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Divergences and convergence

Laurence Jacquet, Stéphane Robin

June 2021



R&D Tax Credits across the European Union: Divergences and convergence[†]

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Abstract

We examine the R&D, innovation and productivity effects of R&D tax credits (R&DTC) in 8 EU countries, in the context of a proposed EU-wide "super deduction" on R&D expenditures. Our econometric analysis, performed on industry-level panel data, shows that past R&D feeds current R&D, whether it is conducted under an R&DTC or not. Our estimate of additionality during an R&DTC phase is generally close to 1. R&D intensity also affects patenting intensity positively in Belgium, Czech Republic, France, Spain and the UK, but this relationship is R&DTC-related only in Belgium, France and Spain. Only in France and the UK do we observe a full (yet fragile) R&D – innovation – productivity relationship. In the UK, this relationship is not affected by the R&DTC scheme. In France, a 1% increase in R&D conducted under the second to fourth phases of R&DTC (1999-2017) entails a cumulated 0.37% increase in patenting intensity, which translates to a 0.16% increase in productivity. The main policy implication of these results is that a "super-deduction" on R&D is likely to help the EU reach its "R&D at 3% of GDP" objective, but only time will tell how generous it must be to really spur innovation and productivity.

Keywords: R&D Tax Credits, Public Support to R&D, Science and Technology Policy, European Policy

JEL codes: O38, H25, H54

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To make the EU "*the most competitive and dynamic knowledge-based economy in the world*", the Lisbon Agenda involved increasing investments in R&D up to 3% of the EU Gross Domestic Product (GDP). This objective was not met by 2010, when the Lisbon Agenda gave way to the Europe 2020 strategy, and remains to be attained in the current Horizon Europe program, which has superseded Europe 2020. In the words of research commissioner Mariya Gabriel, the 3% of GDP figure remains a "guiding light" for Horizon Europe.² The main policy tools to foster an increase in R&D spending are R&D tax incentives and, more specifically, R&D tax credits (R&DTC).

So far, R&D tax incentives have been the prerogative of EU Member States, resulting in a great diversity of instruments (and eligibility conditions) across the EU. Things have begun to change with the 2016 Common Consolidated Corporate Tax Base (CCCTB) proposal, which is currently being examined by the Council of the European Union³ and may be extended to a more ambitious tax agenda at the instigation of the European Commission (EC).⁴ Indeed, the proposal suggested to implement a "super-deduction" that would allow EU-based firms to deduce more than 100% of their R&D expenditures from their tax base. This super deduction may co-exist with national schemes, should Member States wish to go on with their current R&D tax incentives. The proposal of a super-deduction of R&D expenditures at the EU level is grounded in the aforementioned beliefs that economic growth in Europe can only be knowledge-based, and that the current level of R&D investment in the EU is too low to generate the required knowledge. R&D tax incentives, and the proposed super-deduction in particular, are seen as the obvious solution to boost R&D investment throughout the EU, hoping that this increased investment will have positive returns in terms of innovation and, ultimately, growth.

In this paper, we examine whether these expectations have strong foundations by estimating the effect of R&D tax incentives on R&D expenditures, innovation outcome and economic growth in several EU countries. We thus address two oft-mentioned challenges in the literature: the dearth of cross-country comparisons on the one hand, and the fact that most studies limit themselves to the effect of tax incentives on R&D expenditures on the other. Our selected countries include Austria, Belgium, Czech Republic, France, the Netherlands, Italy, Spain and the UK⁵. We conduct econometric analyses on industry-level panel data for these countries over a period that starts in the late 1970s / early 1980s (depending on the country) and ends in 2017.

Overall, we find that past R&D feeds current R&D, whether it is conducted when an R&DTC is available or not. For R&D conducted under an R&DTC, our estimate of input additionality is generally close to 1, which is consistent with the literature and suggests that firms spend all the savings induced by the tax credit on future R&D. Identifying a relationship between R&DTC and innovation output is more difficult. While R&D intensity does affect patenting intensity positively in Belgium, Czech Republic, France, Spain and the UK, this relationship is R&DTC-related only in Belgium, France and Spain. Only in France and the UK do we observe a full R&D – innovation – productivity relationship. In both cases, the relationship depends on which definition of R&D intensity is retained. In the UK, the R&D –

¹ In the words of the EU Parliament: http://www.europarl.europa.eu/summits/lis1_en.htm, Part I, Point 5.

² See for instance: <https://sciencebusiness.net/framework-programmes/news/member-states-asked-sign-pact-higher-rd-investment>.

³ See for instance [https://www.europarl.europa.eu/legislative-train/theme-deeper-and-fairer-internal-market-with-a-strengthened-industrial-base-taxation/file-common-consolidated-corporate-tax-base-\(ccctb\)](https://www.europarl.europa.eu/legislative-train/theme-deeper-and-fairer-internal-market-with-a-strengthened-industrial-base-taxation/file-common-consolidated-corporate-tax-base-(ccctb)).

⁴ At the time of this writing, the EC has emitted a more ambitious proposal, *Business in Europe: Framework for Income Taxation* (BEFIT), which would subsume and extend the 2016 CCCTB.

⁵ While the UK is not part of the EU anymore, it was a fully-fledged EU Member State over the period which we study. We will discuss the implications of Brexit further on in the text.

innovation – productivity relationship is not affected by the R&DTC scheme. In France, we find that a 1% increase in R&D conducted during three successive periods of R&DTC (from 1999 to 2017) entails a cumulated 0.37% increase in patenting intensity and a 0.16% increase in productivity. The main policy implication we derive from these results is that the "super-deduction" on R&D proposed with the 2016 CCCTB is likely to help the EU reach its 3% of GDP objective, but only time will tell whether the remarkably generous character of the said deduction will also spur innovation and productivity.

The paper is organized as follows: In a first section, we present some economic justifications for the existence of R&DTC schemes as well as the rationale for the super-deduction proposed at the EU level. In a second section, we illustrate, using the selected EU countries, the complexity and sheer diversity of R&DTCs schemes and discuss the possible implications of Brexit. In the third section, after briefly replacing our study within the related literature, we present our data and econometric analysis. We summarize our findings and discuss their policy implications in a fourth section. We conclude in a final section.

1. R&DTC schemes in the EU

1.1. Economic justification for the existence of R&DTC

R&D tax incentives and related R&D policies are rooted in the belief that, in modern economies, innovation is the main source of growth, a belief largely grounded in endogenous growth theory (e.g., Romer, 1990). This belief has led to the widespread conviction, in EU policy circles, that innovation may be the only option to get the EU economy out of stagnation and back on the path of growth. The rationale is that innovation-induced economic growth will result in increased wealth, employment and well-being. EU policy makers are therefore searching for the conditions that are more likely to make firms increase their innovation effort. A widespread recommendation consists in creating the conditions of increased competition between firms (or in "letting the market decide"), as the increased competitive pressure would supposedly lead firms to innovate in order to survive or to gain advantages over their competitors.

A potential problem with this recommendation is that markets left to their own devices are likely to generate less R&D⁶, and therefore less innovation, than it would be desirable for the society as a whole (Arrow, 1962). Among economists, this is known as a "market failure". As far as investment in R&D is concerned, there are at least two reasons for such a failure.

One reason is that knowledge created through R&D, just like any type of knowledge, is largely immaterial and presents some characteristics of a "public good": It cannot be completely appropriated by its creators, and the related ideas can be – more or less rapidly, depending on their complexity – copied and used by other firms. Intellectual property rights (e.g., patents) may alleviate this problem, but do not completely solve it (e.g., a patent is effective only for a limited period of time and/or over specific geographical areas).

A second reason is that innovation is a very risky and uncertain endeavour, and that investment in R&D is not a safe investment. Firms may therefore face serious difficulties in finding financial support for their R&D projects, as banks and investors may be unwilling to lend money to projects that they cannot easily monitor (or the outcomes of which they cannot clearly see). This may result in the abandonment of projects that firms would be eager to pursue had they the required funds.

If the assumption that innovation is conducive to economic growth and to social well-being is correct, then the two above-mentioned reasons call for public intervention in order to

⁶ Although alternative innovation channels do exist (see, e.g., Bozeman and Link, 1983, for a thorough examination of these issues), R&D is generally considered as the primary input to the innovation process.

spur firms' R&D effort. This type of public intervention will generally take the form of R&D subsidies or of R&D tax incentives such as R&DTCs.

1.2. Towards a "super-deduction" on R&D in the EU?

So far, we have examined justification for the existence of R&DTCs in general. In practice, tax credits can take a multiplicity of forms, and may vary hugely across EU Member States. At one end of the spectrum, there are States where no tax credit exist (e.g., Germany) and, at the other, States where R&DTCs have been implemented for a long time (e.g., France), possibly experiencing changes along the way. The question of whether this variety should be harmonized at the EU level seems to have finally found, in EU policy circles at least, a positive answer with the proposal, in October 2016, of a revamped CCCTB. This initiative (actually the re-launch of a 2011 proposal) suggested the implementation of a "super-deduction" on R&D expenditures⁷:

"To support innovation in the economy, this re-launch initiative will introduce a super-deduction for R&D costs into the already generous R&D regime of the proposal of 2011. The baseline rule of that proposal on the deduction of R&D costs will thus continue to apply; so, R&D costs will be fully expensed in the year incurred (with the exception of immovable property). In addition, taxpayers will be entitled, for R&D expenditure up to EUR 20 000 000, to a yearly extra super-deduction of 50%. To the extent that R&D expenditure reaches beyond EUR 20 000 000, taxpayers may deduct 25% of the exceeding amount" (European Commission, 2016, pp. 9-10)

This super-deduction is, in effect, a very generous R&DTC scheme, as was clearly stated in the associated press release⁸: *"The CCCTB will support innovation in Europe by allowing the costs of R&D investment to be tax deductible. All companies that invest in R&D will be allowed to deduct the full cost of this investment plus an additional percentage of the costs, depending on how much they spend. The full cost of R&D will be 100% deductible, while an additional 50% deduction will be offered for R&D expenses of up to EUR 20 million. An additional 25% deduction will be allowed for R&D spending over EUR 20 million"*.

The press release illustrated this scheme with the following example. An EU-based company that spends EUR 30 million on R&D in a given fiscal year will be allowed to deduct: (i) the full amount of its R&D expenditures (i.e., EUR 30 million) from its taxable income, *plus* (ii) an additional 50% of the first EUR 20 million (i.e., EUR 10 million) *plus* (iii) an additional 25% of the remaining R&D expenditures above the EUR 20 million threshold (i.e., EUR 2.5 million as 25% of the remaining EUR 10 million). In total, this hypothetical company will be able to deduct EUR 42.5 million from its CCCTB, which only goes to show that "super-deduction" is a rather appropriate term for this R&DTC scheme.⁹

The "super-deduction" seems to have been added to the 2016 CCCTB proposal to serve multiple objectives. The first was probably to make the proposal more appealing to reluctant Member States, as it offers them a channel through which they may maintain their international attractiveness – more specifically towards high-technology and innovative firms. Second, the variety of R&DTC regimes that currently prevails throughout the EU may result in a specific form of tax competition, geared towards R&D: high-tech and R&D intensive

⁷ The 2011 proposal already included a specific regime for R&D-conducting firms. The R&D regime in the 2016 proposal is more generous and constitutes a somewhat more radical proposal.

⁸ http://europa.eu/rapid/press-release_MEMO-16-3488_en.htm

⁹ The scheme is even more generous for "small starting companies" (i.e., start-ups, primarily), which will be allowed to deduct a further 100% of their R&D expenditures, within the limit of EUR 20 million. Thus, a start-up that invests EUR 5 million in R&D will be allowed to deduct EUR 10 million from its CCCTB.

firms may be willing to settle down in countries/regions where the tax regime favors R&D more. This in turn could cause uneven increases in R&D investments across EU regions (with R&D expenditures rising in some States and stagnating in others), which plays against the "3% of GDP" objective for R&D investment in Europe. By introducing a certain degree of harmonization in R&DTCs, a "super-deduction" would lessen this threat.¹⁰ Finally, the "super-deduction" could also be a way – insofar as tax credits are effective science and technology policy instruments – to foster higher investment in R&D despite post-pandemic budget cuts in the Horizon Europe programme.

The EU ECON committee adopted the report on the 2016 CCCTB proposal on February, 28th, 2018 (with some amendments), followed by the Parliament on March 15th of the same year. The CCCTB, and its associated super deduction on R&D, was then submitted to the Council of the European Union for validation. On May 18th 2021, while the CCCTB was still waiting for validation, the EC adopted a new communication on business taxation in which it proposes a new framework dubbed BEFIT (see Footnote 4). The BEFIT framework, which should be introduced in 2023, is destined to replace and extend the 2016 CCCTB proposal. At such, it is likely to incorporate a (possibly updated) super-deduction on R&D.

Whatever the outcome of this long legislative process, the implementation of the super-deduction would not make a clean slate – at least in the short run – of all the R&DTCs that currently exist within EU Member States. This specific EU context therefore makes our projected empirical analysis on EU Member States, with harmonized industry-level data, particularly relevant. Before detailing the precise aims, scope and methodology of our empirical analysis, though, we need to further sketch and illustrate the sheer variety of R&D tax incentives that exist throughout Europe – variety to which we have only hinted at in the present section.

