2007, p. 356).

Second, research institutes have gone through important changes, but the modality and breadth of changes have varied. China's formal S&T system remained unchanged until the end of the 1990s where there was a large movement of restructuration of firms and of institutes, a trend which concerned both institutes associated with the production system, and the institutes of the Chinese Academy of Sciences (Tang, 2003). The destiny of these research institutes has been variable. A large proportion of research institutes have been transformed into firms, or have become part of larger firms, and only a limited number remained separated research institutes (Tang, 2003). To many extents, each institute has gone through a series of change, which might have been accompanied by the renaming of the organization and its incorporation.

Figure 8-1: Organization of former S&T system borrowed to Fischer (Fischer, 1983)



This legacy structures the way large Chinese firms do research in several ways. A first notable way has been through the incorporation of the largest institutes into the structure of state-owned firms. For instance, Aviation Industry of China (AVIC) uses as one of its core research institute the *Beijing institute of aeronautical materials*. This institute was founded in 1956 and specialized in advanced materials (13 patents). Now formally part of AVIC, it maintains strong direct links with governmental research projects. The institute houses "nationalkey laboratories," a national engineering laboratory, and local laboratories, and can confer doctoral degrees.[1] It has set up companies dedicated to being the "main platforms" for transferring research results into production, under the umbrella of Baimtec Co Ltd.. This is particularly the case of ministry-level institutes. In addition, provincial formerly public research institutes have also influenced firms in various ways. Some former research institutes became firms, for instance, before being themselves acquired by a firm.

2.4. Conclusion

We have presented two elements that impact and define the modalities of engagement in research by large firms. These elements encompass two dimensions. The first one is the localization of firms in environments that provide them with resources to do research. We focused on the presence of public nanotechnology research, in universities and in research institutes, whose major impact is to be associated with the presence of trained personnel. According to whether firms are localized in firms with plenty or scarce resources, it is likely that their modality of research will vary. A second dimension we introduced is the legacy of the prior research structures. These have an impact on the way firms do research in two ways. First, in some cases, they have provided resources for doing research. Large formerly public research institutes integrated into large firms play this role. They have, however, a more subtle influence, due to the fact that they influence modern organizational structures. This was particularly the case when these research institutes were re-organized and reformed.

We treated the question of the firms' localisation separately from the question of the influence of the former research structure. It is notable, however, that these two dimensions are intimately linked. Both dimensions, the presence of universities and public research the research infrastructures share the same legacy.

[1] http://www.biam.ac.cn/en/tabid/279/Default.aspx Accessed on 15/10/2016

3. Integration of research into the firms' activities

3.1. Introduction: the challenge of integrating research

The two preceding elements might provide firms with a favourable environment to do research. However, research activities do not directly lead to innovation, and the organizational dimension is central. The capacity to use and mobilize research results within firms is a determinant factor.While the presence of the former research institute might constitute a resource, it is also a challenge to integrate it in the scope of firm-oriented innovated activities. As noted by Liu & White, their original function was restricted and operated in a system where "research (including all creative or innovative activity) was conducted by research institutes, manufacturing by factories, and distribution by distributors" (Liu and White, 2001, p. 1093). The present section pays attention to the capacity of firms to integrate research results.

3.2. Geographic dispersion of nanotechnology research among firms

What can we tell about the way firms integrate research? This relates to the organization of research in the firm, and the circulation of knowledge between entities. One first way to answer this question lies in the localisations of research activities by firms, that we observe at the city-level.[1] Where do firms localize their research centres? Indeed, the geographic scope of operations of large firms varies and includes the national, regional or local levels. Some firms operate in different provinces, notably centrally state-owned firms; others remain in a narrower geographic area and operate within one region or province. In the third case, firms are active in localized geographic contexts. Local and private firms tend to have their main operations in a limited number of cities.

This, of course, relates to China's size. Even though it is a well-known fact, it shall be reminded that a land area of 9.4 million square kilometers makes the country the second largest one in the world, with long distances between cities: Shanghai, for example, is localized 1200 kilometers from Beijing. Transport takes time, even with high-speed trains, and is costly.

[1]Looking at the geographic distribution at the city level, as we do, presents limitations. The first one is that two institutions localized in the same city might be in different parts of the city. The co-location of public institutions and firms does not mean the existence of interactions. Some authors put in evidence a geographic disconnection between large firms localized on the West side of Beijing, and the public institutions mostly in the east part of the city, arguing for a lack of connection between them (Motoyama et al., 2014). Indeed, in many cities, research is localized in determined sub-areas in the cities (Zhongguancun in Beijing, Haidian more generally; and Yangpu and Minhang in Shanghai, etc.). (It is noteworthy to observe that the disconnection they observe can also be linked to the geographic dispersion within firms. In other words, while the headquarters of some large firms might be far from knowledge centres, their research institutes are generally localized close to universities, as in the case for Sinopec. All research institutes localized in Beijing are in the Haidian district, which is also the university area, while their headquarters are on the other side of the city. Conversely, localization in different cities is not equal to an absence of interactions even if it strongly constrains them and, similarly, geographical proximity does not necessarily entail them, even if it tends to favour them.

Consequently, two subsidiaries operating in two provinces might be separated by a few thousand kilometres.

The distribution of nanotechnology patents at the firm level across different locations gives an (imperfect) image of the existence of several "competence centres" in the territory.[1]The distribution of these researchcentres among several localizations is characterized by two dimensions: the repartition of nanotechnology patenting activities in several localizations, and the dispersion or concentration of research around one centre, generally the corporate headquarters. On the basis of these two dimensions, we observe two dominant trends about how nanotechnology research is distributed (Table 8-4):

First, concentration of nanotechnology research is dominant (84 percent of firms in this situation): The concentration of nanotechnology research into one unique or into one dominant localization is the prevalent model among large firms, including some very largefirms. In most cases, this centre is also the unique one. 58 percent of firms only applied for patents in one city. This includes firms whose R&D is centralized (Haier in Qingdao, BOE in Beijing, Baotou Steel in Baotou, Inner Mongolia). It also includes firms whose R&D is organized around several R&D centres, but with one unique localization with nanotechnology patents (Weichai Power). Local firms are more likely than both centrally state-owned firms and private firms to be localized in one unique place, which is the jurisdiction of the local government. Indeed, 79 percent of locally state-owned firms do nanotechnology research in one localization, which is a higher proportion than for private firms (59 percent of firms in one unique localization) while they are comparable in size. This is true for locally state-owned firms engaged in resource-based industry (78 percent), but also for locally state-owned firms that operate in specialised industrials sector (86 percent).

Second, there is a relatively low dispersion of nanotechnology research within firms (42 percent of firms concerned by the phenomena): Many firms have severalresearch centres, but even

[1]Caution is required for patents applications filed at the firms' headquarters. The information contained on subsidiaries is more conclusive, because there is less reason for a subsidiary to apply on behalf of other departments or subsidiaries. Furthermore, the administrative process is as follows for many centrally state-owned firms is as follows: normally, the local subsidiary and the parent company jointly file patent applications. For instance, an application (CN200810225534) is filed jointly by China National Offshore Oil Corp and Cnooc Tianjin chemical research & design institute. Obviously, the first applicant is the parent company, but this means that research teams belong to the research & design institute in Tianjin. Otherwise, the institute would not appear in the patent application. In this case, we consider a unique localization, that of the subsidiary as the entity where research is done, and discard the headquarters as "administrative" applicants. In this particular example (but this is not always the case) , both institutions, are localized in the same city, Tianjin Municipality, but they do not share the same postal addresses,but this is not always the case.

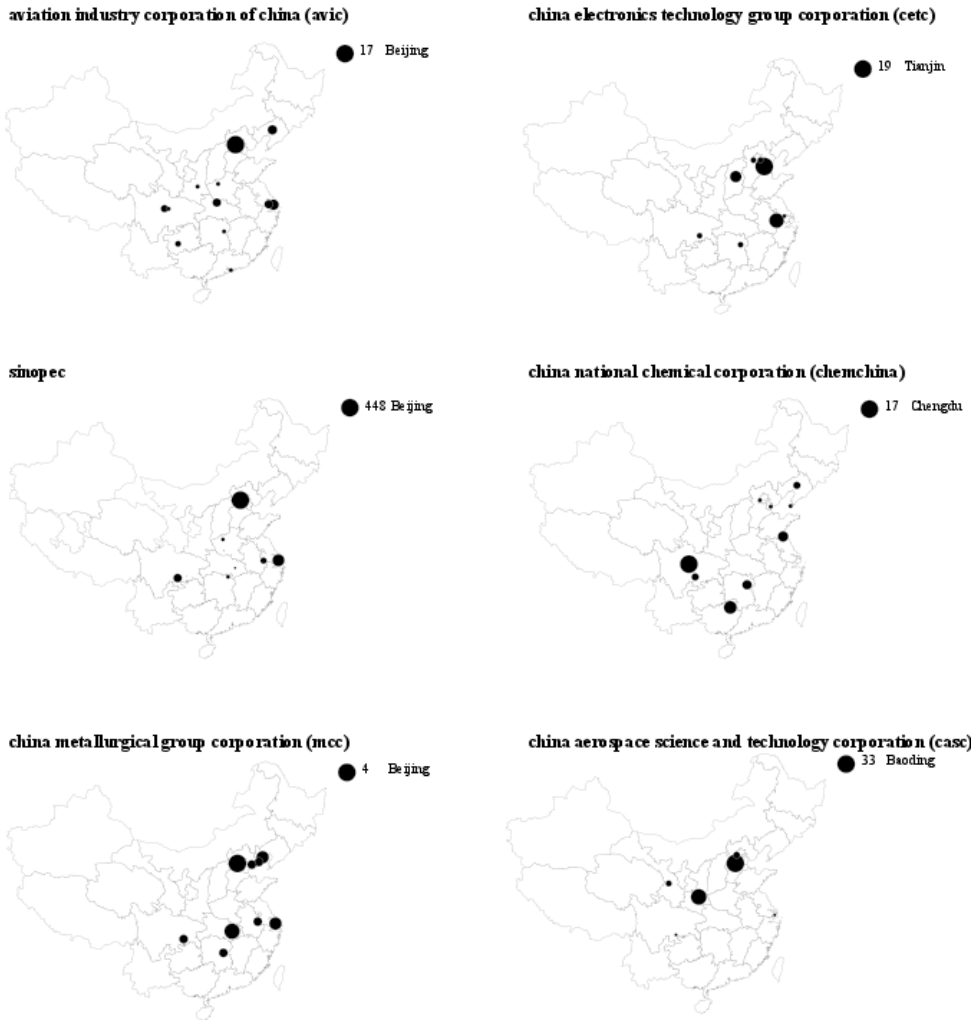
The total number of firms and patents that are concerned by that pattern is not negligible: it represents 763 patent applications and 22 groups: Sinopec (664, 42 percent of patents have been jointly applied between the headquarters and a subsidiary), Haier (22, 43 percent), PetroChina (20), CNOOC (17) and firms with less than 10 patents. This reflects the administrative centralization that occurs in firms. A solution in one other context could be to look at the address of individual inventions. These data are however not available. Similar cautions should be taken for subsidiaries themselves an entity with several localizations.

in this case,theabsence of a dominant centre is rare and concerns 16 percent of firms. These are mostly central state owned firms. Many centrally state-owned firms have a nationaldimension*i.e.* they have research in several provinces, which explains greater dispersion of their competence centres. The largest firms, among which Sinopec, AVIC, Petrochina, or Aluminium Corp, do nanotechnology research through their subsidiaries in several provinces (map 7-5). This category represents most of the firms with relatively balanced nanotechnology in several centres (20 firms out of the 25 firms). It is, however, still possible to identify to identify the core research institutes.