2. The complexity of R&DTCs: An illustration for selected EU Member States

We now turn to the examination of R&DTC schemes in eight EU Member States: Austria, Belgium, Czech Republic, France, Italy, The Netherlands, Spain and the United Kingdom. This selection was partly imposed by data constraints¹¹ (as will be explained in Section 3) but it nevertheless gives a fair representation of the EU, as it includes: (1) four members of the Inner Six (Belgium, France, Italy and the Netherlands), founding members of the European Economic Community (EEC) in 1957, (2) two western European States that joined the European Community (EC, successor to the EEC) in the 1970s (the United Kingdom) and 1980s (Spain), (3) a western European State that joined the EU (successor to the EC) in the 1990s (Austria) and (4) a former Communist State of Eastern Europe that joined the EU in 2004 (Czech Republic).

In the present section, we highlight how the R&DTC schemes that exist in these countries may differ along multiples dimensions. We do not detail the specifics of each scheme, which would be beyond the scope of our study¹², but focus instead on some key dimensions that we illustrate with some aspects of the above-mentioned schemes.

¹⁰ The super deduction would not totally rule out national R&D tax incentives, though. The principles stated in the 2011 CCCTB proposal still prevailed in the 2016 proposal: "*A company which does not qualify or does not opt for the system provided for by the CCCTB Directive remains subject to the national corporate tax rules, which may include specific tax incentive schemes in favour of Research & Development.*" (European Commission, 2011, p. 6).

¹¹ These countries are those for which we were able to gather complete industry-level panel datasets, spanning a time period that goes from the mid-1970s/early 1980s to the late 2010s, and containing information on R&D, innovation and productivity.

¹² For exhaustive comparisons, see Straathof *et al.* (2014), Deloitte (2014) or E&Y (2014). OECD (2010) also provides, for the year 2009, a useful comparative table that encompasses our selected countries.

FIGURE 1 ABOUT HERE

Before comparing R&DTCs per se, it is useful to have a look at the state of investment in R&D in the EU. Figure 1 displays gross R&D expenditures as a percentage of GDP for each of our selected countries over the period 1981-2019. For the sake of comparison, Figure 1 also displays R&D expenditures in Germany (a country that did not implement any R&DTC over the period¹³) as well as the OECD average and the EU 27 average (the latter being available only from 1995 onwards). A first striking feature is that, across the whole period, R&D expenditures in Germany remain consistently above both the OECD average and the EU 27 average. They are also higher than in any of our selected countries for most of the period, being caught up by the Austrian ones from 2012 onwards. By 2017, both countries had reached the afore-mentioned "3% of GDP" objective, and even gone beyond this symbolic threshold, which was approached (but not attained) by Belgium in 2019. At that date, the remaining countries were all neatly below, and the EU27 average had only reached 2% of GDP. This may explain why Germany never felt the need to introduce an R&DTC. The question of whether Austria (and, to a lesser extent, Belgium) would have caught up with Germany in the absence of tax credit remains open, though.

At the other end of the spectrum, R&D expenditures have remained consistently low (below 1.5% of GDP) throughout the period in Italy and Spain, both countries being far below the OECD average and the EU 27 average. Interestingly, Czech Republic (which is observed from 1995 onwards) started with a level of R&D expenditures akin to that of Italy and Spain, but managed to get close to the EU 27 average by the end of the period.

In the remaining countries, R&D expenditures more or less follow the OECD slowly ascending trend, while remaining below the OECD average throughout. Overall, they oscillate between the EU 27 average (which reached 2% of GDP in 2019) and the OECD average (which is higher than the EU average and around 2.5% of GDP in 2019). Among these countries, France is the one where R&D expenditures are the highest, going above the OECD average in the 1990s and remaining close in the 2000's and 2010's. Overall, Figure 1 suggests that our selected countries all have an interest (in the light of the Lisbon Agenda and subsequent Europe 2020 and Horizon Europe objectives) in raising their R&D expenditures. This may explain the reliance on R&DTCs as policy instruments to achieve this objective. Nevertheless, while all these countries have implemented R&DTC schemes, these differ widely in their timeline, tax rate and tax base. In Sub-Section 2.1, we provide a broad picture of these divergences, relying on factual information gathered by crossing the references mentioned in Footnote 12: Deloitte (2014), E&Y (2014), OECD (2010) and, last but not least, Straathof *et al.* (2014).

2.1. Differences in R&DTC schemes

Regarding **timeline**, France was first, among the selected countries, in introducing an R&DTC. This was done in 1983¹⁴. The credit was incremental, based on the yearly variation (increase) in R&D expenditures, and remained so until 1998, with various changes in rates and ceiling across the period, as well as a brief attempt at a co-existing volume-based tax credit from 1987 to 1990. In 1999, the R&DTC was renewed for a final period of five years,

¹³ A system of R&D grants and R&D loans does exist in Germany, but that is also the case in some other EU countries where they come in addition to R&DTC (e.g., in Belgium, innovative firms can benefit from regional R&D grants, which are not subject to corporate taxation).

¹⁴ Giraud *et al.* (2014) present a detailed timeline of the French R&DTC in their report to the French Ministry of Higher Education and Research.

and it was made permanent in 2004, with a volume-based component introduced in parallel to the main incremental component. A major reform made the R&DTC completely volume-based in 2008. Compared to France, the remaining countries are latecomers: Spain introduced its first "real" R&DTC in 1995, Belgium and the Netherlands introduced theirs in 1998, Italy and the UK did so in 2000 and Czech Republic in 2005. Perhaps for this reason, these countries experimented less with their R&DTCs, and did not go through several phases with radical changes in their tax credit schemes. That said, in Italy, the R&DTC was introduced regionally at first, with a tax rebate varying across regions, and only became a harmonized national scheme in 2006. Last but not least, the case of Austria is rather specific, as an R&DTC co-existed with an "R&D tax allowance" (focusing on the outcome of R&D activities) from 1988 to 2010. In order to make the Austrian tax scheme simpler and more consistent, the tax allowance was suppressed in 2010, effectively leaving the tax credit as the sole instrument.

As mentioned earlier, eligibility conditions for an R&DTC may vary widely across countries, which results in tax bases (or, in the case of tax credit, the base for a tax rebate) varying along multiple dimensions. First, tax credits can be **incremental** (i.e., based on the yearly variation in R&D expenditures) or **volume-based** (i.e., based on the yearly volume of R&D expenditures, possibly with respect to a year of reference). The latter form of tax credit make it easier for firms to obtain tax rebates, but whether it gives them a strong incentive to increase R&D expenditures remains doubtful. Nonetheless, R&DTCs are currently volume-based (or primarily volume-based) in all selected countries except in Italy, where an incremental tax credit prevails. The French R&DTC that existed between 1983 and 1999 was also primarily incremental¹⁵ (it coexisted with a volume-based tax credit between 1987 and 1990). In the Czech Republic, a small incremental component may be added to the main R&DTC, which is volume-based. Overall, the current prevalence of volume-based tax credits would likely facilitate a possible harmonization, and indeed the super-deduction conceived in the 2016 CCCTB proposal is volume-based.

The tax base can also vary with **firm size** and with the **industry** in which a firm operates. Thus, the rate of the R&DTC in Italy during 2000-2014 was of 20 to 30% for SMEs (depending on regions), versus 15 to 25% for medium-sized firms and 10 to 20% for large ones. In the UK¹⁶, the R&DTC introduced in 2000 was originally available to SMEs only and a different regime for larger companies was introduced in parallel in 2002. The former could deduce 50% of their R&D personnel expenses from their taxable profit, whereas the latter could deduce 25%. In 2008, these amounts could be as high as 75% of R&D personnel expenses for SMEs and 30% for large firms. In the Netherlands, the amount of the 1998 tax credit was of 40% of "knowledge workers" wages in SMEs versus 17% in large firms. In 2004, it was raised to 42% for SMEs and reduced to 14% for large firms.

By contrast, in France, the current R&DTC does not formally distinguish between SMEs and large firms¹⁷, but the amount of the tax credit varies with respect to the investment in R&D. It is equal to 30% for investments lower than EUR 100 millions and 5% for investments above this threshold. In effect, since SMEs typically invest lower amounts in R&D, they will benefit from the higher tax credit – but this scheme also let large firms benefit from the same rate (provided their investment remains below the threshold), which is not the

¹⁵ For instance, from 1985 onwards, the tax rebate was equal to 50% of the variation of a firm's R&D expenditures between year t and $t-1$.

¹⁶ See for instance <https://forrestbrown.co.uk/rd-tax-credits-explained/> for a business-oriented presentation of the British R&DTC scheme.

¹⁷ In the sense that the applied rates and threshold are the same for SMEs and large firms. The main difference is that refund is immediate for SMEs, whereas it occurs after 3 years for large firms.

case in the UK or in the Netherlands. Not only may this feature of the French tax credit give large firms an incentive to under-invest, it may also make harmonization more difficult.

R&DTC regimes may also be industry-specific, either targeting certain industries or excluding some industries. For instance, prior to 1992, agricultural and textile firms could not benefit from the French R&DTC. In the UK, since 2008, pharmaceutical firms doing vaccine research can deduce about 40 to 50% of their R&D personnel expenses from their taxable profit – this is, in effect, a specific regime, distinct from both the SME regime and the large company regime. In the super-deduction proposed with the 2016 CCCTB (and presumably with its successor), a specific regime for newly-created small firms would apply, as stated in Footnote 9.

Another dimension in which tax bases vary is the existence of a **ceiling** to the R&DTC. Most countries impose a ceiling, and among our selection all have, at some stage, imposed one, except for Czech Republic. In France, the tax credit introduced in 1983 had a ceiling of FF 3 millions (approximately 900 000 euros¹⁸), which was raised up to 5 millions (about EUR 1.3 millions) in 1985 and 10 millions (about EUR 2.5 millions) in 1987. A ceiling still existed in the early 2000's, but was finally suppressed in 2008, probably because it kept on rising (from EUR 8 millions in 2004 to EUR 10 millions in 2006 and EUR 16 millions in 2007). The super-deduction included in the 2016 CCCTB proposal does not impose a ceiling: R&D expenditures are fully deductible from the consolidated corporate tax. A threshold of EUR 20 million exists, however, for additional deductions: an additional 50% deduction is available under the threshold, whereas the additional deduction is of “only” 25% beyond the threshold.

Last but not least, the **contents** of R&D expenditures that entitle firms to a tax rebate vary hugely across country. In the Netherlands, the expense base for the R&DTC is restricted to R&D wages (and social contributions). In Belgium, it primarily consisted in R&D wages as well, but has been extended to include capital assets. Investments in R&D are eligible to the tax credit provided they have no harmful effect on the environment (a condition which does not exist in the other four countries). In the remainder of our selected countries, the expense base includes all R&D expenditures (reported as such in a firm's accounts). Of all these countries, France may be the one where the definition of R&D expenditures is the broadest. For instance, they include external R&D conducted in any European Economic Area (EEA) country. The expense base may also include items that are beyond the actual expenses. Thus, 200% of the wages (and overheads) of young Ph.D. graduates are tax deductible, provided that the graduates are hired on a long-term contract. In the 2016 CCCTB proposal, the super-deduction is supposed to bear on all R&D costs incurred in a given year, with the exception of immovable property.

2.2. Implications of Brexit

One of the countries on which this study focuses is the UK, which was an EU Member State over the observation period (late 1970's to late 2010's) but has officially left the EU in January 2021, at the end of the 4-year process known as Brexit. Although it may be too early to provide a definitive answer, the economic consequences of Brexit seem to have been mostly negative for the UK. Well before the June 2016 referendum on Brexit, a panel of 150 leading academic economists¹⁹ (including 12 Nobel laureates) had warned that leaving the EU would likely result in a drop of investment in the UK, harming both innovation and job

¹⁸ We did all conversions of French francs to euros using the online tool of the French National Statistical Institute (INSEE), <http://www.insee.fr/fr/service/reviser/calcul-pouvoir-achat.asp>², which takes long-term inflation into account.

¹⁹ “Economists for remain”, see: <https://economistsforremain.org/>

growth. Although their warning has not been heeded, their predictions have been confirmed by the stylized facts observed in the three years following the referendum, namely a slower of GDP and a lower productivity (De Lyon and Dhingra, 2019; House of Commons Library, 2020) even before the pandemic struck in 2020.

The answer proposed by supporters of Brexit primarily consisted in drastically lowering tariffs and corporate taxes, a policy which is consistent with R&DTCs. But Brexit addresses many challenges to the UK's science and technology policy and it is unlikely that these R&DTCs, however generous, suffice to answer these challenges. Despite the post-pandemic crisis and budget cuts, the environment for research and innovation in the EU remains head and shoulders above the one that the UK may offer. To the best of our knowledge, no specific agreement on scientific cooperation has been reached during the Brexit negotiations, which places UK science in delicate situation.

In a newspaper article published on June 27th, 2016 in *The Guardian*, one of the UK's leading experts in the economics of innovation warned that "*[c]ollaboration across the continent has made Europe a powerhouse for science. Britain gained disproportionately from EU research funding. The loss of this funding will create a real gap, making our low productivity even harder to resolve*" (Mazzucato, 2016). This opinion reflects that of the majority of the UK's academic and scientific community: "*(...) the majority of evidence suggested that the regulatory harmonisation brought about by the EU was of benefit to the UK. Such harmonisation can provide a strong platform for collaboration and commercialisation in science and research. The Academy of Medical Sciences (AMS) corroborated this perspective and suggested that the collaborative potential brought about by harmonisation warrants the "burden" of engaging with regulatory processes*". (House of Lords, 2016, p. 12).

More recently, a report published by the Wellcome Trust has emphasized the importance for the UK to secure its research relationship with the EU: "*One of the most research-intensive areas of the world is on the UK's doorstep. Europe, including the UK, produces a third of the world's scientific publications with just 7% of the global population. Any country that aims to be a science superpower must have an effective partnership with the EU, due to its scientific strength and density of talent*". (Wellcome Trust, 2020, p. 10). The report also stresses that it is vital for UK research to be formally associated with the EU's Horizon Europe program, as a first step to building worldwide research collaborations.

To narrow things down to R&DTCs, policy instruments that have close connections to Horizon Europe and its ambitions for the ERA, let us consider once again the "super deduction" associated with the 2016 CCCTB package (and presumably with the new BEFIT proposal, if it came into being). Its implications for UK science and technology policy are twofolds. First, British firms may be entitled to this deduction if they chose to relocate their activities (or part of their activities) in the EU. A British company may thus decide to install R&D facilities on the continent, in order to benefit both from the tax deduction and from the scientific environment provided by the EU. If many British firms choose to do so, the UK might lose a significant share of its in-house R&D. This depends on the extent to which UK industries rely on R&DTCs to innovate, something on which our empirical analysis will shed some additional light. The second implication pertains to tax competition: if the UK wants to attract foreign firms and investments through lower corporate taxes, it will enter into a form of tax competition with the EU CCCTB (or its successor) and the associated super deduction on R&D. While the UK might be able to propose a corporate tax attractive enough to large multinational firms that would not want to opt for the CCCTB, it will probably not be able to design a more attractive R&DTC than the super deduction proposed by the EU. This could harm the UK's attractiveness towards innovative, R&D-intensive firms, which would aggravate the first, above-mentioned implication.

3. Empirical analysis

There exists a large literature on the evaluation of R&DTCs, the bulk of which uses micro-data to estimate the effect of specific tax credit schemes on R&D expenditures within countries. These studies rely primarily on structural approaches in IV settings and more rarely on quasi-experimental methods like differences-in-differences (DID).²⁰ A detailed review of this literature would go far beyond the scope of the present paper. The interested reader will find a very thorough one in the 122 pages long report on R&D tax incentives addressed by Straathof *et al.* (2014) to the EC²¹ and a less systematic but more recent one in Bloom *et al.* (2019). When we discuss our results in Section 4, we will naturally refer for comparison to the relevant key references mentioned in these reviews.

Our study finds its own place in this already abundant literature, as we exploit a panel of 13 industries observed for more than 30 years²² across our 8 selected EU countries to address two challenges highlighted in the above-mentioned reviews. The first is the dearth of cross-country comparisons on the effectiveness of R&D tax incentives. There are good reasons for this. On the one hand, harmonized innovation survey micro-data does not necessarily provide precise information on tax incentives, and cross-country comparisons that use this type of data ideally require an international team of researchers. These constraints explain why a comparative study like Czarnitzki and Lopes-Bento (2012) had to focus on a broad measure of public R&D subsidies (and not on tax incentives) and on an *ad-hoc* selection of countries (the Flanders region of Belgium, Germany, Luxembourg and South-Africa). On the other hand, macro-econometric studies like Bloom *et al.* (2002) generally rely on country-level data (a panel of 9 countries observed over 18 years, in the case of these authors), and can only estimate an averaged effect of R&DTCs across all countries.

Since our primary interest lies in comparing EU countries, we address this first challenge head-on. Industry-level panel data is particularly well suited to international comparisons, especially when the number of industries and/or years is large enough to allow for within-country estimations, as is the case with our panel, which we present in detail in Sub-Section 3.1.

The second challenge is that most studies focus on the impact of R&DTCs on R&D expenditures, and not on innovation, let alone productivity. Again, we are able to tackle this challenge head-on, because our panel provides us with a good proxy for innovation output (patenting intensity) and with a rigorously-constructed measure of productivity (an index of Total Factor Productivity growth).

An obvious shortcoming of industry-level data, compared for instance to firm-level data, is that it does not provide precise information on the specifics of a given tax credit scheme. However, we have collected precise information on the *timeline* of R&DTCs in each selected country, and we can use this information for econometric identification and statistical inference. Exploiting the rich time-series dimension of our panel, what we measure is thus the impact of doing R&D *when tax incentives are available*, compared to doing R&D in periods when such schemes are not available. Our methodology is detailed in Sub-Section 3.2. The above-mentioned shortcoming is, in our opinion, more than offset by what our panel allows us

²⁰ Recent exceptions include Bozio *et al.* (2014) et Dechezleprêtre *et al.* (2016). Bozio *et al.* (2014) exploit the major 2008 reform of the French R&DTC to estimate its impact on R&D and innovation in the early 2010's – a drawback to this approach being that it does not allow the authors to estimate the long-term impact of the French R&DTC. Dechezleprêtre *et al.* (2016) conduct a similar study in the UK to study the R&D and innovation effect of a less drastic reform (a change in eligibility thresholds) over 2006-2011.

²¹ The review encompasses works conducted on non-EU and non-European countries.

²² From the late 1970s/early 1980s to the late 2010s, depending on the country.

to do, i.e., capture the long-run dynamics of R&D, innovation and productivity across a relevant selection of EU countries, with and without R&D tax incentives, prior to a planned harmonization of these incentives.

3.1. Data and variables

Our primary data source was the EU-KLEMS database (Stehrer *et al.*, 2019), originally compiled by the Groningen Growth and Development Centre (GGDC) and currently run by the Vienna Institute for International Economic Studies (WIIW). The latest release²³ covers the years 1995 to 2017, while previous releases²⁴ allow researchers to cover a period ranging from the late 1970s to 1995. We completed this data with information from linked OECD and EUROSTAT databases. Our key variables are R&D intensity, patenting intensity and Total Factor Productivity (TFP).

We use two alternative measures of R&D intensity, which correspond to the two definitions that are generally found in the literature: (1) the ratio of R&D capital stock²⁵ to the number of hours worked each year in each industry and (2) the ratio of R&D capital stock to the Value Added (VA) measured each year in each industry.

Patenting intensity is simply defined as the number of patents divided by the number of hours worked. The number of patents is the number of patent applications to the European Patent Office (EPO) by sector of economic activity (EUROSTAT, Sciences & Technology database). A concordance matrix between the International Patent Classification (IPC) and the NACE industry classification then allows patent applications to be distributed across industries for a given country (Schmoch *et al.*, 2003). The division by hours worked yields a continuous aggregate indicator of innovation intensity. We use patenting intensity as a proxy for innovation broadly speaking. We are well aware that patents are not the only output of the innovation process, and that much innovation can occur without patenting. Our rationale for using patenting as a proxy for innovation is that we are conducting an industry-level (not a firm-level) analysis, and more innovative industries are likely to produce more patents on average. Thus, the intensity of patenting in an industry reflects the intensity of innovation, broadly defined, that occurs within this industry.

Finally, our measure of TFP is the TFP growth index computed at the industry level by the EUKLEMS team on the basis of VA and expressed in base 100 for the year 2010. As explained earlier, we will measure the effect of R&DTCs by comparing periods without tax credits to periods that saw the implementation of an R&DTC. We therefore add to our main variables dummy variables that indicate whether an R&DTC is implemented in year t in the country to which industry i belongs.

Since our panel of industries has a long time dimension (around 30 years in most countries), our variables of interest may display a behavior that is more typical of time series than of panel data. In particular, we need to check their stationarity, since non-stationary variables would lead to invalid econometric inference. To do so, we conduct unit root tests adapted for panel data. We thus perform Im-Pesaran-Shin (IPS) tests (Im *et al.*, 2003) on the logarithms of all of our variables. For each panel variable x_{it} , the IPS test statistic is built as the average of the usual Augmented Dickey-Fuller (ADF) test statistic computed for each time series in the variable (i.e., x_{1t} , x_{2t} , ..., x_{nt}). We compute the ADF test statistics using Autoregressive Distributed Lags (ADL) models with drift and trend. We implement a version of the IPS test that allows the errors of the underlying ADL models to be serially correlated. The results of the IPS tests are displayed in Table 1. The tests shows that all our variables are

²³ 2019 release, available at <https://euklems.eu/>

²⁴ Available at <http://euklems.net>

²⁵ Provided by the EU-KLEMS linked database, derived from OECD ANBERD.

stationary in all countries, except for the log-R&D intensities in the UK and, to a lesser extent, in Austria. We will address this non-stationarity issue by using the first-differenced variables²⁶ in our econometric modeling. This only requires minimal modifications in the modeling for these two countries because the baseline econometric models already include lagged variables, as will be seen in Sub-Section 3.2.

TABLE 1 ABOUT HERE

We further describe our sample in the Appendix. We first present the list of industries in Table A1. We also present our innovation variables²⁷ (R&D intensities and patenting intensity) by industry for each selected country in Figures A1 to A3. In all countries except Czech Republic, we observe an overall increasing trend in R&D intensity defined with respect to hours worked. At the end of the period, this measure of R&D intensity is the highest in Belgium, France, and the Netherlands closely followed by the UK. It is at its lowest in Czech Republic. Although the increasing trend concerns most industries, we notice that, in each selected country, a couple of industries are more R&D-intensive than the rest. These are primarily “Chemicals and Chemical products” and “Electric, Electronic and Optical Equipment”, with some country-specific R&D champions like “Transport equipment” in France and Italy and “Coke, Petroleum and Nuclear fuel” in France, Spain and the UK.

Things are much more contrasted with the second measure of R&D intensity, defined with respect to VA. Although an increasing trend can still be observed in countries like Austria or France, a certain stagnation prevails in many other countries, like the Netherlands, sometimes accompanied by a decrease in certain industries, like in Czech Republic, Italy and the UK. In Belgium, overall stagnation is accompanied by an increasing trend in the “Electric, Electronic and Optical Equipment” industry. In Spain, R&D intensity slightly increases in some “traditional” industries but decreases in supposedly more innovative ones like the “Chemicals and Chemical products”, “Electric, Electronic and Optical Equipment” and “Transport equipment” industries.

Rather reassuringly for the R&D-innovation relationship, we observe that patenting intensity follows the same increasing trend as our first measure of R&D intensity, although a slight decline may be observed in two UK industries (“Chemicals and Chemical products” and “Transport equipment”). At the end of the period, patenting intensity is at its highest in Belgium, the Netherlands and France, like R&D intensity was. We also notice that, in each country, the most R&D-intensive industries are also the most patent-intensive ones, which, again, is reassuring for the R&D-innovation relationship that is at the heart of the Horizon Europe strategy.

3.2. Methodology

3.2.1. IV regressions for countries with a single phase of R&DTC

The first analyses we conduct on our panel of industries consist in estimating, within each selected country, a structural econometric model that relates (log-)patenting intensity to past (log-)R&D intensity, and past (log-)R&D intensity to its own lag.²⁸ Assuming that the lag

²⁶ The first-differenced variables are stationary. Their IPS test statistics are featured under Table 1.

²⁷ In order to save space, we do not present TFP. Summary statistics for this variable can be found on the EU-KLEMS websites and in their related literature, e.g. Adarov and Stehrer (2019).

²⁸ Since the introduction of the tax credit in these countries is comparatively recent, and since the sample size in some countries is comparatively small, we prefer keeping to one-year lags between patenting and R&D on the one hand and between current and past R&D on the other.

has a direct effect on R&D but not on patenting, the model can be specified as an IV model. Based on the literature initiated by Hall *et al.* (1986), this assumption is reasonable provided one controls for industry-specific and time-specific effects. We introduce R&D both as a single regressor and in interaction with indicators of the time period in which the R&DTC was implemented. Formally, using i and t as the respective indices of industry and year, this model²⁹ can be written as:

$$\begin{aligned} \ln PI_{it} &= \beta_{11} \ln RD_{it-1} + \beta_{12} \ln RD_{it-1} \times TC_{t-1} + u_{1i} + v_{1t} + w_{1it} \\ (1) \quad \ln RD_{it-1} &= \beta_{21} \ln RD_{it-2} + \beta_{22} \ln RD_{it-2} \times TC_{t-2} + u_{2i} + v_{2t} + w_{2it} \\ \ln RD_{it-1} \times TC_{t-1} &= \beta_{31} \ln RD_{it-2} + \beta_{32} \ln RD_{it-2} \times TC_{t-2} + u_{3i} + v_{3t} + w_{3it} \end{aligned}$$

where PI denotes patenting intensity, RD denotes R&D intensity and TC_t is a dummy variable equal to 1 if an R&DTC exists in year t and to 0 otherwise. This dummy variable, in interaction with the log-R&D intensity, captures the effect of doing R&D when an R&DTC is available. Each equation j ($j = 1, 2, 3$) includes an industry fixed effect u_{ji} , a time fixed effect v_{jt} and a random error w_{jit} . All of the selected countries except France have known a single phase of R&DTC that was still ongoing at the end of the observation period. Therefore, estimating Model (1) in these countries is equivalent to splitting the sample into two periods (“before” the introduction of the R&DTC, and “after” its introduction) and estimating a simpler model, without interaction term, in each sub-sample. We will apply a different model to France, where the R&DTC scheme encompasses several well-distinct phases (see Sub-Section 2.1). We will dedicate Point 3.2.2. to this model.