Table 8-4: Repartition of the model of nanotechnology distribution

Distribution	**Dispersion**	**Competence centres**	**Number of Firms**	**Total of patents**	**Examples of firms**
Distributed around several competence centres (42 percent)	Dispersed	Balanced with other centres (the most prolific centre represents between 25 percent - 49 percent of the total patent applications)	25 (16 percent)	1377	China electronics technology group
	Concentrated around one unique or dominant localisation (84 percent)	Dominant localisation (>50 percent)	41 (26 percent)	1702	Fosun TCL Huawei ZTE
Centralized in one unique localisation		Unique localisation (100 percent)	91 (58 percent)	630	Chery, Hongdou, Harbin Pharma

Source: author



Map 8-5: Geographic repartition of nanotechnology research of very large state firms

3.2.1. From geographic proximity to organizational integration of nanotechnology research

Having nanotechnology research in different localizations reflects various underlying realities. Several types of firms can be in that situation. It can be a business group organized in subsidiaries that operate independently, with a subsidiary more active in nanotechnology than the others, or a firm with an R&Dorganized around a network of several competence centres in China, which involves some degree of coordination and exchange between them. These two models refer to very different types of firms. The degree in which research teams and subsidiaries in a firm work together and interact with one another can be characterized as their "space compactness," which was showed to have an impact on the capacity of firms to catch-up with their technological capabilities (Nam, 2015). Compact organizational space has two dimensions: geographic proximity and organizational proximity (ibid).

3.2.2. Integration of research: organizational aspects of China's nanotechnology research

To some extent, geographic proximity appears easier to characterize than organizational proximity. What can we tell about the degree of integration of Chinese firms on the organizational side? The composition of a research team is partly visible in the technological inventions they patent. Each invention refers to one or more technological fields. The International Patent Classification (IPC) was established by the Strasbourg Agreement in 1971 and provides for a hierarchical system of classification of the different areas of technology to which patents pertain.[1] At the firm level, we might consider that the patents taken by a firm give indications on the orientation of its research, and, in turn, on the composition of its teams.[2] The bigger the number of areas of technology a patent pertains to, the more it refers to general and interdisciplinary knowledge. In such configuration, it is more likely that the research team gathers people from different backgrounds (Avenel et al., 2007).

The implication at the organizational level is that the firm is more "integrated". By integration, we refer to what we previously mentioned, *i.e.* the circulation of knowledge among divisions and departments. We measure two dimensions in the patenting profile of firms: the diversity of the technological base, measuring the breadth of the firm's nanotechnology R&D activities, *i.e.* their degree of spread over many fields, and the specialization of each patent.[3]These indicators have limitations, but they provide a point of comparison between integration of large Chinese firms, and that of firms in other countries in nanotechnology.

Indeed, the results we obtain (Table 8-5) suggest lesser integration of nanotechnology research in Chinese large firms, on average, which is consistent with their "latecomer status".

Prior research has shown that global firms tend to develop a specialized and integrated

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[1] See http://www.wipo.int/classifications/ipc/en/

[2]For instance, Petrochina's patents in nanotechnology refer to the following technological fields:*Processes or means e.g. batteries for the direct conversion of chemical energy into electrical energy (22 percent) Devices or arrangements, the optical operation of which is modified by changing the optical properties of the medium of the devices or arrangements of the intensity, colour, phase, polarisation or direction of light e.g. switching, gating, modulating or demodulating; frequency-changing optics; non-linear optics: optical logic elements; optical analogue/digital converters (14 percent) and Non-metallic elements (11 percent*). This shows a different technological base than Huawei Technologies, which is more concentrated (one technological field represents 74 percent of IPC), and in other technological fields: *Devices or arrangements, the optical operation of which is modified by changing the optical properties of the medium of the devices or arrangements of the intensity, colour, phase, polarisation or direction of light e.g. switching, gating, modulating or demodulating; frequency-changing optics; non-linear optics: optical logic elements; optical analogue/digital converters (74 percent) Telephonic communication (9 percent) Transmission of digital information (47 percent), Transmission (11 percent), Selecting (10* percent).

[3]To measure the diversity of the technology base of a firm, we follow the authors and use a normalized Herfindahl-Hirschman Index (commonly used to measure market concentration) to measure the concentration in technology areas - Thus we calculate the sum of the squares of the proportion of each IPC of the patent applications within each firm -. An index of 1 indicating a maximum concentration in the number of technological fields, we take 1 minus the Herfindahl index as the measure of diversity: the greater the number the greater the diversity.

knowledge in nanotechnology (Avenel et al., 2007). Their knowledge base covers a broad scope of technological areas. However, each patent is specialized, with a limited number of fields. This reflects a collection of independent scientific and technological fields and the integration of knowledge at the corporate level. We do not find similar patterns in large Chinese firms though. Patents are on average less specialized - each patent refers to more than 3 technological areas, against 2 for global firms. At the firm level, patents are also less concentrated towards technological fields, which means a greater diversity of their technological knowledge base in nanotechnology.

These results can be interpreted by the fact, as above mentioned, that nanotechnology research is "performed by teams grouping together researchers and engineers from widely different backgrounds" (ibid, p.865) but that they are not integrated at the firm level. A low integration of knowledge at the firm level suggests the absence of circulation and interactions between research centres.

This would reflect that the repartition in different localizations of nanotechnology research is not associated with a network of research units, but rather with research by parallel teams. A further element goes in that sense. Table 8-5 indicates that there are no striking differences regarding the two indicators between types of firms. The factor that seems to impact on the degree of integration is the fact that nanotechnology patenting is in one unique location (0,76). Such interpretation has to be taken with caution. This would indicate that the existence of dispersed centres is not associated with an integrated strategy of research, but with parallel research activities. We also find that the diversity increases with the intensity of patent applications. This suggests that the increase in patents does not mean the consolidation of the firms' existing technological areas.

Table 8-5: Profile of the technological bases of large Chinese firms

	Measure of diversity of the firms' technological base (average)	**Patent specialization (average)**
Large Chinese firms	*0,83*	*3,19*
Among which		
Centrally state-owned firms	0,88	3,36
Locally state-owned firms	0,79	2,90
Private Firms	0,83	3,31
Among which		
Balanced with other centres	0,93	3,34
Slightly dominant localization	0,92	3,73
Dominant localization	0,95	3,15
Unique Localization	0,76	3,02
Among which		
Important nano patenting activity >15 p	0,93	3,32
Significant (> 4)	0,92	3,21
Limited (2-4)	0,79	3,34
Low (1)	0,57	2,75

Global norm (data Avenel & al – 2007)	**0,51***	**2,08**

Source: author's calculations

3.3. Conclusion of the first two sections

The way firms have emerged conditions their access to nanotechnology research. We introduced two major dimensions: the role of their localisation in the Chinese territory; and the influence of the past research structures. In addition, recognizing that a major difficulty was to integrate research results in the scope of the firms' activities, we looked at two indicators of the degree of integration of research within firms, and we proposed to measure the degree of integration regarding two dimensions: the geographic dispersion of nanotechnology research, and its content (using indicators based on the technological fields to which patents pertain). These two measures, though difficult to interpret, give indications, and allow further characterisation of the different modalities of integration of research into the large firms.

We see that nanotechnology research by large Chinese firms tends to be concentrated around a dominant localization within firms, but that this is associated in many cases with the existence of secondary localisations. This is however not associated with the existence of integrated research at the firm level. Another crucial element is the role of local roots and histories of firms.

4. Description of the profiles of nanotechnology research among firms

4.1. Introduction

As we have introduced at the beginning of the chapter, our objective is to look at the different modes associated with nanotechnology research by large firms. For that purpose, we propose to categorize large Chinese firms according to their profiles. We describe these alternative profiles of engagement to research in this section, that are gathered into four large categories: - large business groups (including large sectorial firmsorganized around parallel entities, 'localized' firms, and conglomerates), - the global industrial players, - the specialized industrial firms, and - firms in resource-based industries. General characteristics of each profile (Table 8-6 p. 190) illustrate that the ways they do research are not uniquely linked to the nature of the shareholders, and to the industry. More specifically, these pathways combine differently four main dimensions: the firms' ownership, their historical development, their industries and their degree of specialization.

Table 8-6: Profile of firms according to their engagement in nanotechnology research

Categories				**Patent Indicators**				**Firms' features**	
Type	**Examples**	**Description**		**Dominant Number of Patents**	**Geographic scope of nano patents**	**Repartition – weight most important localization****		**Dominant ownership type**	**Firm's size***
Large 'sectorial 'firms (41)	Large sectorial firm organized around parallel business entities (Sinopec)	No integration of R&D		Important or Significant	National or Local	25 percent < ~ < 75 percent		Central state	Very Large *(>= 100 000 employees)*
	Localized central state-owned firms (Baosteel)	Limited integration of R&D		Important or Significant	Local	> 50 percent (slightly dominant localization)		Central state	Large & Very Large *(>= 34 000)*
Conglomerate (15)	Fosun	Integration of R&D in some subsidiaries		Low to significant	National or Regional	> 50 percent (slightly dominant localization)		Central state, Private	Large & very large *(>= 34 000)*
Global industrial firms (20)	Huawei	Integrated & international R&D network withdominant localization		Limited to important	Local	>75 percent (dominant)		Local state, private	Large & very large *(>= 34 000)*
Industrial specialized firms (49)	Yurun Food	Upgrading strategy using local resources (university, research institutes)		Low or Limited	Local	> 50 percent (slightly dominant localization)		Local state, private firms	Small and Medium *(< 34 000)*
	Shanghai Huayi	Integrated R&D Leverage local resources Domestic R&D		Significant	Local	> 50 percent (slightly dominant localization)		Local state, private firm	Small and Medium *(< 34 000)*
Firms in resource-basedindustries (32)	Hebei Iron & Steel	Upgrading strategy through local resources		Limited or Significant	Local	> 50 percent (slightly dominant localization)		Local state	Medium, large *(16 000 – 100 000)*

*Calculated according to data distribution (quartile)** For firms with nano research at more than 2 localizations

4.2. Large business groups[1]

4.2.1. Large sectorial firm organized around parallel business entities

Large business groups are divided into three sub-categories.

The first profile we introduce 'Large sectorial firm organized around parallel business entities' gathers centrally state-owned firms that mostly come from the restructuration of the production system. These firms operate on a national scale, in different provinces, and do research across China. Keeping in mind that the average Chinese province is about 40 million people, we find that these firms have research institutes with nanotechnology patents in 2 to 12 different provinces.