Model (1) is an IV model with two endogenous variable in the second-stage equation (the “ $\ln PI_{it}$ ”, or “patenting intensity”, equation) and, therefore, two first-stage equations (the “ $\ln RD_{it-1}$ ” and “ $\ln RD_{it-1} \times TC_{t-1}$ ”, or “R&D intensities”, equations). We estimate Model (1) using fixed-effect two-stages least squares (FE-2SLS) with heteroskedasticity- and autocorrelation-consistent (HAC) standard errors, using the `ivreg2` and `xtivreg2` software components developed by Baum *et al.* (2007) and Schaffer (2010). As a sensitivity analysis, we experimented with two alternative estimators, (1) the Generalized Method of Moment (GMM) and (2) Limited Information Maximum Likelihood (LIML), and found that this did not qualitatively affect our results. Both alternative estimators yielded very close estimates for the key parameters of the model. These alternative estimates are available upon request.

In Model (1), applied to our data as explained above, some coefficients of specific interest are β_{32} , β_{31} , β_{11} and β_{12} . Coefficient β_{32} measures the effect on current R&D intensity of past R&D conducted *when an R&DTC is available* while β_{31} measures the baseline effect on current R&D intensity of past R&D intensity conducted *in the absence of R&DTC*. Similarly, coefficient β_{12} measures the effect on patenting intensity of past R&D conducted in the presence of a tax credit, while β_{11} measures the baseline effect of R&D on patenting intensity. The estimate of β_{32} corresponds in our framework to what is known in the literature as *input additionality* or *bang for the buck* (BFTB), i.e. as the share of R&D expenditures attributed to the R&DTC, with respect to the size of the tax credit itself. For this reason, comparing the estimate of β_{32} to the estimate of β_{31} will give some appreciation as regards the effectiveness of R&DTCs. Our econometric modeling make our estimation of input additionality falls within what Straathof *et al.* (2014) call the “direct approach”, because it does not rely on the

²⁹ Equation (1) is actually the benchmark specification of our model. We experimented with more elaborated specifications including additional regressors such as the export share of production (to control for innovation driven by international demand). Besides consuming precious degrees of freedom, these additional controls were overall insignificant and did not change the results of our benchmark specification.

intermediate economic decision variable known in the literature as the *user cost of R&D*.³⁰ In the second-stage equation, the estimate of $\beta_{11} + \beta_{12}$ provides a measure of the elasticity of patenting with respect to R&D intensity, with β_{12} measuring the contribution of R&D conducted during a phase of R&DTC to this elasticity. Model (1) can be interpreted as an empirical representation of the so-called "innovation production function". We thus expect elasticity $\beta_{11} + \beta_{12}$ to be positive. The larger this elasticity, the higher the degree of "innovativeness" or "innovativity" in the country of interest (Mairesse and Mohnen, 2002; Mohnen et al., 2006).

After estimating Model (1), we try to push things further by estimating a variant of Crépon, Duguet and Mairesse (1998)'s structural model (generally referred to as CDM) of the R&D – innovation – productivity relationship. Our version of this model is specified as:

$$\begin{aligned}
 \ln \widehat{\text{TFPG}}_{it} &= \alpha_1 \widehat{\ln PI}_{it} + u_i + v_t + \omega_{it} \\
 \ln PI_{it-1} &= \beta_{11} \ln RD_{it-2} + \beta_{12} \ln RD_{it-2} \times TC_{t-2} + u_{1i} + v_{1t} + w_{1it} \\
 \ln RD_{it-2} &= \beta_{21} \ln RD_{it-3} + \beta_{22} \ln RD_{it-3} \times TC_{t-2} + u_{2i} + v_{2t} + w_{2it} \\
 \ln RD_{it-2} \times TC_{t-2} &= \beta_{31} \ln RD_{it-3} + \beta_{32} \ln RD_{it-3} \times TC_{t-2} + u_{3i} + v_{3t} + w_{3it}
 \end{aligned}
 \tag{2}$$

where TFPG is the TFP growth index provided by EU-KLEMS and where the "hat" symbol on the $\ln PI_{it}$ variable in the first equation (i.e., the TFP equation) indicates that this variable is the predicted value from the previous equation (i.e. the patenting intensity equation). Model (2) can thus be seen as an extension of Model (1) with a third stage dedicated to TFP, α_1 measuring the effect of innovation on TFP growth. If growth is driven by innovation, then one should expect α_1 to be positive. If innovation is indeed fed by R&D, as the "innovation production function" framework suggests, then R&D may have an indirect effect on growth, mediated by innovation. And if R&DTCs do spur R&D, then they in turn may have an effect on growth. Model (2) allows us to examine the empirical relevance of this supposed relationship. We estimate it by FE-2SLS with HAC standard errors, using the same procedure and software components as for Model (1). In addition, we bootstrap the standard errors in the productivity equation to account for predicted regressor bias.

3.2.2. "L'exception française".

France has experimented with different phases of R&DTC in a sense that set the country apart in our selection of EU member States. In all countries, there can be changes in R&DTC schemes, but these changes correspond to comparatively minor adjustments (typically, a change in the share of R&D expenditures that can be claimed back by R&D-doing firms). In France, the different phases correspond to deeper changes that can radically alter the design of the tax credit scheme. The French R&DTC was originally introduced in 1983 as an experiment. It was an incremental scheme (see Sub-Section 2.1) set for a fixed period of time (five years), at the end of which its relevance was examined, and the decision to proceed or not with the scheme was taken. This lasted from 1983 to 1998, and the 1999-2003 period was the final five-year renewal period of the original R&DTC. In 2004, a new R&DTC scheme was introduced, on a permanent basis. This new scheme remained primarily incremental (as the original scheme had been), but now comprised a volume-based component. Finally, a major reform made the R&DTC completely volume-based in 2008.

³⁰ The user cost of R&D capital is a measure of the actual costs of R&D for a firm eligible to a tax credit.

To account for this relatively tumultuous history, we have to distinguish at least four periods of implementation in our empirical analysis. These periods correspond to major changes in the tax credit scheme: (i) 1983-1998 is the period of the original incremental tax credit; (ii) 1999-2003 is its final five-year renewal period, with uncertainty regarding the existence of a tax credit in the future; (iii) 2004-2007 is the period in which the tax credit, now primarily incremental with a volume-based component, was made permanent; (iv) 2008 to 2017 (final year in the 2019 EU-KLEMS database) is the period in which the tax credit has become wholly volume-based. This leads us to adapt Model (1) as follows:

$$\begin{aligned} \ln PI_{it} &= \beta_{11} \ln RD_{it-3} + \beta_{12} \ln RD_{it-3} \times TC1_{t-3} + \beta_{13} \ln RD_{it-3} \times TC2_{t-3} + \beta_{14} \ln RD_{it-3} \times TC3_{t-3} \\ &\quad + \beta_{15} \ln RD_{it-3} \times TC4_{t-3} + u_{1i} + v_{1t} + w_{1it} \\ \ln RD_{it-3} &= \beta_{21} \ln RD_{it-4} + u_{2i} + v_{2t} + w_{2it} \\ \ln RD_{it-3} \times TC1_{t-3} &= \beta_{31} \ln RD_{it-4} \times TC1_{t-4} + u_{3i} + v_{3t} + w_{3it} \\ (3) \quad \ln RD_{it-3} \times TC2_{t-3} &= \beta_{41} \ln RD_{it-4} \times TC2_{t-4} + \beta_{42} \ln RD_{it-4} \times TC1_{t-4} + u_{3i} + v_{3t} + w_{3it} \\ \ln RD_{it-3} \times TC3_{t-3} &= \beta_{51} \ln RD_{it-4} \times TC3_{t-4} + \beta_{52} \ln RD_{it-4} \times TC2_{t-4} + u_{3i} + v_{3t} + w_{3it} \\ \ln RD_{it-3} \times TC4_{t-3} &= \beta_{61} \ln RD_{it-4} \times TC4_{t-4} + \beta_{62} \ln RD_{it-4} \times TC3_{t-4} + u_{3i} + v_{3t} + w_{3it} \end{aligned}$$

where $TCj_t = 1$ if France was in phase j of its R&DTC at time t , and $TCj_t = 0$ otherwise (the period of reference is 1980-1982, when no R&DTC existed). The other variables and parameters are defined as in Model (1).

Although both are empirical representations of the "innovation production function", Model (3) and Model (1) present some noticeable differences. First, due to the comparatively longer history of R&DTC in France, we are able to experiment with longer lags in the patenting equation. Doing so is relevant because later contributions in the vein of Hall *et al.* (1986) (such as van Ophem *et al.*, 2002 and Gurmu and Pérez-Sebastián, 2008) have found stronger lagged effects in some countries in the more recent period. Based on this literature, we assume a 3-year lag between patenting intensity and our various measures of R&D intensity. We also experimented with a one-year lag as in Model (1), but this did not change qualitatively our results – some estimated parameters were just slightly less significant. In order to capture the dynamics of knowledge accumulation and the effect of passing from one phase of R&DTC to the next, each interacted R&D intensity variable is instrumented with its own lag *plus* the lag of the interacted variable that corresponds to the previous phase of R&DTC. Baseline R&D is instrumented with its own lag only.³¹

While Model (3) is technically an IV model, its specification is less straightforward than that of Model (1), which is closer to textbook standard. The software components on which we relied in 3.2.1 to estimate Model (1) do not accommodate the estimation of as convoluted a model as Model (3). We therefore estimate Model (3) by 3-Stages Least Squares with industry fixed effects (FE-3SLS) and perform post-estimation tests for heteroskedasticity and for the autocorrelation of the random errors.

As was already the case in the other selected countries, the model can readily be extended to a CDM-type model by adding a productivity equation:

³¹ Because of the succession of four distinct phases of R&DTC, instrumenting the baseline R&D intensity with the interacted R&D intensities makes less sense here than in Model (1). When we did so as a sensitivity analysis, we found that these other "instruments" were actually non significant and thus useless for statistical inference.

$$\ln \text{TFPG}_{it} = \alpha_1 \ln \text{PI}_{it-1} + v_i + v_t + \omega_{it}$$

$$\ln \text{PI}_{it-1} = \beta_{11} \ln \text{RD}_{it-4} + \beta_{12} \ln \text{RD}_{it-4} \times \text{TC1}_{t-4} + \beta_{13} \ln \text{RD}_{it-4} \times \text{TC2}_{t-4} + \beta_{14} \ln \text{RD}_{it-4} \times \text{TC3}_{t-4} \\ + \beta_{15} \ln \text{RD}_{it-4} \times \text{TC4}_{t-4} + u_{1i} + v_{1t} + w_{1it}$$

$$\ln \text{RD}_{it-4} = \beta_{21} \ln \text{RD}_{it-5} + u_{2i} + v_{2t} + w_{2it}$$

$$(4) \ln \text{RD}_{it-4} \times \text{TC1}_{t-4} = \beta_{31} \ln \text{RD}_{it-5} \times \text{TC1}_{t-5} + u_{3i} + v_{3t} + w_{3it}$$

$$\ln \text{RD}_{it-4} \times \text{TC2}_{t-4} = \beta_{41} \ln \text{RD}_{it-5} \times \text{TC2}_{t-5} + \beta_{42} \ln \text{RD}_{it-5} \times \text{TC1}_{t-5} + u_{3i} + v_{3t} + w_{3it}$$

$$\ln \text{RD}_{it-4} \times \text{TC3}_{t-4} = \beta_{51} \ln \text{RD}_{it-5} \times \text{TC3}_{t-5} + \beta_{52} \ln \text{RD}_{it-5} \times \text{TC2}_{t-5} + u_{3i} + v_{3t} + w_{3it}$$

$$\ln \text{RD}_{it-4} \times \text{TC4}_{t-4} = \beta_{61} \ln \text{RD}_{it-5} \times \text{TC4}_{t-5} + \beta_{62} \ln \text{RD}_{it-5} \times \text{TC3}_{t-5} + u_{3i} + v_{3t} + w_{3it}$$

We estimate Model (4) by FE-3SLS and perform post-estimation tests for heteroskedasticity and for the autocorrelation of the random errors. We do not need to bootstrap the standard errors in the productivity stage equation because the standard deviation formulas of 3SLS already accounts for possible predicted regressor biases.

4. Findings and discussion

4.1. Countries with a single phase of R&DTC

We display in Table 2 the results we obtained for the seven selected countries with a single phase of R&DTC. The left-hand side panel of Table 2 features the results obtained when R&D intensity is defined with respect to employment (number of hours worked), while the right-hand side panel features those obtained when R&D intensity is defined with respect to VA. The first striking result is that, no matter what measure we use, past R&D feeds current R&D in all countries except Austria.³² More specifically, baseline R&D correlates with its lag and the interacted term indicating R&D conducted during a phase of tax credit correlates with its own. The latter result confirms that doing R&D when an R&DTC is available is conducive to more R&D. The associated coefficient, β_{32} , can be interpreted in terms of additionality (see 3.2.1). A glance at Table 2 reveals that this coefficient is close to 1 in all countries except Belgium, where it is closer to 0.75.³³

An input additionality close to one means that firms spend on R&D every euro they save on taxes. Our finding is consistent with the literature. For instance, in Italy, Caiumi (2011) finds, using firm-level data, that a tax cut of EUR 1 leads to an additional investment in R&D of EUR 0.86. In the Netherlands, Lokshin and Mohnen (2012), using simulations on firm-level data, find an estimate of input additionality roughly equal to 1 in the short run (i.e., in the first four years of the tax credit), which goes down to 0.5 in the long run (i.e., after fifteen years). In Belgium, Dumont (2013), using a panel of firms, finds estimates of input additionality equal to 0.79 for an R&DTC targeting young innovative companies and to 0.82 for an R&DTC granted to firms that hire R&D personnel with a Master's degree. It seems that results obtained using firm-level data are persistent at our more aggregated industry-level of

³² This exception is likely due to the fact that in Austria (1) the R&D variables are used in first-difference to ensure stationarity and (2) the period of observation is comparatively small.

³³ In Belgium, when R&D intensity is defined with respect to hours worked, a small effect of baseline R&D (estimated at 0.17) can be added to the 0.75 estimate to reach a value of 0.92, similar to what is observed elsewhere.

analysis (which makes sense since all the econometric analyses at hand aim at estimating *average* effects).

TABLE 2 ABOUT HERE

The relationship between innovation (as measured by patenting intensity) and R&D is much more difficult to identify than the dynamics of R&D described in the above paragraphs. In the patenting equation, Belgium, Czech Republic and Spain are the only countries where we observe a positive association between innovation and R&D. In Belgium and Spain, this association holds for both measures of R&D intensity, whereas in the Czech Republic it is only valid with the first measure (R&D stock per hours worked) and only holds for baseline R&D intensity. In Belgium and Spain, the estimated elasticity of patenting to R&D conducted when an R&DTC is available is equal to about 0.20 overall, no matter which definition of R&D intensity we retain. In Spain, this elasticity comes in addition to an estimated elasticity of patenting to baseline R&D of about 0.30 to 0.40 (depending on which definition of R&D intensity is used). In Belgium, it stands alone – which could be due to the existence, for a number of years, of "patent boxes" in parallel to the R&DTC. By contrast, the Spanish result could be driven by the generosity of the tax credit (one of the most generous in Europe, according to Straathof *et al.*, 2014).

This second finding is somewhat less optimistic than those reviewed in Straathof *et al.* (2014), who consider that “[o]verall, studies on the effectiveness of R&D tax incentives tend to find a positive impact on innovation.” (p. 38). Indeed, Ernst and Spengel (2011) find that R&D tax incentives have a positive effect on patenting in Europe. However, this study does not use cross-country comparisons *per se*, but relies on a database pooling patents applied for at the EPO, from various European countries. Similarly, Westmore (2013), using a panel of OECD countries (with the country as the relevant unit of analysis) finds that R&D incentives are positively associated with patenting at the OECD level. But, again, the nature of the data is such that the author can only derive a global estimate and cannot conduct cross-country comparisons. Compared to these studies, the relationship between innovation and R&D is likely to be more tenuous and difficult to identify at the industry level, especially after controlling for unobserved heterogeneity with fixed effects and accounting for endogeneity, heteroskedasticity and autocorrelation of the error terms as we do here.

TABLE 3 ABOUT HERE

As can be seen in Table 3, the results pertaining to TFP are even more tenuous. We find that patenting intensity is associated with a higher TFP growth in three countries only: Italy, the UK and, to a lesser extent, the Netherlands. These countries are not those where we observed a relationship between patenting and the R&D conducted when an R&DTC was available. The supposedly virtuous circle leading from R&D to growth through innovation is thus even more difficult to identify at our level of analysis than the relationship between R&D and innovation.

4.2. Effects of the French R&DTCs

We now turn to the estimates of Model (3), dedicated to France, which we present in Table 4. A first striking feature, observable with both measures of R&D intensity, is that, as we already observed the other countries of our selection, past R&D feeds current R&D. Past baseline R&D investments are associated with higher investments in baseline R&D and past R&D conducted during a phase of R&DTC is associated with more R&D in that phase

(and/or in the next one). Thus the different phases of R&DTC in France seem to have contributed to the dynamics of R&D investment.

TABLE 4 ABOUT HERE

Whatever the measure of R&D intensity we consider, input additionality³⁴ is close to 1 in the first three phases of the French R&DTC (which goes hand in hand with what we observed in the other countries of our selection) and slightly above one in the fourth and final one, when the tax credit became volume-based.³⁵ More precisely, when R&D intensity is defined with respect to hours worked, input additionality is equal to 0.87 in the first phase, $(0.80 + 0.06 =) 0.86$ in the second phase, $(0.20 + 0.75 =) 0.95$ in the third phase and $(0.24 + 1 =) 1.24$ in the final phase. When R&D intensity is defined with respect to VA, these figures amount to 0.87, 0.76, 0.90 and 1.20 respectively, which is overall very close. The interpretation of these figures are as follows: when input additionality is close to 1, firms invest every euro they save on taxes in R&D, as explained in Sub-Section 4.1. When input additionality is larger than 1, i.e. around 1.20 or 1.24, then firms spend 20% to 24% more than they receive as a tax credit.

Finding an estimate of input additionality close to 1 in the first three phases of the French R&DTC is consistent with the literature on the French tax credit. Thus, Duguet (2012), using Propensity Score Matching on firm-level data, finds an estimate of input additionality equal to 1 prior to 2003, an observation period which corresponds to our first two phases. Over 2000-2007 (which roughly corresponds to our second and third phases), Mulkay and Mairesse (2013), using a more structural approach, find an input additionality³⁶ of about 0.7. Relying on simulations to assess long-run additionality after the 2008 reform (which made the tax credit fully volume-based), they conclude that additionality should gradually rise above 1 in the five years following the reform, and then slowly decrease to 0.7 by 2020. Our estimate of 1.20 in the fourth phase is in line with these previsions – although we do not observe the expected long-run decline.

Our second important result concerns the patenting equation, which allows us to identify a significant relationship between patenting intensity and R&D intensity. Among the other selected countries, we observed such a relationship only in Czech Republic, Belgium, Spain and the UK. It was an overall tenuous relationship, except in Spain where it was well identified. In France, the R&D-to-patents relationship is strongly identified with both measures of R&D intensity and concerns baseline R&D as well as R&D conducted during an R&DTC phase. A 1% increase in baseline R&D intensity entails a 0.25% to 0.7% increase in patenting intensity, depending on whether R&D intensity is defined with respect to VA or to hours worked. With the latter (former) definition, R&D performed under the third and fourth (second, third and fourth) phases of the tax credit leads to an additional 0.15% (0.37%) increase in patenting over 2004-2017 (1999-2017), which corresponds to an additional 0.005% (0.01%) per year.

Overall, the R&D-to-patents relationship identified in France is quite similar to the one observed in Spain. The reasons for which these two countries are the only ones in our selection where we observe such a strong and clear-cut relationship may have to do with the characteristics of the tax credit schemes that prevail in these countries. Indeed, in both countries, the R&DTC scheme is long-running and comparatively generous (according to

³⁴As in model (1), input additionality is measured here by the coefficient (or sum of coefficients) associated with the lag(s) of the R&D x TC interaction term(s) in the R&D equations.

³⁵This is probably *not* a coincidence, as we will discuss in the next paragraph.

³⁶Formally defined, in their model, as the elasticity of R&D capital with respect to its user cost, it is equal, using their preferred estimates, to $1 - 0.08/0.24 \sim 0.67$.

Straathof et al., 2014, the Spanish and French schemes are among the three most generous in all OECD countries).

TABLE 5 ABOUT HERE

Finally, when we add a productivity equation to our econometric model, extending it to a CDM-type framework, we find that patenting intensity may have a positive effect on TFP, depending on which measure of R&D intensity we use in the model. As can be seen in Table 5, a 1% increase in patenting intensity entails a 0.44% increase in the TFP growth index when R&D intensity is defined with respect to VA, but has no effect on TFP when R&D intensity is defined with respect to hours worked. Since a 1% increase in R&D performed under the second, third or fourth phase of the French R&DTC scheme entails a 0.37% (cumulated) increase in patenting intensity over 1999-2017, this same 1% entails a $(0.37 \times 0.44 \sim) 0.16\%$ increase in TFP, through the effect of patenting. Despite the *caveat* that it is valid only with our second measure of R&D intensity, this result makes France the only country in our selection where the R&D-innovation-productivity relationship is not only fully identified, but also strengthened by an R&DTC scheme. We could therefore make our own Val Waxman's punchline in *Hollywood Ending*: "Thank God the French exist."

4.3. Policy implications

To sum up our findings, we can safely conclude that, in spite of their differences, the various national R&DTC schemes that exist throughout the EU all seem to spur further investment in R&D. Their effect on innovation output is more tenuous, though, and it is extremely difficult to identify any effect on productivity at all (even in France, the identification of latter effect depends on the definition of R&D).

Regarding the effect on R&D, we observe that input additionality (or BFTB) is always close to 1, which means that firms spend all their R&DTC savings on R&D. This effectiveness of R&DTC in pushing firms towards more investment in R&D is probably associated to the fact that all the R&DTC schemes we have considered are volume-based, which makes the tax deduction easy to claim and more generous than in an incremental scheme. France is a case in point: there, we observe that switching to a fully volume-based scheme after 2008 boosts the BFTB from about 1 to roughly 1.20. Overall, this result is good news for the aforementioned EU objective of having an amount of R&D expenditures equivalent to 3% of GDP. In addition, since the "super deduction" associated with the 2016 CCCTB proposal (and presumably with its successor) is a very generous volume-based scheme, it is likely to work towards the 3% objective as well.

As regards the elusive effect of R&DTCs on innovation output, we can note that France and Spain, the only countries where we identify a significantly positive effect, both have a long-running and extremely generous tax credit. This observation suggests that, in order to have an effect on innovation output, tax credits had better be generous – a conclusion which is corroborated by the review of literature conducted in Straathof *et al.* (2014). Again, since the EC has made the "super deduction" associated with the 2016 CCCTB proposal extremely generous, as highlighted in Sub-Section 1.2, chances are that this policy will have a positive impact on innovation output. This remark on generosity extends to the supposedly positive effect of R&DTCs on productivity, which we observe only in France, one of the three OECD countries with the most generous R&DTC scheme. Since any "super deduction" in the vein of the one mentioned earlier would be extremely generous, it can be expected to have a productivity effect.

Nevertheless, it might then be effective but too generous to be efficient. This is another issue, which goes beyond the scope of the present paper, and on which but few studies exist. Akcigit et al. (2019) constitute a welcome exception. Their theoretical reflections, complemented by empirical estimations, lead them to conclude that there is indeed room for improvement in R&DTC policies. They suggest for instance conditioning R&D tax incentives on innovation performance.

Our final remark is for the UK. This country was an EU Member State during the whole of our observation period (1980-2017) but left the EU in 2021, which places it in a rather unique situation. Interestingly, our results for the UK allow us to identify an R&D – innovation – productivity relationship, but this relationship is not influenced by the UK's R&DTC scheme. Rather, past baseline R&D intensity (when defined with respect to hours worked) feeds current baseline R&D, which feeds future patenting intensity, which in turn feeds TFP growth.

This lack of effectiveness of R&DTCs suggest that the UK should not rely too much on in this instrument for the future of its science and technology policy. It should rather, as suggested in the sources reviewed in Section 1.2, try to create new cooperations in research with the EU. But the lack of effectiveness of R&DTC also has a potentially brighter side for the UK's post-Brexit science policy. Indeed, if the R&D – innovation – productivity relationship holds without the need of an R&DTC, then UK firms do not need any "super deduction" on R&D expenditures to generate knowledge and diffuse it throughout the economy. Our estimates suggest that this relationship is fragile, though, and the UK may never see this brighter side. At the micro level, as was said earlier, any UK firm that performs R&D (or has an R&D-performing subsidiary) on EU territory will be eligible to the super-deduction associated with the 2016 CCCTB proposal or the yet-to-come BEFIT proposal. But the perspective is of course quite different at the national science policy level.

5. Conclusion

Using industry-level panel data, we have examined the R&D, innovation and productivity effects of R&DTC schemes implemented in 8 EU countries, in the context of the 2016 proposal of an EU-wide "super deduction" on R&D. The data covers a period ranging from the late 1970s/early 1980s to 2017 and concerns Austria, Belgium, Czech Republic, France, Italy, the Netherlands, Spain and the UK. Our econometric analysis shows that, overall, past R&D feeds current R&D, whether R&D is conducted during an R&DTC phase or not. For R&D conducted during an R&DTC phase, our estimate of "input additionality" (or BFTB) is generally close to 1, which is consistent with the literature and suggests that firms spend all the savings induced by the tax credit on future R&D.

Identifying a relationship between R&DTC and innovation output is more difficult. While R&D intensity *does* affect patenting intensity positively in Belgium, Czech Republic, France, Spain and the UK, this relationship is R&DTC-related only in Belgium, France and Spain. In Spain, a 1% increase in baseline R&D translates to a 0.26% to 0.44% increase in patenting intensity (our measure of innovation output), to which R&D conducted in a period of R&DTC adds an extra 0.20%. In France, a 1% increase in baseline R&D entails a 0.25% to 0.70% increase in patenting intensity, to which R&D conducted in a recent phase of R&DTC adds an extra 0.15% (cumulated over 2004-2017) to 0.37% (cumulated over 1999-2017), depending on which definition of R&D intensity we use. In Belgium, R&D affects patenting only during the R&DTC phase, with a 1% increase in R&D intensity yielding a 0.17% to 0.29% increase in patenting intensity.