Large sectorial firms appear among the largest applicants. However, when looking more precisely at where research is done within firms, we see that most of the research in nanotechnology is done in research institutes that are not integrated in the firm.

i. The case of Sinopec: doing research in parallel institutes

The oil producer Sinopec is one characteristic example. Sinopec can hardly be considered an innovative firm. However, its number of patent applications in nanotechnology approaches one thousand between 2001 and 2008, which makes it the largest applicant of the entire group.

The firm Sinopec does its core research in its research institutes, which are organized by specialized scientific and technological fields. The largest contributors in patent applications are its research institutes in Beijing: *Research Institute of Petroleum Processin*g, and in Shanghai; the *Shanghai research institute of petrochemical technology*. The two institutes constitute two of its core centres in nanotechnology. They used to be ministry-level institutes built in the late 1950s. The Research Institute of Petroleum Processing was created

[1] Large sectorial groups (excluding conglomerates)
Sinopec ; aluminium corporation of china; petrochina ; Datang Telecom Technology & Industry Group ; baosteel group corporation ; pangang group ; china electronics technology group corporation; china aerospace science and technology corporation Angang group ; china national building materials group corporation ; aviation industry corporation of china ; china national chemical corporation; China National Tobacco Corporation ; china national offshore oil corporation ; china shipbuilding industrial corp ;china metallurgical group corporation (mcc) ; state grid corporation of china ; china north industries group corporation ; china national materials group corporation ; sinochem corporation ; sinosteel corp ; china state shipbuilding corporation; china national nuclear corporation ; china national machinery industry corporation; china minmetals corporation ; china cnr corporation limited ; china communications construction company ; China Aerospace Science and Industry Corporation ; China National Coal Group Corporation ; china southern power grid ; China Electronics Corporation ; china national salt industry corp ; China state construction engineering corporation ; CSR Corp ; China National Chemical Engineering Corp ; china telecommunications corporation ; Shenhua Group ; china mobile communications corp ; china national gold group corporation ; China Railway Construction Corporation ; china unicom (group) co ltd ;

in 1956 and is a large R&D organization focused on refining technologies, with a growing focus on new alternative fuel and energy sources. Based in Beijing, at the time of writing, it has 17 research departments. employing 1299 people, of which 221 have Ph.D. degrees and 256 master degrees. The second one, the Shanghai Research Institute of Petrochemical Technology (SRIPT) was created in 1960 and specializes in petrochemicals, also for refining technologies. It includes research facilities in different localizations (Nanjing, Yueyang, Tianjin, Yizheng, and Chongqing).

Beijing Research Institute of Petroleum Processing (RIPP) and Shanghai Research Institute of Petrochemical Technology (RIPT), with respectively 284 and 157 patent applications, contribute the most to nanotechnology research. Other research institutes are also active though. Sinopec Fushun research institute of petroleum and petrochemicals was created in 1953. Fushun city, close to Shenyang in Liaoning Province, is rich in natural resources and originally oriented on coal mining, until the Fushun Government changed its strategy to focus on petroleum processing, and on paper making. The institute is focused on refining techniques such as hydro-cracking.[1] We should also mention the Beijing Research Institute of Chemical Industry, created in 1958, for which we find 86 patent applications in nanotechnology between 2001 and 2008.[2] In 2010, it set up three branches: Qilu Branch, Yangzi Branch, and Yanshan Resin Branch.[3]

Altogether, they constitute a large proportion of Sinopec's patents. Reading the description of their activities – by the research institutes and by Sinopec themselves – one understands that they are considered as "independent" entities on both the administrative and operational sides. The relation of research institutes to Sinopec, therefore, does not reflect an integrated research structure (which would consist of research activities linked to the production system of the group), but rather as a technology provider to the group (see descriptions next page p.191). They oftenfocus on process innovations and operate through sales. They provide technologies that are directly commercialized, and their scope is not limited torefining subsidiaries of Sinopec Their clients include Chinese refining enterprises and plants as well as foreign units. This explains for example the fact that Shanghai Research

[1] There are several techniques to refine petroleum by cracking the molecules (i.e. to break the molecules into simpler molecules): Fluid catalytic cracking produces a high yield of petrol and LPG, while hydrocracking is a major source of jet fuel, Diesel fuel, naphtha, and again yields LPG.

[2] According to Sinopec's website, "t*he history can be traced to the August of 1922 when the famous patriotic industrialist Mr. Fan Xudong and the famous scientist Dr. Hou Debang founded the Huanghai Research Institute of Chemical Industry in Tanggu, Tianjin."* It is actually a privately invested research institute at that time (Morgan, 2004)

[3] On the basis of the existing structure, which means that previous research facilities at these localizations were integrated within the scope of BRICI

Institute of Petroleum Technology is part of the "going out" strategy of the firm.

They play a role in the improvement of the processes of Sinopec through the sales of new techniques, but as they have external customers, the respective advantage that it gives to Sinopec is difficult to measure.[1]

[1]Similar patterns are observed at the lower level of the pyramidal structure of the group. We can take the example of the Research Institute of Sinopec Nanjing Chemical Industrial Group. Specialized on methanol synthesis catalysis, the institute's activities are not directly related to the refining businesses. It originates in the Chemical Industrial Research Institute of the Ministry of Chemical Industry, created in Nanjing in 1958, and holds 25 nanotechnology patent applications.

The **BeijingResearch Institute of Petroleum Processing** *"has now successfully developed and commercialized many technologies, such as the production of clean gasoline and diesel fuels, deep processing of heavy crudes, increasing the yield of light oil, the processing of sour crudes, high total acid number (TAN) crudes, heavy crude and refractory crudes. .... These technologies have state proprietary intellectual property and meet the requirement of Chinese refining units, which made Chinese oil refining enterprises upgrade gasoline in a comparatively short period with less investment and lower cost, and contributed a remarkable economic and social benefits as well while confronting great challenges." (Sinopec Website*[1]*)*

Shanghai Research Institute of Petrochemical Technology: *"Now, a portfolio of the advanced petrochemicals technologies have been developed and commercialized by SRIPT […]. Both the catalysts and technology packages developed by SRIPT... are commercially licensed to and used in the large and medium scale plants at home and abroad."*[2]

Sinopec Fushun research institute of petroleum and petrochemicals *"has developed several hydrocracking processes […] FRIPP also has developed high-grade road asphalt, emulsified asphalt and high quality construction asphalt production technologies and over 100 kinds of specialty waxes used in, electronics, rubber, agriculture, machinery, automobile, daily chemistry etc., part of them have been applied worldwide. […] FRIPP has developed series of technologies for treating waste gas, wastewater and waste residue in*oil fields*and petrochemical plants*…"[3]

[1] http://english.sinopec.com/about_sinopec/subsidiaries/research_institutions/20080326/3088.shtml Accessed on 15/10/2016

[2] http://english.sinopec.com/about_sinopec/subsidiaries/research_institutions/20080326/3092.shtml Accessed on 15/10/2016

[3] http://english.sinopec.com/about_sinopec/subsidiaries/research_institutions/20080326/3091.shtml Accessed on 15/10/2016

ii. A case not specific to resource-based industries

To what extent these ways of organizing research is specific to large national resource firms? Indeed, the industrial specialization might explain part of the organization around independent research institutes. Because research aims at improving the refining / exploitation process, strong links are not necessary between production and research. Indeed, we observe that we tend to find the same thing in the case of aluminium.

The core activities of Aluminium Corp of China consist of extracting aluminumoxide and processing it to produce aluminum, thus encompassing little added-value activities. Nanotechnology patenting is observed in this firm's institutes, among which one fourth (23 percent) are localized within two research institutes, with respectively 40 and 35 patents. The first, the Guiyang Aluminium Magnesium Design & Research Institute was established in 1958. It was successively placed under the administration of the Ministry of Metallurgical Industry (1958, 1983), under the China Non-ferrous Metal Industry Corporation (1983 – 1998), under the State Non-Ferrous Metal Industry Bureau (1998, 2000) and finally Guizhou Provincial People 's Government (2000 – 2001). It was transferred to Aluminium Corporation of China (2001 – 2003), and located into China Aluminium International Engineering since 2003. It is focused on light-metal smelting design &research and acts as a provider of technology for Aluminium Corp and other international aluminium companies. In particular, it maintains collaborations with *"aluminum companies from USA, Japan, UK, Germany and etc. And GAMI's proprietary technology has been applied in some countries such as India, Kazakhstan, Brazil, Malaysia, etc. to win the very high technical reputation*" (China Aluminium International Engineering Corporation Website*)*.[1]Shenyang Aluminium & Magnesium Engineering & Research Institute exhibits a similar history and profile: founded in 1951, it was put under China Aluminium Industry Group in 1999.[2]

This modality of organization might be extended towards other industrial sectors, as is shown by two cases: one in a traditional industry, chemistry, by the company Sinochem, and the other in high-tech industries, illustrated by the case of the China Electronics Technology Group.

Sinochem is a large chemical manufacturer. Its level of patenting activities is significant but very modest regarding its specialization. The firm applied for 14 patents

[1] http://www.chalieco.in/index.php?m=content&c=index&a=show&catid=63&id=57 Accessed on 15/10/2016

[2] The predecessor of SAMI was the Civil Construction Engineering Company of Ministry of Industry of Northeast People's Govement. It was created in 1951 in Harbin.

between 2000 and 2008, at the level of its research institutes or of its subsidiaries. We identify research institutes as applicants in about one-third of patent applications (36 percent).

One of them, the Shenyang Research Institute of Chemical Industry, established in 1949, became an independent technological firm under the central government in 1999. It was reorganized in 2007 as a subsidiary of Sinochem Group. The institute includes an Engineering Research centre, state key laboratories, is accredited to give Master degrees, and localizes its activities at the light of public intervention: "*During the past 60 years, SYRICI has gained glorious success. ... Additionally, the institute has completed a remarkable 149 National Key Science and Technology Projects during the 6th to 11th "Five-year's Plan" and set up more than 1000 national and industrial standards" (SYRICI*institute website).[1].The research institute is engaged in commercialization and technology transfer through specialized firms. It set up three subsidiaries which aim for technology transfer in their respective fields of competence, as well as commercial developments.[2] In addition, two such firms indicate exporting chemical products abroad, which suggest that they oversee technical and commercial development based on the research results of the institute.

We find example in other industries as well. China Electronics Technology Group Corporation is a state firm in the electronic and information industry, engaged in both civil and military sides, with important research on nanotechnology, through several subsidiaries. The group, headquartered in Beijing, was created in 1962, and operates in the electronic industry (control system, radar products, electronic warfare and intelligence system, communication systems and equipment, anti-terrorism and security products, electronic optic devices, test equipment, electronic materials and components, electronic processing equipment, computer equipment, and radio and television equipment – source: Bloomberg).