Finally, only in France and in the UK do we observe a full R&D – innovation – productivity relationship. In both cases, the relationship is fragile and depends on which

definition of R&D intensity is retained. In the UK, the R&D – innovation – productivity relationship is not affected by the R&DTC scheme. In France, we find that a 1% increase in R&D conducted under the second to fourth phases of R&DTC (1999-2017) entails an indirect 0.16% increase in productivity (measured by TFP). This increase is indirect because it is mediated by patenting intensity. The main policy implication we derive from all these results is that an EU-wide "super-deduction" on R&D, in the vein of the one proposed with the 2016 CCCTB, is likely to help the EU reach its "R&D at 3% of GDP" objective, but only time will tell whether it is generous enough to really spur innovation and productivity.

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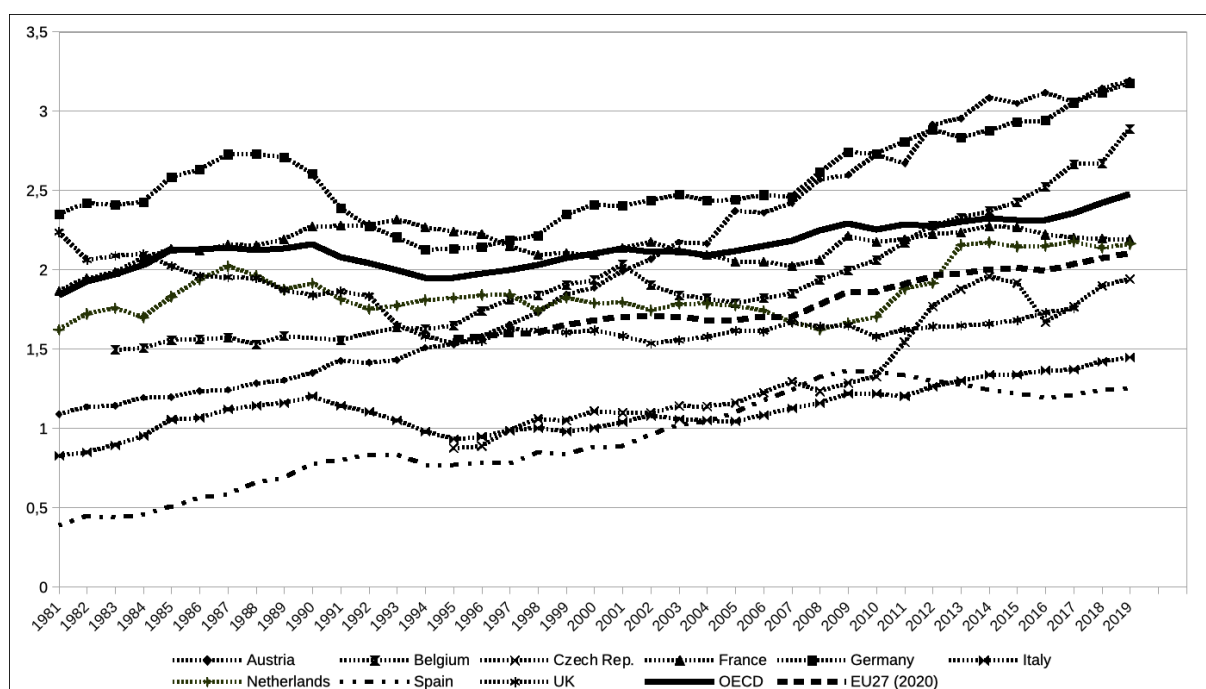
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Figure 1: R&D expenditures in % of GDP for selected EU countries, 1981-2019



Source: OECD (<https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm>), authors' own representation

Table 1: unit root tests for non-stationarity of main variables

	Country							
	Austria	Belgium	CZ	Italy	NL	Spain	UK	France
ln TFPG	-1.80 ^b	-1.82 ^b	-2.01 ^a	-3.23 ^a	-3.12 ^a	-3.57 ^a	-2.59 ^a	-2.88 ^b
	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 12	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13
	<i>T</i> = 36	<i>T</i> = 36	<i>T</i> = 19	<i>T</i> = 43	<i>T</i> = 37	<i>T</i> = 36	<i>T</i> = 36	<i>T</i> = 36
ln patenting intensity	-6.84 ^a	-8.71 ^a	-2.31 ^a	-5.31 ^a	-9.96 ^a	-7.64 ^a	-12.19 ^a	-11.48 ^a
	<i>N</i> = 11	<i>N</i> = 11	<i>N</i> = 10	<i>N</i> = 11	<i>N</i> = 11	<i>N</i> = 11	<i>N</i> = 11	<i>N</i> = 11
	<i>T</i> = 34	<i>T</i> = 34	<i>T</i> = 19	<i>T</i> = 35	<i>T</i> = 36	<i>T</i> = 35	<i>T</i> = 37	<i>T</i> = 37
ln (R&D/employment)	-0.16	-1.63 ^c	-3.05 ^a	-2.34 ^a	-2.51 ^a	-2.42 ^a	-0.06	-5.33 ^a
	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13
	<i>T</i> = 21	<i>T</i> = 22	<i>T</i> = 21	<i>T</i> = 35	<i>T</i> = 36	<i>T</i> = 46	<i>T</i> = 36	<i>T</i> = 38
ln (R&D/VA)	-1.44 ^c	-2.89 ^a	-2.26 ^b	-2.60 ^a	-1.56 ^c	-1.66 ^b	-0.22	-2.46 ^a
	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 12	<i>N</i> = 13	<i>N</i> = 13	<i>N</i> = 13
	<i>T</i> = 21	<i>T</i> = 22	<i>T</i> = 21	<i>T</i> = 35	<i>T</i> = 36	<i>T</i> = 46	<i>T</i> = 36	<i>T</i> = 38

CZ: Czech Republic, NL: Netherlands

N: number of industries, *T*: years. In some countries, records of R&D stock start *after* records of productivity and patenting, which explains the shorter time dimension for the R&D intensity variables in these countries.

Significance levels: ^a p-value < 0.01, ^b p-value < 0.05, ^c p-value < 0.10.

Notes: In the UK, both log-R&D intensities are non-stationary. Our econometric modelling will thus rely on their first-difference, which are stationary with a test statistic of -9.42^a for ln (R&D/employment) and -12.13^a for ln (R&D/VA). The same problem occurs, to a lesser extent, in Austria, calling for the same cure. Again, the first-difference of the log-R&D intensity is stationary, with a test statistic of -6.41^a for ln (R&D/employment) and -6.93^a for ln (R&D/VA).

Table 2: innovation production function 2SLS estimates for countries with a single RTC period

First stage – dependent variable: R&D Intensity ($\ln RD_{it-1}$)														
	R&D intensity = R&D / hours worked							R&D intensity = R&D / VA						
	AT	BE	CZ	IT	NL	SP	UK	AT	BE	CZ	IT	NL	SP	UK
$\ln RD_{it-2}$	0.44 ^a <i>0.09</i>	0.99 ^a <i>0.03</i>	0.92 ^a <i>0.06</i>	1.00 ^a <i>0.02</i>	0.97 ^a <i>0.02</i>	0.99 ^a <i>0.02</i>	0.98 ^a <i>0.01</i>	-0.28 <i>0.18</i>	0.75 ^a <i>0.13</i>	0.81 ^a <i>0.12</i>	0.98 ^a <i>0.01</i>	0.90 ^a <i>0.03</i>	0.98 ^a <i>0.01</i>	0.88 ^a <i>0.04</i>
$\ln RD_{it-2} \times TC_{t-2}$	0.01 <i>0.01</i>	0.01 <i>0.01</i>	-0.01 <i>0.01</i>	-0.03 ^a <i>0.01</i>	-0.002 <i>0.004</i>	-0.01 <i>0.01</i>	-0.01 ^a <i>0.003</i>	-0.00 <i>0.05</i>	0.01 <i>0.03</i>	-0.02 <i>0.03</i>	-0.03 ^a <i>0.01</i>	-0.02 <i>0.01</i>	-0.02 ^c <i>0.01</i>	-0.01 <i>0.01</i>
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.002	0.000	0.000	0.000	0.003	0.135	0.000	0.042	0.009	0.000	0.000	0.221	0.134	0.028
<i>F</i> test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exclusion test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.139	0.000	0.000	0.000	0.000	0.000	0.000
First stage – dependent variable: R&D with Tax Credit ($\ln RD_{it-1} \times TC_{t-1}$)														
	R&D intensity = R&D / hours worked							R&D intensity = R&D / VA						
	AT	BE	CZ	IT	NL	SP	UK	AT	BE	CZ	IT	NL	SP	UK
$\ln RD_{it-2}$	0.76 <i>0.70</i>	0.17 ^b <i>0.08</i>	0.14 <i>0.09</i>	0.02 <i>0.03</i>	-0.01 <i>0.05</i>	-0.06 <i>0.04</i>	0.14 <i>0.09</i>	0.08 <i>0.16</i>	-0.06 <i>0.14</i>	0.04 <i>0.11</i>	0.004 <i>0.03</i>	-0.06 <i>0.04</i>	-0.03 <i>0.03</i>	0.15 <i>0.09</i>
$\ln RD_{it-2} \times TC_{t-2}$	-0.07 ^a <i>0.02</i>	0.75 ^a <i>0.04</i>	0.90 ^a <i>0.04</i>	0.92 ^a <i>0.02</i>	0.94 ^a <i>0.02</i>	0.89 ^a <i>0.02</i>	0.94 ^a <i>0.02</i>	-0.07 <i>0.05</i>	0.74 ^a <i>0.05</i>	0.89 ^a <i>0.04</i>	0.92 ^a <i>0.02</i>	0.93 ^a <i>0.02</i>	0.89 ^a <i>0.02</i>	0.92 ^a <i>0.02</i>
Year FE	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.023	0.000	0.003	0.889	0.999	0.968	0.998	0.078	0.003	0.002	0.829	0.677	0.957	0.999
<i>F</i> test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exclusion test	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.118	0.000	0.000	0.000	0.000	0.000	0.000
Second stage – dependent variable: Patenting Intensity ($\ln PI_{it}$)														
	R&D intensity = R&D / hours worked							R&D intensity = R&D / VA						
	AT	BE	CZ	IT	NL	SP	UK	AT	BE	CZ	IT	NL	SP	UK
$\ln RD_{it-1}$	1.61 <i>2.53</i>	0.10 <i>0.17</i>	0.60 ^b <i>0.24</i>	0.02 <i>0.02</i>	0.13 <i>0.17</i>	0.44 ^a <i>0.14</i>	0.26 ^a <i>0.07</i>	-0.79 <i>1.20</i>	-0.04 <i>0.20</i>	0.38 <i>0.33</i>	0.01 <i>0.03</i>	0.01 <i>0.12</i>	0.26 ^c <i>0.14</i>	0.18 <i>0.13</i>
$\ln RD_{it-1} \times TC_{t-1}$	-1.65 <i>1.14</i>	0.17 ^b <i>0.08</i>	0.03 <i>0.07</i>	-0.02 <i>0.02</i>	-0.02 <i>0.05</i>	0.21 ^a <i>0.00</i>	-0.04 <i>0.03</i>	-1.14 <i>0.92</i>	0.29 ^c <i>0.10</i>	0.03 <i>0.10</i>	-0.01 <i>0.02</i>	-0.02 <i>0.06</i>	0.20 ^a <i>0.05</i>	-0.02 <i>0.05</i>
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>F</i> test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	184	198	172	352	352	378	352	184	198	172	352	352	378	352
Under-ID test	0.097 <i>0.005</i>	0.004 <i>0.000</i>	0.011 <i>0.000</i>	0.000 <i>0.000</i>	0.001 <i>0.000</i>	0.000 <i>0.000</i>	0.000 <i>0.000</i>	0.299 <i>0.303</i>	0.002 <i>0.000</i>	0.002 <i>0.000</i>	0.000 <i>0.000</i>	0.001 <i>0.000</i>	0.000 <i>0.000</i>	0.002 <i>0.000</i>
Weak ID test	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

AT: Austria, BE: Belgium, CZ: Czech Republic, IT: Italy, NL: Netherlands, SP: Spain, UK: United Kingdom

Significance levels: ^a p-value < 0.01, ^b p-value < 0.05, ^c p-value < 0.10.

HAC standard errors are provided in *italics* below the estimates.

“Year FE” and “Industry FE” report the p-values of Fisher tests for the year and industry fixed effects, respectively.

Goodness-of-fit: “*F* test” reports the p-value of the usual Fisher test of a regression.

In the first-stage regressions, “Exclusion test” reports the p-value of a Fisher test of the null hypothesis that the coefficients of the instruments are both equal to zero.

In addition, goodness-of-fit statistics at the very bottom of the table include: (1) the p-values of the Lagrange Multiplier (LM) and Wald versions of Kleibergen-Paap (2006)’s under-identification test (H_0 : “Instruments are uncorrelated with the endogenous regressors”); (2) “Yes” (“No”) if the estimation passes (does not pass) Kleibergen-Paap (2006)’s weak identification test (H_0 : “Instruments are weakly correlated with the endogenous regressors”) at the 5% level (the test statistic must be compared to the 5% level critical values tabulated in Stock and Yogo, 2005).