We find 12 research institutes localized in 8 different cities with nanotechnology patents. This reflects a particular organization: The firm appears to be a collection of independent research institutes, each focused on developing different technologies. These institutes represent 94 percent of patent applications by the group. It appears that the formal organization has remained the same since the firm was corporatized. Research institutes have kept their original name and are designed by their number. The research institutes N° 18, 13, 55, 2, 46 have more than 3 patent applications.

[1]http://www.syrici.com/english/about.asp?lan=Overview&zlan=About Accessed on 15/10/2016
[2]*Design Engineering Co., Ltd, Shenyang Cenkey Chemical Co., LTD, Shenyang Bomeida Chemical Co., Ltd.*

4.2.2. Other centrally state-owned firms: The existence of alternative trajectories

The second categories, while still gathering central state-owned firms, have adopted another mode of research. While in the preceding case, firms have incorporated formerly public research institutes as comprehensive entities that mostly act as a technology provider, the second category of central state-owned firms indicate more integrated research, and has a corporate research department centre.

We shall present the case of Baogang (Baosteel Group), which is a Shanghai-based steel producer under the State Asset Supervision and Administration Commission. Baosteel is considered as a steel producer with "world-class capacity". It is an iron & steel company created in 1978 and employs 130 000 people at the time of writing.

It presents a specific interest as it is explicitly engaged in nanotechnology and nanomaterials research. Baosteel has adopted the discourse on the transformation of the Chinese economy through frontier technology, including nanotechnology. *"We attach great importance to the cutting-edge research in the steel industry by developing frontier technologies like strip casting, NANO technology, non-BF iron making, jet-spray forming and vacuum coating etc.; ... We also aim at strategic newly-rising industries and technological hot spots; actively cultivate our future competitive advantage; actively carry out technology source searching and discretion in strategic newly-rising industries like new energy, new material and new-energy automobiles etc."* (Baosteel website).[1] The firm is also engaged in scientific and technological collaborations with a university's research centre in nanomaterials in Shanghai to which it provides funds (interview # 4).

This is associated with concrete research outputs in patents: we find 174 patent applications in nanotech between 2001 and 2008. These patent applications, however, weigh little in the whole patent portfolio of the firm (1688 patent applications in 2012 alone including priority and non-priority patents). The repartition of nanotechnology research is as follows. There are two main types of research activities: the core activities of the firm under Baosteel Group, and based in Shanghai Baoshan District, and research done by its acquired subsidiaries that was not integrated. The geographic distribution of the nano-patent applications reflects both the firm's local implantation and its geographic expansion through the acquisition of steel capacity in China.[2] Several subsidiaries applied for nano-patents, but

[1] http://www.baosteel.com/group_en/contents/2887/40017.html Accessed on 15/10/2016

[2] The acquisition strategy of Baosteel Group is to be understood at the light of the ongoing consolidation of the steel industrial sector, which is very fragmented, with many local actors, and that is undertaken under national leadership. Instead of the present categorization we adopt, we could have chosen to include all firms operating in this sector in the same category of 'resource-based firms', but the size and central ownership make it a specific

most of them are localized in Shanghai: 163 patent applications have a Shanghainese address. The remaining patent applications were filed by acquired subsidiaries: in the surrounding provinces but also much farther, Xinjiang Bayi in Urumqi, some of them prior to their acquisition by Baosteel.[12]

At the corporate level, research is supposed to aim to improve its production process as illustrated by an article in*Mena Report* (2013, July 24th) "A nano-spray coating technology can prolong the on-line working time and life span of working rolls effectively, reduce the roll changing time and lower the roll repairing cost…. the pulling-straightening roll which uses nano spray coating technology has been successfully used in the plant's pickling line, saving the coat of more than 490,000 yuan annually. It is also the first time that the nano-coating pulling-straightening roll is successfully applied to Baosteel Cold Rolling." (Mena Report, 2013).[3]

Notwithstanding the case reported above, it appears that in many cases, results are not used by the firm. For instance, the firm does not use research results of joint-project with a university. *We have some collaboration with Baosteel. There are permanent researchers* [paid by Baosteel] *because there is money every year. They do not apply recent research in their applications* (interview # 4). It is not the quality of research done with Baosteel that is under question, but the absence of utilization of research results.

The activities of the research institute of the firm are oriented towards the firm's activities (rather than being a technology provider). This, however, does not mean that there is no issue related to the integration of research results. Indeed, the integration of research results into their own production process does not always appear so straightforward. In their research collaborations, Baosteel looks for "ready to use" products rather than technologies. They do not use research results in their products, to use them to commercialize the

case.

[1]Ningbo Baoxin Stainless Steel in Ningbo, Shanghai Meishan Iron & Steel in Nanjing, and Baosteel Changzhou roll manufacturing company

[2]Xinjiang Bayi Iron & Steel was created in 1951, and was acquired in 2007 by Baosteel. It has the complete process of production from mining to steel making and steel rolling. Ningbo Iron and Steel was acquired in 2009, in the context of "Steel Industry revival plan". These acquisitions obey generally governmental injunctions. Baosteel finally became the main shareholder of Guangdong Shaoguan Iron & Steel, established in 1966, in 2011. In addition, it re-organized its business units: Baosteel Stainless Steel Co Ltd, and Baosteel Special Steel Co Ltd. Baosteel stainless steel was established in 2012 on the basis of the former Stainless Steel Business Unit

Xinjiang Bayi did research on nanotechnology and applied for patents in 2004, 2005 and 2007, before it was acquired by Baosteel in 2007. In Shanghai, besides patents taken at the level of the headquarter Baoshan Iron & Steel Co Ltd, there are other subsidiaries: Shanghai Baosheng Iron & Steel Metallurgical Charge Co Ltd (12 patent applications).

[3] Mena Report: business news source established in 2001 and run by Al Bawaba (Amman, Jordan, and Dubai).

technology. "*While large state-owned firms develop technology and research in nanotechnology, they do not use them in their products. They also tend to prefer "ready to use" products [when working with universities]."* (interview # 4).[1]

However, this is a different configuration than that of previous firms whose research was done by research institutes (like in Sinopec). Baosteel Group has reorganized its research organization. More specifically, it formally re-organizes Central Research Institute in 2012: *For adapting to Baosteel's strategic transformation from iron and steel to materials and strengthening the sharing and synergy of R&D resources at the Group level, Baosteel Central Research Institute was set up on June 19th, 2012 on the foundation of the existing R&D platform* (CSR Report, Baosteel 2012). This reflects that the research done is considered in the wider scope of the firms. The institute is divided into several departments. Departments include a testing centre, energy and environment institute, a refractory division, a research institute of stainless steel, a central research institute, an automation department, a metallurgical process department.

It is, according to the company website, responsible for *"R&D of key, cutting-edge, and fundamental technology, particularly new products, new process, new technology and new equipment, in order to resolve all kinds of quality and technical problems arising from production practices, and providing strong technical support to major project and customer service. The institute is an R&D base features high-level, outstanding performance, multi-discipline, multi-function and openness, it combines technology development and application, and it is also a high-tech talents pool."* Independently of the ambition of these proclaimed objectives, they somehow contrast with the mission attributed to research institutes in firms in the previous category.[2]

[1]This might be related to the fact that research by centrally state-owned firms is not driven by corporate strategies, but also follows administrative decisions that obey a non-strategic external incentive - which includes local and national innovation programs, as well as political objectives, notably through the Party's participation (Cho and Huang, 2012). The obedience to political objectives is explicit: "*a lot of its key innovation achievements have been commended by the state, province, city and industry, among which "Research on the varieties, production and application technologies of Baosteel high grade automotive sheets" was awarded the first prize of National Award for Science and Technology Progress*" [1] http://www.baosteel.com/group_en/contents/2887/40017.html Accessed on 15/10/2016

[2]http://www.baosteel.com/plc_e/05development/ShowArticle.asp?ArticleID=28Accessed 15/10/2016

4.2.3. Conglomerate-type large firms[1]

Another profile of firms gathers firms that are organized around different entities, in different industries. They are large firms organized in several industries, and operating in a broader range of industrial and non-industrial sectors compared to the firms hitherto studied. In these firms, the construction of technological capabilities deployed at sectoral level may differ widely from one subsidiary to another, depending on the way an individual entity deploys its research. The way they do research follows differentiated strategies in these entities.

A characteristic of the 'conglomerate' group is that it includes both state companies, including local and centrally state-owned firms, and, private firms. We discuss two cases, Fosun Group, and Shanshan Group (a conglomerate that was privatized). We selected these cases for two reasons. Firstly, they illustrate the existence of differentiated technological strategies in the firms' subsidiaries. Second, they also illustrate alternative ways in which the previous research system influences the way firms do research. The fact that they are both private firms show that the legacy that constitutesformerly public research institutes is not limited to state firms.

Table 8-7: List of conglomerates with nanotechnology research (more than 5 patents)

Firm	Nano	Localization	Yr	Employees	Ownership	Headquarter
Shougang group	Important (30)	Dominant loc.	1919	75 000	Local government	Beijing
Fosun Group	Significant (14)		1992	34 218	Private	Shanghai
Shanshan	Important (15)	Slightly dominant loc.	1980	11 713	Private	Ningbo
Shandong Xiwang sugar co ltd	Significant (7)	Slightly dominant	1986	10 000	Private	Zouping

Source: author

i. Fosun Group

Fosun Group is among the 31 private firms involved in nanotechnology research. It is a diversified conglomerate created in the 1990s doing market research that then extended towards real estate, tourism, pharma, and is known for its international acquisition strategy in

[1]Firms in that category: Shanshan Group ; Fosun Group; tsinghua tongfang co ltd ; Citic Group ; Guosheng Group; shandong xiwang sugar co ltd ; china merchants group ; founder group ; midea holding co ltd; China South Industries Group Corporation ; Hongdou group ; Xinxing Cathay International Group Co., Ltd; china faw group corporation ; China Resources Holdings ; suzhou chuangyuan invest development (group) co ltd

different sectors abroad.[1]

We have identified nanotechnology research within two industrial activities, biopharma and the steel industry. The most productive activity is in the biopharmaceutical sector; Fosun Pharma is among the country's large pharmaceutical manufacturers. Specialized in generic drugs, its R&D intensity is inferior to the sectoral average, but like that of its foreign competitors with similar strategies on the generic market (See chapter 5 on R&D, Section 4.1). Its R&D activities, employing 766 pharmaceutical R&D employees, are dispersed in two main Chinese localizations, Shanghai and Chongqing, and Fosun Pharma also has research capacity in the United States.[2] R&D is centralized under "Fosun Pharma Industry Research Institute" around four main lines of research that reflect the different operating businesses: generics, small molecule chemical innovative drugs, large molecule biopharmaceutical drugs and specialized formulations.It is done under the umbrella of four legal subsidiaries. Two of them are in Chongqing (Chongqing Pharmaceutical Research Institute Co Ltd. Chongqing Fochon Pharmaceutical Research Co Ltd), and two of them are localized in Shanghai (Shanghai SunTech Pharmaceutical Co Ltd, and Shanghai Henlius Biotech Co Ltd (See Map 6). One of the firms in Chongqing integrates nanotechnology research: Chongqing Institute of Pharmaceutical Industry Co., Ltd, applied for 14 patents between 2004 and 2008, often in association with a small invested Shanghai-based firm (Shanghai Kelong Biology Gaojishu Limited Company). Patent applications in nanotech position Fosun among pharmaceutical firms actively doing research, along with the local firm Guangzhou Baiyunshan Pharmaceutical (13 patent applications between 2002 and 2007). Nanotechnology research by Fosun Pharma suggests a concrete implementation of the firm's proclaimed strategy, which aims to both target generic market and to integrate more advanced research.

In addition, it illustrates some dynamics characteristic of the ways firms develop their technological capabilities. A first notable element is the acquisition of a state-owned former research structure by a private firm to develop research skills and do early stage research. In this case, Fosun Pharma uses the resources from a former research institute specialized in pharma R&D acquired in 2001. Chongqing Pharmaceutical Research Institute Co., Ltd., was

[1] "*Guo's [GUO Guangchang, Fosun CEO] purchases include a stake in French tourism firm Club Med, Greek jewellery and fashion brand Folli Follie and most recently, a bid for control of Portugal's biggest insurer Caixa Seguros. In 2016 Fosun's healthcare unit announced a $1.3 billion deal to buy Indian drugmaker Gland Pharmaceutical. Other acquisitions made in the same year include English football club Wolverhampton Wanderers, Brazilian asset manager Rio Bravo and British handbag maker Aspinal*" (Week in China, 2016, p. 82)

[2] Fosun Pharma has R&D operations in San Franciso, through the extension of the Shanghai based entities.

originally a research laboratory subordinated to a military pharmaceutical factory created in 1950. Its above-mentioned collaboration with a Shanghai-based firm invested by Fosun further indicates the effective construction of collaborations and links between the former state-owned unit and other subsidiaries of the company after the acquisition, despite the geographic distance (1700 km).

Map 8-6: Distribution of nanotechnology patents by Fosun Group

According to the firm's corporate communication, Fosun Pharma aims at positioning itself at the technological frontier while maintaining other activities that are less innovative: "*The Company continuously promotes R&D on generic drugs and innovative drugs and proactively follows the latest technological frontier of global pharmaceutical industry."* The rhetoric of independent innovation is also present *"Fosun Pharma always takes independent innovation as the driving force of enterprise development,"*and is recognized as such by the Chinese authorities.[1]In 2013, **S**hanghai Fosun Pharmaceutical Groupwas awarded the title of "China's Most Innovative Pharmaceutical Enterprise" (Manufacturing Close-Up, 2013). The concept of "low-cost innovation is present in its strategy. Fosun Pharma introduces its acquisition in 2015 as part of its strategy of creating a "*high-level, low-cost, large-scale research and development capacity.*" Fosun Pharma's strategy is double. In addition to R&D investments, it obeys to an opportunistic approach that includes acquisitions of different types of entities (acquisitions of US biopharmaceutical firms, of former research institutes) as a

[1] http://www.fosunpharma.com/uploads/20151120104853.pdf Accessed on 15/10/2016

strategy to acquire new competences.[1]

Another subsidiary of the conglomerate is present in nanotechnology research. This subsidiary (Nanjing and Iron Steel) follows a trajectory very different from Fosun Pharma. Nanjing Iron & Steel is one of the few private steel makers. Based in Jiangsu Province, it was jointly set up by Fosun and Nanjing Iron & Steel United Ltd. We found 4 patent applications in 2007 and 2008, but it is not possible to determine whether they were all taken at the firm level or at the level of its parent company. In the present case, Fosun has kept the model of research specific to locally state-owned firms.

The case of Fosun Group illustrates that the firm pursues mixed strategies through its subsidiaries.Investments in R&D and emerging technologies are operationalized through the opportunistic acquisition of resources. Fosun as a private firm uses existing resources, state-owned firms or institutes in China, and high-tech firms abroad that it acquires, transforms or extends.

ii. Shanshan Group

Shanshan Group is also a private conglomerate that operates in several industrial sectors. Its trajectory differs from Fosun Group; it was originally a state-owned firm founded in 1989 in Ningbo as a garment company (a firm rapidly named the Yonggang costume factory, based on the name of Zheng Yonggang).[2] The firm was privatized in 1991 when Zheng Yonggang bought the state shares. Diversification occurred ten years later, in 1999, while the company moved its headquarters to Shanghai and included high-tech industries in the framework of the national development strategy. 1999 is the year of the creation of Shanghai Shanshan Science & Technology Co Ltd aimed at doing research in the fields of new energy and materials. The entry on the market of Li-ion battery anode materials, one important part of the firm, was done through the acquisition of the Changchun-based China-Kinwa High Technology Co Ltd in 2002. This move reflects the influence of former research institutions. China Kinwa High Technology was a company held by Changchun Applied Chemistry Research Institute, affiliated with the Chinese Academy of Science (Sanders and Yang, 2007).

The conglomerate Shanshan Group has grown through acquisitions of state assets.[3] On the manufacturing side, there are two main industries: the garment industry, which is Shanshan Group's original core business, and the battery material industry, that has become

[1] 2015: Shanghai Fosun Pharmaceutical Group Co. acquired Ambrx, an American biopharmaceutical company
[2] He later renamed it Shanshan Group Source: Week in China (Week in China, 2016)
[3] For example, it bought in 2004, 24.92 percent of Songjiang Copper Industry

central to its activities. The R&D base in li-ion battery materials was developed in 2006 on the basis of the existing production site. Shanshan Group applied for 16 nano-patents between 2002 and 2008, through three legal subsidiaries that are all connected to the energy material business. It emphasizes a frontier strategy, here characterized as the "Japanese block": *The company possesses a high quality and well-experienced R&D team specializing in multiple industries and fields including electrochemistry, carbon powder process and chemical engineering. With the support from National Post-doc research station and the scientific research platform provided by the company, the company now owns 19 national technological invention patents and more than 30 invention patents in progress. […] Shanshan has broken the technological block of Japan in the field of Lithium-ion battery anode material and its market monopoly* (Shanshan Technology's website).[1] In that sector, we find research in nanotechnology in Shanshan's subsidiary engaged in solar cell industry.[2] Ningbo Ulica Solar Science & Technology has applied for three patents in nanotechnology.

Nanotechnology research, by contrast, is absent in the garment industry, a second manufacturing activity of Shanshan.

4.2.4. Conclusion

In this section, we have focused on the largest groups. We have distinguished three main cases regarding the way they organize their nanotechnology research, which pertains to the organization of the group. We paid a specific interest in distinguishing profiles in this group because they represent an important proportion of nanotechnology patents.Indeed, 69 centrally-state owned firms alone represent 72 percent of patent applications taken by large firms between 2001 and 2008.

The first category refers to large groups that operate in a sector (for which we can identify a core sector): Sinopec, Aluminium, Sinochem and China Electronics Technology Group operate in industries more or less demanding in R&D, and of different nature(resource processing, manufacturing of chemical products, or electronics). They use formely public research institutes for their research, and in our case, in the deployment of nanotechnology research. These institutes operate independently and their research seems not integrated as part of a group's strategy. Instead, it seems to be part of a national or sectoral strategy. It also suggests that the intensity of nanotechnology research attributed to one such firm is not

[1] http://www.shanshantech.com

[2] It produces solar cells, solar modules. 17 patents were obtained, among which N-type mono-crystalline silicon solar cell is awarded as a National Torch Program. Ulica is a National Hi-tech Enterprise and an engineering centre of Ningbo city, it is also cooperating closely with Ningbo Material Technology& Engineering Institution of Chinese Academy of Sciences, Shanghai Donghua University.

associated with the intensity of its overall technological orientation, but to the intensity of research within research institutes it has access.

This is however not the only model. Alternatively, a smaller number of central state-owned firms are associated with more integrated research at the group level.

In addition, a third profile gathers firms that follow internal differentiated strategies. One might argue that differentiated strategies characterize both state and private firms.[1] We have already presented the case of China South Industries and showed existing disparities between its different subsidiaries (

Table 6-6: R&D by subsidiaries of China South Industries Group Corp. (2013), p. 125). One subsidiary, Chang'An Automobile invests in R&D and has re-organized the way it does research. In contrast, Jianshe, another subsidiary of China South Industries also engaged in the automobile and part sector did not significantly reorganize or invest in its R&D.

4.3. Global industrial firms with integrated R&D[2]

4.3.1. Introduction

This category of firms is among the most studied of Chinese firms, for their technological strategies (Larcon, 2009, pp. 175–202), and for R&D-related topics such as their internationalization (Von Zedtwitz, 2006).

China's global industrial firms are characterized by the fact that they engage in research by adopting similar models of organization centred arounddomestic R&D departments and an international R&D network. To some extent, the trajectories followed by these global industrial firms are comparable to that of global firms. Their international networks of R&D centres include China-based research institutes as well as R&D institutes abroad, including in advanced economies: Europe, USA, Japan. This internationalization appears to be a way for Chinese firms to access to the local market, and access to local technology and skills (von Zedtwitz and Gassmann, 2002).

[1]Another observation is that private conglomerates are generally associated to a strong individual personality. This was the case of Guo Guangchang in Fosun and Zheng Yonggang for Shanshan. This is not the case for state groups. In the case of some private conglomerates, the distinction between some conglomerates and investment companies is not so clear. This is the case of Fosun Group, considered as a global investment company. This most likely conditions its mode of management which indirectly impacts the ways individual entities do research.

[2] Firms with international R&D
byd company limited ; boe technology group co ltd; huawei ; zte corporation ; haier group ; hisense ; tcl corp ; lenovo (beijing) co ltd ;; fuyao group ; sany heavy industry co ltd; wanxiang group corp ; chery automobile co ltd; SAIC Motor ;; Changzhou trina solar ltd ;Suntech Power ; Weichai Power ; dongfeng automobile co ltd ; zoomlion (Including 2 specific cases: alcatel-lucent shanghai bell co ltd Shenzhen Skyworth rgb electronics co ltd (R&D center in Hongkong))

We can, however, add one element to previous research on the organization of R&D by these firms. The data we obtained suggest the importance of centralization of nanotechnology research in one main Chinese localisation.

The characteristics of these firms (Table 8-8 for the largest applicants) reflect the private sector is well represented. Nine global firms with nanotechnology research are privately owned, and ten have a local government as the controlling shareholder, often at the city or municipal level (which contrasts with firms in resource based industries for which there is a broader engagement of provincial governments). Firms in this category cover a quite large range of industries: electronic and electrical equipment (5); technology hardware & equipment (4); automobile & parts (3); industrial engineering (2); and household goods and home construction (2). We note the absence of two traditional industries: chemicals or textile industries.