Table 3: Third stage of a CDM-type model for countries with a single RTC period

	Dependent variable: Total Factor Productivity ($\ln TFP_{it}$)													
	when R&D intensity = R&D / hours worked							when R&D intensity = R&D / VA						
	AT	BE	CZ	IT	NL	SP	UK	AT	BE	CZ	IT	NL	SP	UK
$\ln PI_{it-1}$	-0.06 <i>0.06</i>	-0.12 <i>0.22</i>	-0.11 <i>0.18</i>	3.27 ^a <i>0.76</i>	0.93 ^a <i>0.41</i>	-0.06 <i>0.13</i>	2.13 ^a <i>0.35</i>	-0.14 <i>0.16</i>	0.07 <i>0.11</i>	-0.51 <i>0.33</i>	2.55 ^a <i>0.75</i>	-1.38 <i>1.54</i>	-0.05 <i>0.20</i>	3.44 ^a <i>0.54</i>
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>F</i> test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	184	198	172	352	352	364	352	184	198	172	352	352	364	352

AT: Austria, BE: Belgium, CZ: Czech Republic, IT: Italy, NL: Netherlands, SP: Spain, UK: United Kingdom

Significance levels: ^a p-value < 0.01, ^b p-value < 0.05, ^c p-value < 0.10.

HAC standard errors are provided in *italics* below the estimates.

“Year FE” and “Industry FE” report the p-values of Fisher tests for the year and industry fixed effects, respectively.

Goodness-of-fit: “*F* test” reports the p-value of the usual Fisher test of a regression.

Table 4: innovation production function 2SLS estimates for France

First stage: R&D intensity										
	R&D intensity = R&D / hours worked					R&D intensity = R&D / VA				
	$\ln RD_{it-3}$	$\ln RD_{it-3}$ $\times TC1_{t-3}$	$\ln RD_{it-3} \times$ $TC2_{t-3}$	$\ln RD_{it-3}$ $\times TC3_{t-3}$	$\ln RD_{it-3}$ $\times TC4_{t-3}$	$\ln RD_{it-3}$	$\ln RD_{it-3}$ $\times TC1_{t-3}$	$\ln RD_{it-3} \times$ $TC2_{t-3}$	$\ln RD_{it-3}$ $\times TC3_{t-3}$	$\ln RD_{it-3}$ $\times TC4_{t-3}$
$\ln RD_{it-4}$	1.02 ^a <i>0.01</i>	—	—	—	—	0.89 ^a <i>0.02</i>	—	—	—	—
$\ln RD_{it-4} \times TC1_{t-4}$	—	0.87 ^a <i>0.03</i>	0.06 ^b <i>0.03</i>	—	—	—	0.87 ^a <i>0.03</i>	0.02 <i>0.02</i>	—	—
$\ln RD_{it-4} \times TC2_{t-4}$	—	—	0.80 ^a <i>0.04</i>	0.20 ^a <i>0.04</i>	—	—	—	0.74 ^a <i>0.03</i>	0.19 ^a <i>0.02</i>	—
$\ln RD_{it-4} \times TC3_{t-4}$	—	—	—	0.75 ^a <i>0.04</i>	0.24 ^a <i>0.03</i>	—	—	—	0.71 ^a <i>0.03</i>	0.24 ^a <i>0.02</i>
$\ln RD_{it-4} \times TC4_{t-4}$	—	—	—	—	1.00 ^a <i>0.04</i>	—	—	—	—	0.96 ^a <i>0.02</i>
Year FE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industry FE	0.000	0.439	0.999	0.999	0.999	0.003	0.280	0.984	0.999	0.999
<i>F</i> test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Second stage – dependent variable: Patenting Intensity ($\ln PI_{it}$)										
	R&D intensity = R&D / hours worked					R&D intensity = R&D / VA				
$\ln RD_{it-4}$			0.70 ^a <i>0.07</i>					0.25 ^a <i>0.06</i>		
$\ln RD_{it-4} \times TC1_{t-4}$			-0.02 <i>0.02</i>					0.002 <i>0.03</i>		
$\ln RD_{it-4} \times TC2_{t-4}$			0.04 <i>0.03</i>					0.09 ^a <i>0.03</i>		
$\ln RD_{it-4} \times TC3_{t-4}$			0.06 ^b <i>0.03</i>					0.11 ^a <i>0.04</i>		
$\ln RD_{it-4} \times TC4_{t-4}$			0.09 ^a <i>0.03</i>					0.17 ^a <i>0.04</i>		
Year FE			0.000					0.000		
Industry FE			0.000					0.000		
Cum. effect			0.15 ^a <i>0.05</i>					0.37 ^a <i>0.08</i>		
Yearly effect			0.005 ^a <i>0.001</i>					0.01 ^a <i>0.002</i>		
<i>F</i> test			0.000					0.000		
Autocorrelation			0.249					0.104		
White test			0.171					0.038		
Observations			352					352		

Standard errors are provided in *italics* below the estimates.

Significance levels: ^ap-value < 0.01, ^bp-value < 0.05, ^cp-value < 0.10.

“Year FE” and “Individual FE” report the p-values of Fisher tests for the year and industry fixed effects, respectively.

“Cum. effect” is an estimate of the cumulated effect of the R&DTC over the whole period and “Yearly effect” is an estimate of the average yearly effect over the period.

Goodness-of-fit: “*F* test” reports the p-value of the usual Fisher test of a regression. “Autocorrelation” reports the p-value of a test for the autocorrelation of the error term of the second-stage equation (H_0 : “No autocorrelation”), conducted along the lines of Wooldridge (2002, p. 282-283). “White test” reports the p-value of a test for heteroskedasticity *à la* White (H_0 : “No heteroskedasticity”).

Table 5: Third stage of a CDM-type model for France

Dependent variable: Total Factor Productivity (ln TFP_{it})		
	R&D intensity = R&D / hours worked	R&D intensity = R&D / VA
ln PI_{it-1}	-0.03 <i>0.09</i>	0.44 ^a <i>0.12</i>
Year FE	0.000	0.000
Industry FE	0.000	0.000
<i>F</i> test	0.000	0.000
Autocorrelation	0.000	0.000
White test	0.006	0.048
Observations	352	352

Significance levels: ^a p-value < 0.01, ^b p-value < 0.05, ^c p-value < 0.10.

HAC standard errors are provided in *italics* below the estimates.

“Year FE” and “Industry FE” report the p-values of Fisher tests for the year and industry fixed effects, respectively.

Goodness-of-fit: “*F* test” reports the p-value of the usual Fisher test of a regression.

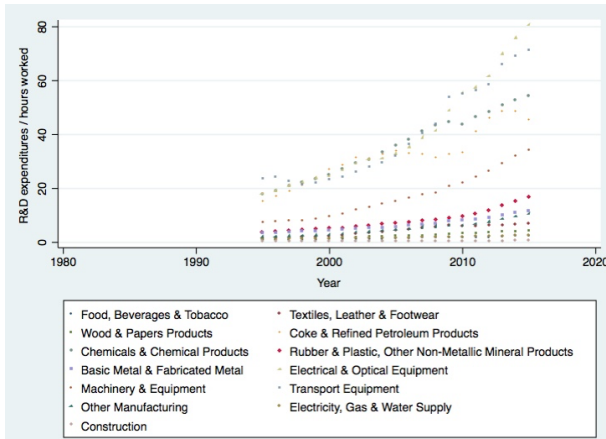
Appendix

Table A1 – List of industries (NACE, 2 digits)

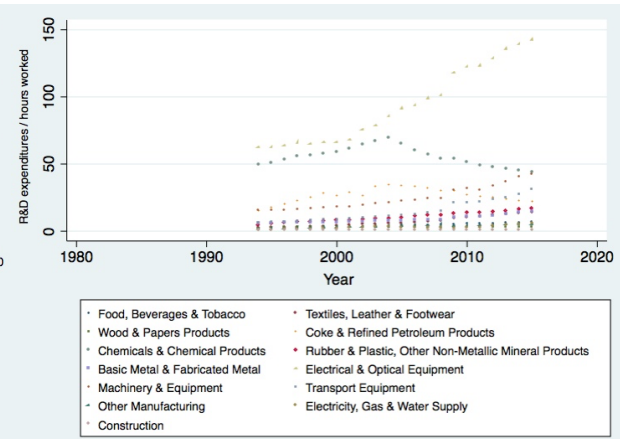
Code	Description
15t16	Food, Beverages and Tobacco
17t19	Textiles, Textile products, Leather and footwear
20	Wood and Products of wood and cork
21t22	Pulp, Paper, Paper products, Printing and publishing
23	Coke, Refined petroleum and Nuclear fuel
24	Chemicals and Chemical products
25	Rubber and plastic
26	Other non-metallic mineral
27t28	Basic metals and Fabricated metal
29	Machinery, Other Machinery
30t33	Electrical equipment, Electronics and Optical equipment
34t35	Transport equipment
36t37	Other manufacturing, Recycling

Figure A1 – R&D intensity (R&D / hours worked) by industry for each selected EU country

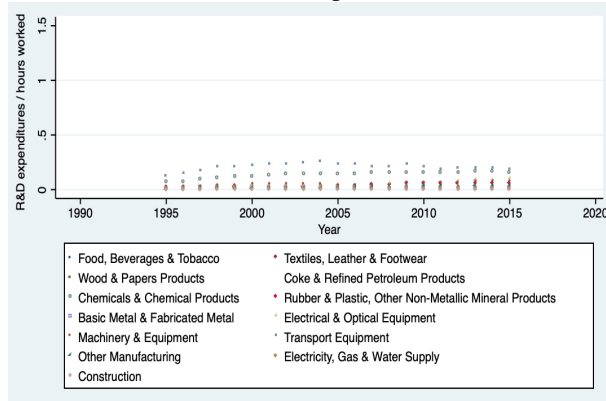
Austria



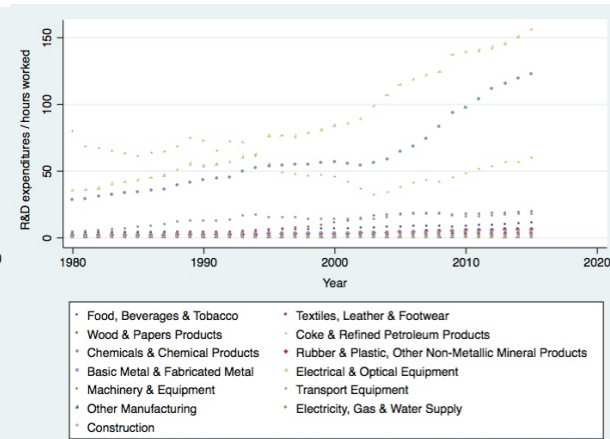
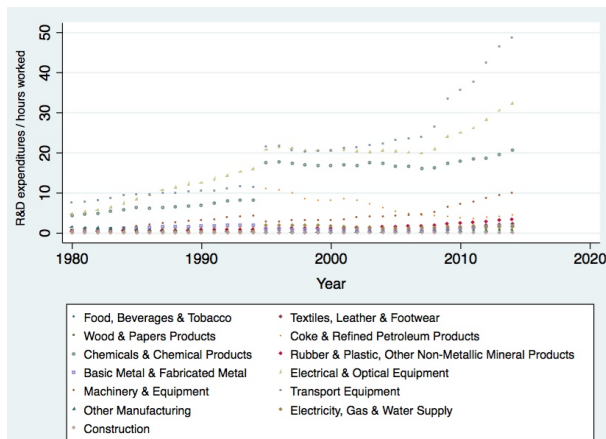
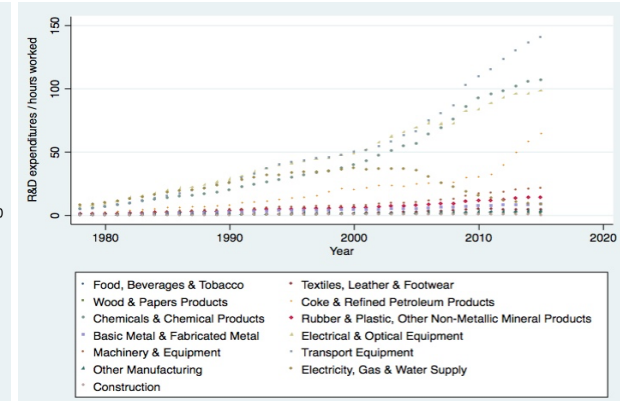
Belgium