These firms invest in research, and they have set up R&D departments, even though they are not all part of the largest world R&D spenders. Two main paths are associated with R&D; that reflects alternative strategies during technological catch-up. A few firms considered R&D central for their development since the beginning. These firms started R&D early and have backed their research on state research institutes (Lenovo, Huawei).[1] In contrast, other firms focused on manufacturing activity, and active technological learning in the initial stage (BOE, BYD). They started their research activities later, with a progressive integration of further technological complexities.[2]

Table 8-8: Global leader firms in nanotech (more than 15 patents)

Firm	Nanotechnology	Localization of research	Industry	Employees	Ownership	Headquarters
byd company	Important (202)	Dominant loc.	Electronic & Electrical Equipment	159 000	Private	Shenzhen
boe technology group	Important (115)	Unique loc.	Electronic & Electrical Equipment	26 922	Local government	Beijing
Huawei	Important (113)	Dominant loc.	Tech. hardware & Equipment	150 000	Private	Shenzhen

[1] Naughton notices the interesting trajectory of Lenovo which despite being backed by a high-profile institution started in low-tech manufacturing. Lenovo was a spin off from the Institute for Computer Technology of the Chinese Academy of Sciences in 1984 (Naughton, 2007, p. 359).

[2]BOE Technology Group, formerly Beijing Orient Technology Group, was created in 1993. It started as a manufacturer of LCD (liquid crystal displays), and its main industry is LCD for TVs and computers, and semiconductor displays. More than 70 percent of revenue comes from foreign countries. BOE's R&D expenses amounted to 1 904 million RMB (2013), which represents 5,64 percent of its operating revenues. The level of R&D increases and reaches 2,477 million RMB in 2014 (6,73 percent). BYD (189,000 employees) was founded in Shenzhen in 1995 as a cell phone battery maker. BYD rapidly expanded to become a leader in the electric energy storage market and a new entrant in the electric vehicle business, through external growth.

ZTE corp.	Important (62)	Dominant loc.	Tech. hardware & Equipment	69 093	Private	Shenzhen
Haier group	Important (24)	Unique loc.	Household goods & home Construction	55 762	Local government	Qingdao
Hisense	Important (24)	Dominant loc.	Household goods & home Construction	33 090	Local government	Shunde
TCL corp	Important (17)	Slightly dominant	Electronic & Electrical Equipment	75 233	Local government	Huizhou
Lenovo	Important (16)	Unique loc.	Tech. hardware & Equipment	54 000	Private	Beijing

Source: author

4.3.2. Centralization of nanotechnology research

The central laboratory is a dominant model among Chinese industries and is particularly favoured by locally-owned central firms. Most firms have established an R&D base to centralize their activities, sometimes associated with the construction of a dedicated building for R&D (ZTE R&D building, Huawei R&D.). This is reflected in the concentration of nanotechnology research in one Chinese location by these firms.

i. Centralization of all activities: Haier

Haier originated in a refrigerator factory in Qingdao in 1984. At first, it produced one model of household refrigerator, today it is a global leader in home appliances and electronics. The firm has only one Chinese localization in Qingdao, which houses all the firms' activities: Hai'er Street 1, in the Haier building, where operations and research are carried in the firm's different business units (refrigeration, electronics). The main research institute is the "Haier Central Research Institute."Developed at the same time than the factory, it was recognized officially as a national technological centre by the State Economic and Trade Commission in 1993.

All nanotechnology research is done at Qingdao. Haier's centralization of R&D is interesting; Haier is among the largest firms with more than 50 000 employees and is present in different nations through its network of R&D centres abroad. It is also part of a contrasted strategy. The firm emphasizes the importance of "open innovation" for the group's innovation strategy, with a particular focus given to innovation partnerships with start-ups and to the role of users, and to a flat organization (Duysters et al., 2009). Centralized R&D, in contrast, is often linked to lesser interaction with people and organisations external to the firms.

The firm's 24 patent applications by 2008 reflect nanotechnology research in different technological fields, with research that also involves different entities working together. The existence of a company dedicated to nanotechnology development, in collaboration with a local university of science and technology, reflects both the open innovation model promoted

by Haier and its commitment to emerging technologies.[1] This subsidiary is associated with another one that is the Qingdao institute of refrigeration technology (3 co-patents in 2002).

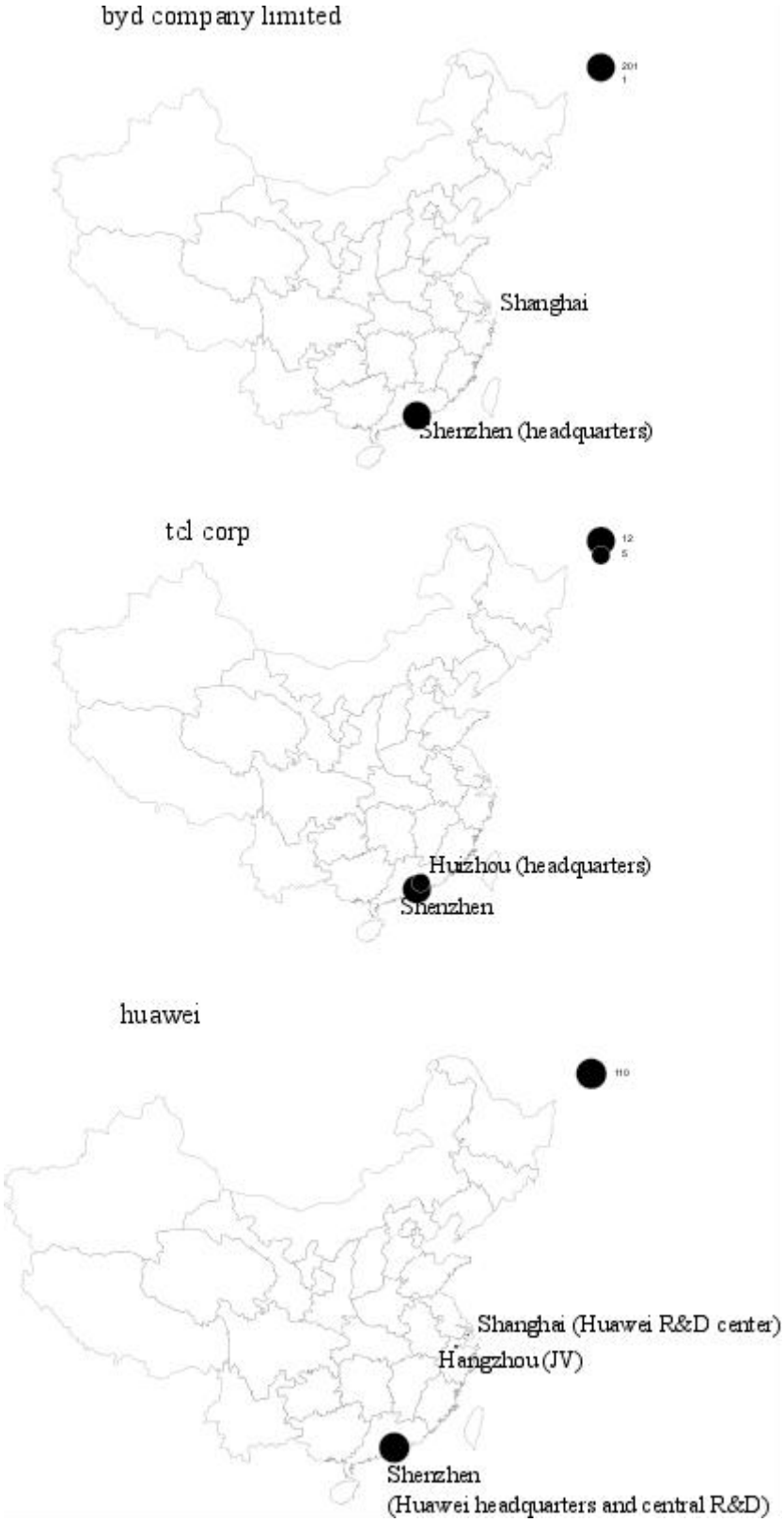
ii. R&D network and centralization of nanotechnology research

Haier, with a single R&D centre, is an exception. Most of the largest firms that operate in global markets have set up R&D centres in different cities in China.

This does not mean that nanotechnology research is organized around dispersed research centres; there is a dominant centre for nanotechnology patenting (Map 8-7). This is partly explained by administrative reasons– patent applications filed by the headquarters, but, also reflects the rarity of dispersed R&D without corporate R&D centre as an organisation mode. Most firms have corporate R&D at the level of the parent company, with activities localized close to the headquarters that are the historical localization of a firm. These firms patent in nanotechnology in one centre. There are some indicators of nanotechnology research in other cities, indicated by a few patent applications outside the headquarter (Shanghai for a Shenzhen-based firm or Shenzhen otherwise), but it is a very modest trend.

[1] *qingdao haier gust nano technology development co., ltd*

Map 8-7: Distribution of nanotechnology patents: BYD, TCL, Huawei



We find in the category of "global industrial firms" firms among the most studied, and

observe the centralization of their nanotechnology research. For instance, Huawei is, with its direct competitor ZTE, among the world's largest patent applicants (Kang, 2014). It applied for 113 patents in nanotechnology between 2001 and 2008. Nanotechnology research seems largely centralized in Shenzhen, where its central R&D building is also located.[1]BYD, automobile company and a major battery manufacturer, is a smaller firm than Huawei. Now one of the leading groups in the electric vehicle industry, it is a private company that was created in 1995 in Shenzhen. With more than 200 patent applications, it is among the most productive firms. Patents in nanotech are centralized in Shenzhen, which also coincides with the fact that BYD's central research institute is based in Shenzhen.[2]

4.3.3. What about global industrial firms with few nanotechnology patents?

Some firms in the category of global industrial firms, including R&D focused ones, have a low or a limited number of patent applications. Patents' quantity is difficult to interpret, but important differences between competitors in the same industry might suggest differences in the intensity of nanotechnology research. For instance, Weichai Power is a local government firm created in 2002 in Shandong Province in the automobile sector. It employs more than forty thousand people with several manufacturing sites and brands, and set up R&D centres in national and international locations (R&D centres in the United States, Europe (Austria) and Weifang, Shanghai, Chongqing, Hangzhou, Yangzhou, Xi'an in china). It has applied for two patents, which reflects a limited commitment to nanotechnology research. Other local state and private firms are in the same case. This includes Wanxiang, Chery, Zoomlion, Suntech and SAIC Motor. Their limited contribution to nanotechnology patenting might be due to the period considered, which may be too early in their learning history. We checked this hypothesis by looking at nanotechnology patents taken by these 325 large firms in an alternative patent database, which covers a more recent period.[3] In most

[1]In addition, Shanghai Huawei, where there is an R&D department, also applied for one patent in nanotechnology-related fields. We can wonder to that extent this pattern is significant. The number of patent applications taken by the Shanghainese subsidiary is low but might reflect alternative situations: a difference in the research specialization of the two localizations or the fact that research is a marginal activity in Shanghai. In both cases, itindicates a relative decentralization in nanotechnology research.

[2]Shanghai appears as an alternative localization, even though it is limited in the number of patents. BYD has a central research institute, and two adjunct research institutes organized in different subfields (automobile, electronic).

A similar trend is observable for ZTE. ZTE have also two different localizations for patenting its nanotechnology research.