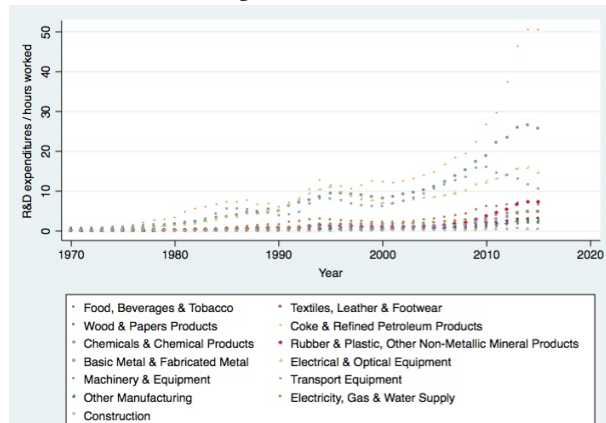
Czech Republic



France



Spain



United Kingdom

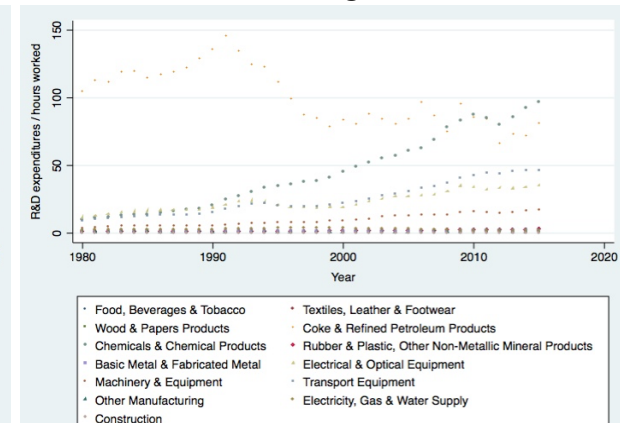
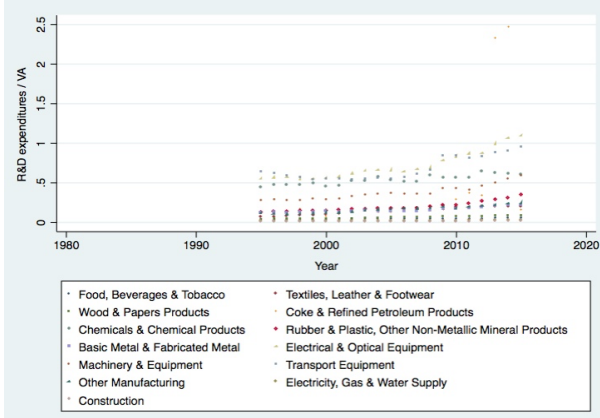
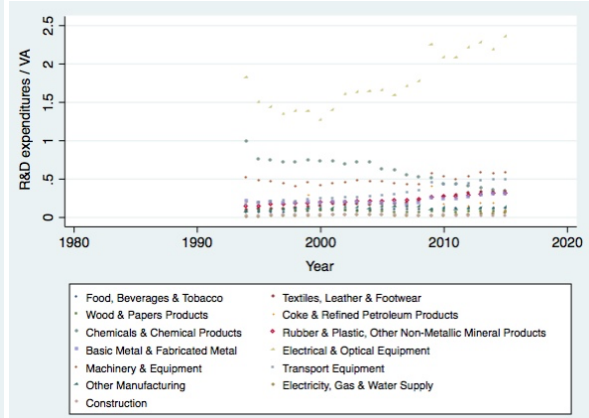


Figure A2 – R&D intensity (R&D / VA) by industry for each selected EU country

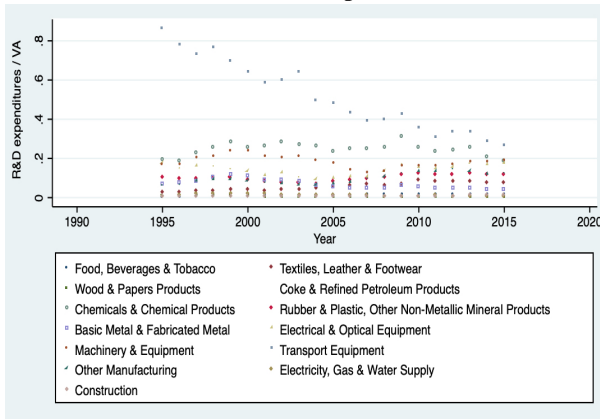
Austria



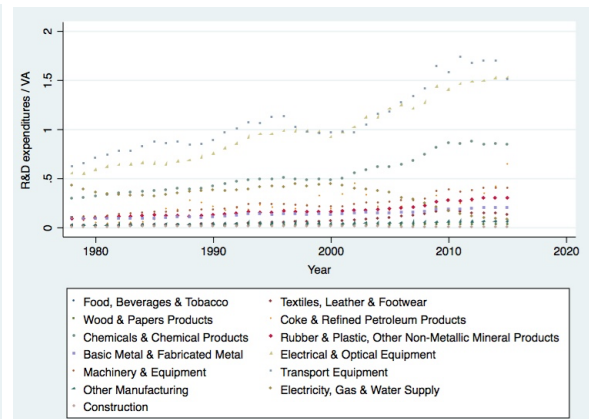
Belgium



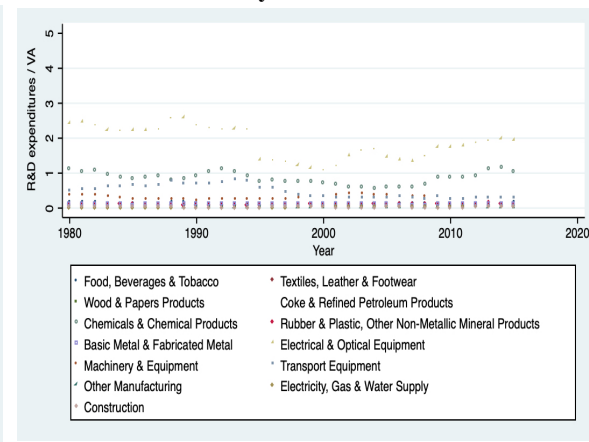
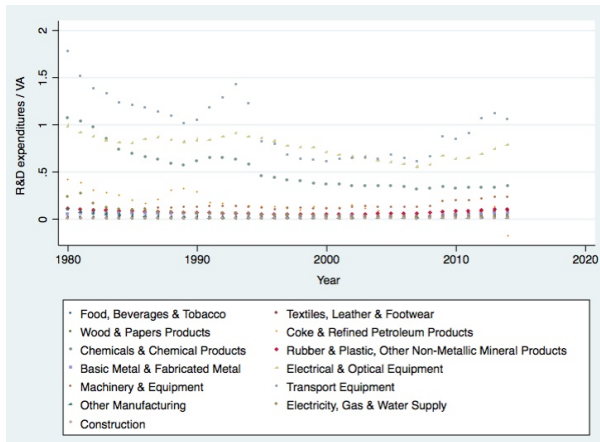
Czech Republic



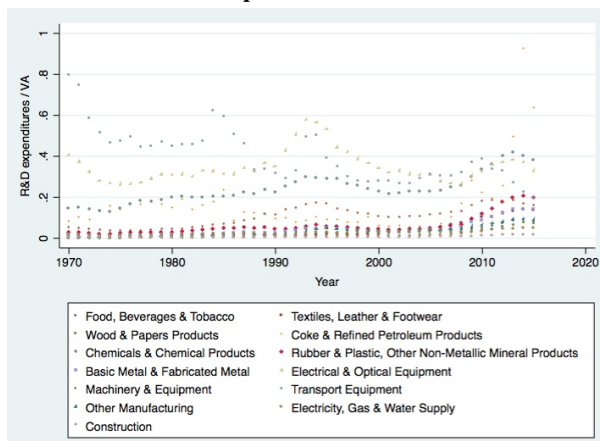
France



Italy



Spain



United Kingdom

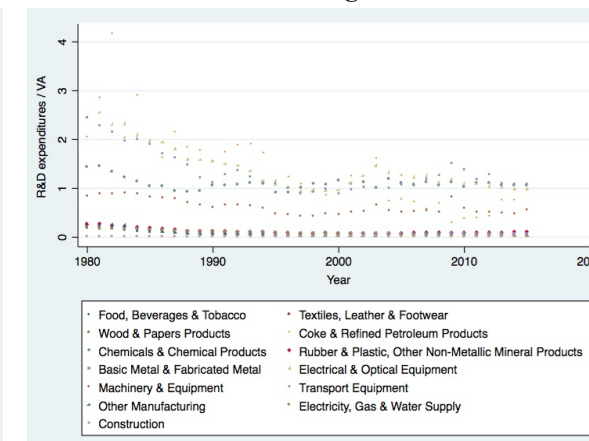
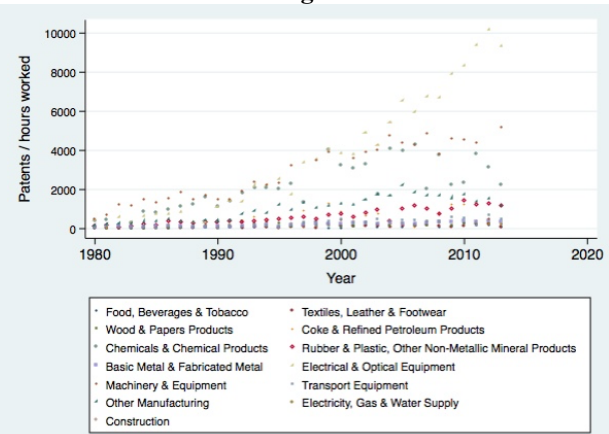
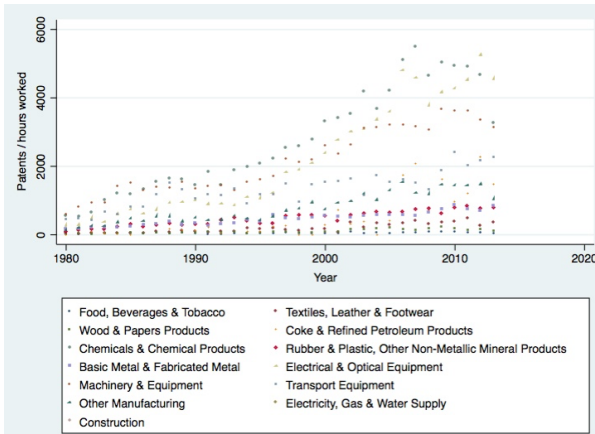
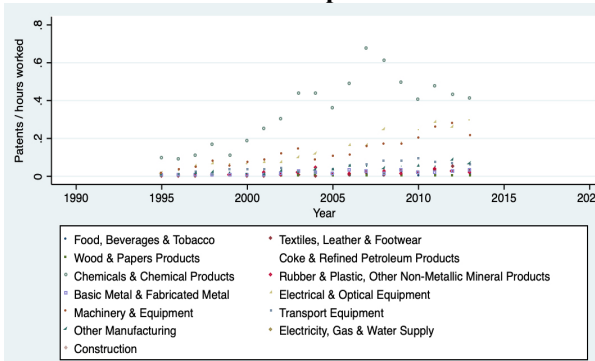


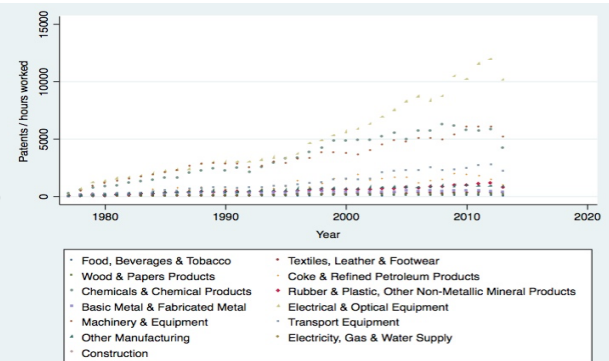
Figure A3 – patenting intensity by industry for each selected EU country
Austria **Belgium**



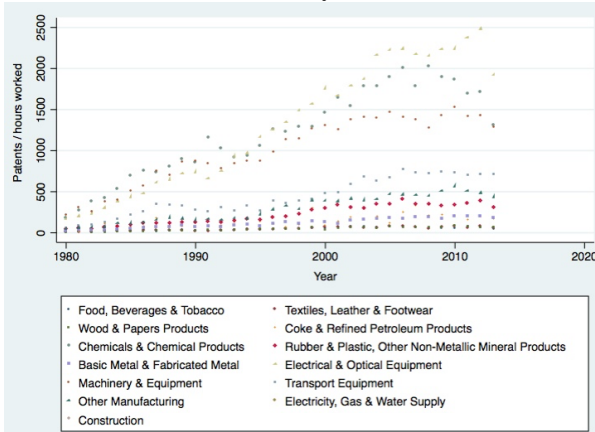
Czech Republic



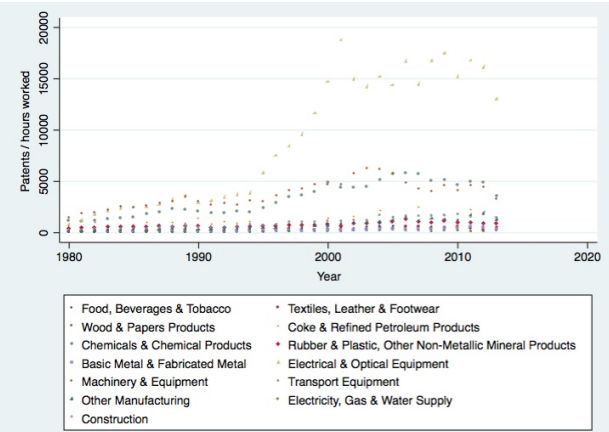
France



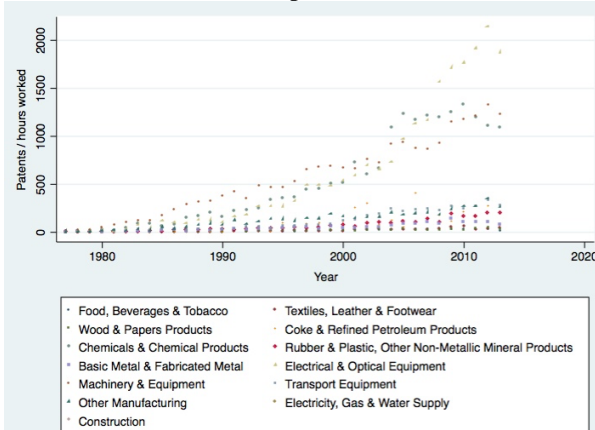
Italy



Netherlands



Spain



United Kingdom