[3]These data, however, does not provide information on the subsidiaries of firms that patent. It can therefore only give an estimated figure. It is, however, more representative for global industrial firms that have centralized nanotechnology research than for firms organized in business groups with independent entities.

cases, there was not a significant increase in the level of nanotechnology patent applications.[1]

In this case, the absence of nanotechnology patents might suggest that firms focus their R&D activities towards applied or engineering research, and are not engaged in leadership strategies.

In contrast, firms have appeared since then among the most prolific applicants at the end of the decade. This is the case of Chery Automobile, which had applied for 3 patent applications in the period 2001 – 2008 in our main database, and had applied for 71 patents by 2013. This change in the number of patent applications reflects a change of strategy in terms of research over the years, as well as the time required to deploy it efficiently.

[1] We find that most firms stay in the same range of nanotechnology patents. By 2013, Wanxiang had 10 patent applications, SAIC Motor 10, Suntech 3, Weichai Power 3, Zoomlion 6 patent applications. These figures reflect there has not been an intensification of nanotechnology research at the end of the 2000s.

4.4. Other large firms in resource based industries[1]

This category covers 32 firms involved in the mining and processing of resources.It includes firms that mine and extract natural resources such as coal, iron non-ferrous metals (aluminium, copper, nickel, cobalt, platinum…), or transform and manufacture these resources into intermediary products used by other firms (mostly steel makers). It is interesting to note the significant presence of miners of natural resources among firms which do nanotechnology patenting.

Their presence might be explained by the capacity of firms to leverage their access to resources. One of thefirms with the largest number of patents in this category is Jinchuan Group, headquartered in Jinchang, in Gansu Province. Specialized in the production of nickel, copper, and cobalt, it benefits from its localisation in Gansu Province (which is endowed with rich natural resources). The importance of its patenting activity (30 patents) suggests Jinchuan Group's ability to leverage its access to natural resources to support technological development, despite not being in an environment dynamic in terms of public research.

It is also explained by the important number of local actors, notably in the steel industry. Steel making refers to a vast range of activities that are more or less demanding in technology, have various types of customers and industrial use. China's steel industry was particularly fragmented, so there are many local government steel producers.[2]

There is, consequently, contrasting evidence on the level of technological capabilities. The degree of commitment to nanotechnology research varies from low to important, as well as their size (from small to very large) and their technological base profile. This shows that despite common features and similar patterns of development, they engaged, in technological innovations to various degrees. Sixteen firms (out of 32firms in this category) with nanotechnology patenting are headquartered outside of the three main economic regions (Bohai Rim region, Pearl River Delta region, or Yangtze River Delta area).

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[1]wuhan iron and steel (group) corp ; Jinchuan Group ; shougang group ; taiyuan iron and steel (group) co ltd ; ma'anshan iron and steel co ltd ; Shandong Iron and Steel Group Co., Ltd ; yunnan metallurgical group ; Hebei Iron and Steel ; baotou iron & steel corporation ; chongqing iron and steel (group) co ltd hunan valin steel ; zijin mining group ; xinjiang tianye (group) co ltd ; yankuang group company limited ; jiangsu shagang group co ltd ; shandong nanshan aluminium co ltd ; Shandong Energy Group; BBMG; tangshan sanyou group ; hangzhou iron and steel (group) co; jiuquan iron and steel (group) co ltd ;shenzhen zhongjin linnan nonfemet company limited ; xinyu iron and steel co ltd ; Datong Coal Mining Group ; daye non ferrous metals co ltd ; henan shenhuo ; jiangxi copper industry co ltd ; pingdingshan tianan coal mining co ltd ; qingdao iron and steel group co ltd ; Shandong Zhaojin Group Co Ltd ; taishan iron group co ltd ; Bohai Steel

[2]The large groups we have already presented, the centrally state-owned firm Baosteel, and the private firm Jiangsu Shagang, are exceptions and most steel producers are owned by local governments (provincial, municipal).

Local steel makers generally use the technology centre located at their headquarters for nanotechnology research, which appears as the applicant in patent applications. Even in the case of a firm which does research in several provinces, the local implantation remains dominant. For instance, Hebei Iron and Steel is not limited to Hebei Province, but it remains locally implanted. It is now the first Chinese steel firm in capacity since the acquisitions of Handan Iron and Steel and Wuyang Iron and Steel.[1] Nanotechnology research is done within each subsidiary at the level of the subsidiary's technical centre, and it is the Intellectual Property division that applies for patents.

4.5. Other large specialized industrial firms

Besides large state sectoral firms, and global firms, there are smaller, industrial firms localized in one geographic area. These firms include local state-owned firms or private firms specialized in one particular industry.This category gathers (relatively) small firmswhich are characterized by the fact that theyhave not extended their R&D abroad, by contrast with global industrial firms. To support their research, they use resources they can find in the national and local environment.[2]Among these firms, we distinguish between firms with barely any research and firms with significant research activities in nanotechnology.

4.5.1. Significant nanotechnology research: leveraging resources in R&D[3]

Among them, 16firmsare especially active in nanotechnology patenting (five or more patents). Dominant industries in that category are chemicals (3 firms) and technology hardware and equipment (4 firms). The two largest patent applicants arefirms that belong to electronic &electrical equipment and chemical industries.

The chemical firm Shanghai Huayi, based in Shanghai, was estimated to spend 575 000 million RMB in R&D in 2010. With 35 patent applications in nanotechnology, it is one of the most prolific chemical firms in nanotechnology research. Shanghai Huayi has seven subsidiaries localized in six different places, all in Shanghai city, with various distances between them. A second pharma firm for which we identified nanotechnology patents is

[1] This is part of the national restructuration of the steel sector. In line with 1997's new policy for industrial conglomerates, Handang Steel had to acquire Wuyang Iron and Steel which was heavily indebted (Huchet, 1999, p. 16)

[2] This, of course, includes all kinds of interactions with foreign firms based in China.

[3] Firms in that category (local and private specialized industrial firms, 5 patents and more
irico group corporation ; shanghai huayi (group) company ; China Mengniu ; fiberhome technologies ; konka group co ltd ; guangzhou baiyunshan pharmaceutical co ltd ; shanghai electric (group) corp ; wuliangye group ; Tianjin Zhonghuan Electronic and Information (Group) Co Ltd ; shandong liuhe group co ltd ;sichuan chemical industry holding (group) co ltd ; tianjin bohai chemical industry co ltd ; Fasten Group ; sichuan changhong electric appliance co ltd ; north china pharmaceutical corp ; csg holding corp

Guangzhou Baiyunshan Pharma, based in Guangzhou in Guangdong Province.[1] These two cases reflect the capacity of a firm to benefit from the localization in an environment with qualified S&T personnel, in cities like Shanghai, or Guangzhou.

Regarding firms localized outside these centres, we can formulate the hypothesis that local industrial firms, in their deployment of nanotechnology research, need to have access to local resources, and notably local research. The modality of historical development of some cases of firms with nanotechnology and located in cities outside the main centres support this hypothesis. These firms benefited from their local resources, including in western regions.

The Changhong Groupis based in Mianyang, Sichuan. It originates in a factory that produced military radar equipment, created in 1958. It was in 2011 the biggest television set producer(Chen, 2011). That same year, the company represented about 40 percent of the city's GDP, and could, as such, benefit from local support. This firm had applied for 6 nano-patents by 2008. According to Chen Minglu, the research capacity of the firm is made possible by the socialist legacy of the "third front project" in Mianyang City. The city was established as a centre of national defence technology during the Third Front period, and more recently as a centre of science and technology in western China (since 2000, thecentral government decided to make it a science and techno city). This allowed the presence of qualified S&T human resources, and provided an environment with universities and research institutes (Chen, 2011).

There are also examples in industries not intensive in R&D of firms with significant nanotechnology patenting activities. For instance, Liuhe Group Co. Ltd was founded in 1995 in Qingdao. This food producer owns more than 265 subsidiary companies nationwide and has about 50,000 employees. According to its website, the company has three technology centres, all three related to one of the business operations under the meat segment. A joint participation to one conference with Shandong Agricultural University suggests that the firm is engaged in research collaborations with local universities.[2] Other food & beverage firms (Tsingtao, Yanjing) exhibit similar features.[3]Liuhe Group had applied for eight patents by

[1] Guangzhou Baiyunshan Pharmaceutical Co., Ltd. is a small local firm (around 11 000 employees) principally engaged in the pharmaceutical industry. The Company's main businesses are the production of chemical raw medicines and pharmaceutical preparations, as well as the processing of traditional Chinese medical materials and Chinese traditional patent medicines. The company through its different subsidiaries has a significant patent portfolio: it applied for 62 invention patents in 2013 and obtained 33 patent licenses. In nanotechnology, the group – under its headquarters name – applied for 13 patents between 2002 and 2007.

[2] 'Application of gelatin-based antimicrobial edible coatings on the preservation of chicken meat and prepared products' (Liang et al., 2011)

[3]It should be mentioned, however, that some firms in that category grew by diversifying towards other

2008.

4.5.2. Moderate patenting activities: local resources for technological upgrading[1]

Among industrial specialized firms, partof them applied for a limited number of patents between 2001 and 2008 (33 firms). Regarding the interpretation that can be made of their patenting activity, there are two distinctive cases depending on the nature of the industrial sectors they operate on.

The first case is that of industries little demanding in R&D: food production (3 firms) or beverage production (2 firms), leisure good (1 firm), construction and materials (3 firms), industrial metals and mining (1 firm), household goods & home construction (1 firm). This is, for example, the case of the food industry. Most firms in the food and beverage industry have a low R&D intensity, which can be linked to a lower propensity to patent. They are local firmsheadquartered in the city or area where they originated, with a production base sometimes dispersed across the province and across the regions. Theirtechnologicalcentreis localized at theheadquarters. An example of such firm in this industry is Yurun Food. Yurun Food is headquartered in Nanjing, in Jiangsu Province. It is a private meat supplier created in 1993 by Zhu Yicai. The production network is localized across China (65 factories in slaughtering business), but other functions are centralized in the historical headquarter. This includes the R&D team (that consists of 300 members according to the company's website). Research on nanotechnology is limited, we find only one patent application by Yurun Food, but the limited number of patents can be related to the low intensity of research in the industry.

However, thesecond caseincludes firms from industries traditionally more demanding in R&D like chemicals (3 firms), the electronic and electrical equipment industry (7 firms), pharmaceuticals (4 firms) and industrial engineering (5 firms), or the automobile & parts

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businesses (Henan Shuanghui, China Mengniu, Wuliangye Group), and are increasingly adopting a conglomerate-type.

[1] Firms in that category (Local or private specialized firms, Small Central state firm. 4 patents or less)
China Electric Equipment Group ; Dongfang Electric ; china national heavy duty truck group company limited; beijing dabeinong technology group co ltd ;; hubei yihua group co ltd ; sichuan hongda co ltd; sichuan kelun pharmaceutical co ltd ; China Erzhong deyang ; shanghai delixi group co ltd; China Hualu Group Co. Ltd ; chongqing lifan industry (group) co ltd ; gree electric appliances inc of zhuhai ;harbin pharmaceutical group ; hefei meiling co ltd ; henan shuanghui investment and development co ltd ; tsingtao brewery group ; zhejiang sanhua group co ltd ; Shanghai Pharmaceuticals holding; tebian electric apparatus stock co., ltd. (tbea); china national pharmaceutical group corporation (sinopharm); China Railway Engineering Corporation; Beijing Yanjing Brewery; china first heavy industries (cfhi); china xidian electric co ltd; ;China Yaohua Glass Group Corp; jingwei textile machinery co ltd ; naijing yurun food co ltd; nanjiecun (group) co ltd henan prov ; Taiyuan Heavy Machinery Group Co Ltd ;Yuntianhua Group ; zhejiang chaowei power co ltd ; BENEFO;

industry (2 firms). Firmsin these industries with limited nanotechnology research usually have one technological centre that concentrates their technological activities. This can be interpreted as a relatively low commitment to technological learning through research.

4.6. Synthesis and conclusion

Our chapter aimed to introduce the variety of profiles in nanotechnology research among the 157 firms that have filed nanotechnology patents. We have adopted a two-step approach to tackle this difficult task. First, we have assessed and described the weight of China's innovation geography and the weight of the 'endowments', which are the legacy of the previous system, on the firms' capacity to engage in nanotechnology research. In the second section, we have proposed to characterize different profiles of engagement in nanotechnology research around a series of examples.

Based on these elements, we can make a series of comments. First, a determinant factor of the way firms engage in nanotechnology research is the firms' size. Very large firms present specificities because they regroup entities with diverse technological trajectories. Theyare, therefore, characterized by differentiated trajectories among their subsidiaries: some subsidiaries might be engaged in R&D and nanotechnology research, whereas others rely on their original technical centers and do not engage in research.

Second, the results we obtainedshow the need to account for China's previous research system when looking at the technological trajectories of large Chinese firms. The latter have inherited from a research infrastructure that, despite being restructured and reorganized, influences the way they doresearch. This influence is not limited to state firms, even if it is more rare for private firmsto exclusively rely on formerly public research institutes.

Finally, it appears necessary to look at the modality of integration of research with the rest of the firms' activities. This is especially crucial when research is done in a formerly public research unit. It results that the 'intensity' of nanotechnology research within a firm, as measured by the number of patents, might reflect the technological capabilities of these research institutes. They, however, donot necessarily reflect the level of capabilities available within the firms.

Chapter 9: **Discussions and conclusion of the dissertation**

The question of the technological frontier in emerging countries has guided our doctoral research. This issue refers to national dynamics of development and to the possibility of the transformation of formerly developing countries into technological leaders of the world economy. The capacity of firms originating from these countries to position themselves among global firms conditions these national dynamics. Among the various dimensions of these dynamics, we focused in this dissertation on the possibility of firms to produce innovation based on advanced technology, notably through the opportunity to innovate and to produce breakthrough innovations, at the national level.

To deal with this question, we observed the conditions of transition to the technology frontier obtaining for large Chinese industrial firms. Large Chinese firms are an important topic because of the position they have taken in the world during the last decade. There is one Chinese company out of five among the world's 500 largest firms, which, indeed, is like China's proportion of the world's population. Also, our comparisonwith India and Brazil has shown that the emergence of China R&D firms, among global R&D firms, is unique and specific to China rather than being a trend shared by other emerging countries. The interest that the Chinese case represents goes beyond these considerations, however. Large firms in China propose an alternative to dynamics observed among large firms in other countries concerned with the technological transition. The situation differs from historical precedents, Japan, and South Korea. It also differs, on the other hand, from contemporary dynamics among other large emerging countries, with which China is often associated, India and to some lesser degree, Brazil.

The particularity of China is based on three factors that are likely to have an impact on the modality of a transition. Before entering into the core results of our research, let us summarize them briefly. A first factor is structural, and refers to the composition of the group of the major Chinese firms. As our selection and description of firms illustrated, despite the presence of a few diversified groups, including private firms, such as Fosun Group or national firms, China's industries are not dominated by business conglomerates. These only represent 13 percent of the entire group, and their size is relatively modest. Instead, a high proportion of the large firms operates in a specific industrial sector, or even in a particular market segment. A second factor is their minor role in the production system. This minor role contrasts with

Korea in which Samsung alone represents 17 percent of the national GDP. Altogether, the 325 industrial firms we observed play a limited role in terms of total employment: they employ about 16 million persons, which is a small proportion of a work force estimated at 700 million persons.Finally, a specificity of China is the existence of transversal conditions that transcend the specificities of the firms' industrial sector or their ownership regime. Instead, the trajectory of firms is largely related to the territory in which they originate and their mode of operation is marked by disparities rooted in local conditions and in the availability of resources, as well as in the legacy of China's first period of industrialization.

We have grounded the question of the technological frontier for large Chinese firms in innovation studies and catch-up literature. The use of the notion of innovation transition to look at current Chinese dynamics and its characterization in the literature has led us to formulate the hypothesis that large Chinese firms were investing in building tomorrow's competences, in their own specific ways. Therefore, we looked at the modalities of their deployment towards an emerging technology among the most advanced in reference to scientific publications, as well as the breadth of this deployment with its potential impact on the entire industrial structure. Nanotechnology provides an ideal setting, not only because it corresponds to the conditions previously mentioned, (its general purpose character across industries, and its degree of advancement), but also by its modalities of technology diffusion. Existing firms, across all industries, have integrated nanotechnology into the scope of their research programs. Understanding the breadth and the eventual modalities of the deployment of research capacities in nanotechnology of these firms were our two guiding objectives.

What then are our conclusions about the transition to the technological frontier by large Chinese firms then?A first response emphasizes the breadth of their deployment in nanotechnology research. It is this breadth which justifies the relevance of the mobilization of transition in the Chinese context. This deployment occurs in all types of firms. Indeed, we paidattention to the way we built our database of firms and selected large firms independently of their innovative capacities to avoid innovation bias. Our selection of large firms only relied on criteria of size, and excluded any technology or innovation related criteria. Despite this restrictive choice, an important proportion of firms, 157 firms, about 48 percent of the total had applied for patents in nano-related areas through at least one of their subsidiaries during the 2000s. Two conclusions can be derived from these results. Large Chinese firms have already invested in developing technological capabilities. Their patenting in nanotechnology

shows that firms have integrated the latest techniques in emerging fields like nanotechnology. In that perspective, one might conclude that large Chinese firms are at the technological frontier.

This, however, does not mean that they have reached the frontier in other aspects, notably regarding organizational capabilities. The lack oforganizationalcapabilities, understood in its broad sense, is considered to be a major limitation for China. Conversely, we might consider that the development of technological capabilitiesdrives and accelerates the acquisition of these organizational capabilities. An element that supports that hypothesis is the importance of China's outward foreign investments. The breadth of the trend of the acquisition of foreign firms that goes beyond a strategic access to natural resources and includes large and high-technology targets reflects the capacity to choose strategic targets.

The second series of results produced by our research concerns the modality of deployment of research of large Chinese firms. Thanks to a detailed analysis of the composition of the group of large industrial firms, and on the distribution of nanotechnology research among one or several centres, we have emphasized the variety of these modalities. Large Chinese firms have clearly followed differentiated pathways.

Part of the firmsdeploy their research according to modalities that are similar to what can be observed in Europe or the United States. These globalized firms, among which we count the most studied ones, tend to do research across a network of research centres localized both in China and abroad. However, they only represent one modality of research deployment. The largest firms, especially centrally state-owned firms, follow another pathway. These firms use research institutes inherited from the research system, notably at the national and provincial levels, associated with the system established before 1978. These research institutes form a very heterogeneous group and their integration with other activities also differs considerably from one firm to the other. But they act as a structuring element of research done by large Chinese firms. The legacy of the previous period is not limited to state firms, however. Private conglomerates, which grew by acquiring distressed state-owned factories, have also acquired former research institutes as part of their acquisition strategy, which are now active in nanotechnology, and are part of the technological basis of the group.

Conglomerates, like the largest multi-unit state-owned firms, display internally differentiated pathways to research. The trend is visible whether their entities operate in one core industry or are diversified. It is quite common that one group's entity participates in R&D and nanotechnology research, while another has madefewer efforts in restructuring its

research activities. We have shown this pattern among firms that operate in different sectors, in conglomerates - here the case of Fosun was illustrative – or among entities which are in the same industrial sector, like in the case of China South Industries Group, in line to what is observed among Korean firms like Samsung. The existence of differentiated pathways shows that the largest firms have mixed strategies regarding their research capacity. It also reflects the legacy of the intervention of state towards the consolidation of industries, which obliged efficient state firms to acquire indebted and inefficient firms (Huchet, 1999).

Also, some large industrial specialized firms have not globalized their operations. These firms are not as visible as firms previously described.They however illustrate another industrial phenomenon.A first limit of manystudies is the differentiation between high-technology and low-technology industries. The attention paid to high-technology industries is easily explained by the visibility of global leaders, mostly in these industries. Half of the global firms are either in the electronic and electric equipment, or in the telecommunication industries. Specialized industrial firms also operate in these sectors(as described by us in the case of Changhong in Sichuan). But there are also firms in traditional industries such as chemicals and construction materials, or in the food sector that do research. Our industrial coverage shows that the deployment of research capacity is not limited to centrally state-owned firms and global leaders, even though these two categories do it in a more massive way. This modality of research deployment is linked to the inscription of firms in their local environment. Another contribution of our work was to look at firms,that are not central in innovation studies and include steel makers and producers of resources such as nonferrous metals or coal. The share of firms from those sectors for which we find nanotechnology patents suggests that resource industries play a role regarding the technological frontier. These firms have a particular trajectory in research, as they both leverage their access to natural resources, and more generally their local environment. It is noticeable that some of these resource-based industries suffer many problems that include overcapacity associated witha fragmentation among small actors. The development of technological capabilities thusoperates in the context on ongoing restructuration of industries.

The topic of the technological frontier for developing nations opens a vast range of questions, many of which are stillunanswered. In our dissertation, we were only able to capture a small part of it, i.e. the modality of deployment of nanotechnology research in Chinese firms. In this regard, we need to emphasize one point. Our research design is originalbecause we proposed a new type of indicator for the transition to technological

leadership, based on an argument embedded in the existing theory. Indeed, we considered nanotechnology patents not primarily as an indicator of technological capabilities, as is often the case, but above all as an indicator of dynamics of technological learning, i.e. an indicator of the dynamics of construction of technological capabilities in emerging technologies. We therefore provide an analytical tool to observe a nation's industrial transformations, by focusing on nanotechnology. Our research design opens further possibilities, and shows the need for developing analytical tools and indicators specifically designed to follow technical changes in developing countries, in regard both to reasearch as ours, but also to production capabilities, and organizational features. The development of these tools also requires thinking about a more systematic way forintegrating qualitative research with these indicators.

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Annex: list of interviews mentioned in the dissertation

Interview # 1 Expert, National Center for Science and Technology Evaluation

Interview # 2 Program Manager, Shanghai Nanotechnology Promotion centre

Interview # 3 Manager, Shanghai Nanotech Association

Interview # 4 Project Manager at a University's centre of nanoscience and nanotechnology