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How Internationalisation affect the productivity in large R&D intensive firms? A conditional nonparametric investigation

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Abstract:

This work explores the relationship between R&D multinationality and innovation productivity in top corporate knowledge and R&D producers, adopting a twofold concept of internationalisation: the firm's degree of R&D internationalisation and its geographic diversification. We model the patent production process with an appropriate and robust conditional Data Envelopment Analysis (DEA) estimator, using a unique database of firms that matches financial indicators and patent information.

Our results reinforce the fundamental role of internationalisation in the knowledge production process. But the internationalisation process must be properly and strategically managed. We read our empirical evidence in the light of the theoretical lens of the learning theory of internationalisation and we postulate that a high R&D intensity is a key driver to overcoming the challenges of internationalisation.

Keywords: R&D productivity; multinationality; conditional efficiency; patents; DEA modelling

JEL classification O32, F23, L25, C44

1-Introduction

Firms in high-cost economies have increasingly globalised their activities and processes, including knowledge-intensive processes (Sidhu and Volberda, 2011). In this context, “R&D activities of foreign affiliates was found as one of the most dynamic elements of the process of globalisation” at the end of the 20th century (OECD, 2005; OECD, 2011; UNCTAD, 2005; Dachs et al., 2014; Dachs, 2017). R&D internationalisation aims at enhancing competence exploitation, competence creation among MNEs in advanced economy (Awate et al., 2015).

The emerging countries have received an increasing interest, but EU countries and the USA are still the main host destinations for relocating R&D and the home regions of multinational firms. However, the R&D multinationality patterns are changing, and R&D internationalisation becomes more widespread (Laurens et al., 2015).

The firms' R&D location decisions are complex and subject to several factors. Centrifugal and centripetal forces pulling R&D abroad compete. Multiplying R&D activities in different places and countries requires good technical absorbing (Kafouros, 2020). Management capacities and organisational skills have to be fully optimised. As the firms need to align their R&D strategies with their overall strategy to succeed, we expect different models of multinational innovation to be effective. International R&D activities exhibit a high heterogeneity across countries, industries and first of all across firms.

Most studies have concluded to a benefice of R&D internationalisation to the firm innovative activities (Ambos, 2005; Papanastassiou and Pearse, 2009; Wang et al., 2018; Belderbos et al., 2015; Hurtado-Torres et al., 2018) but negative effects have also been evidenced (Belderbos, 2001). The impact of the R&D internationalisation on the innovation capacities was estimated measuring R&D outputs; an increase of the patent number when internationalising R&D was interpreted as a positive effect.

A further question has yet not been addressed: Does the positive impact of the R&D internationalisation on the innovative performance result from a gain of the R&D productivity, i.e., does the higher number of patents is obtained at constant (or reduced) R&D investments when internationalising? This is the research question we address here.

When the R&D internationalisation induces a rationalisation of the R&D production function, an enhanced R&D productivity could be hypothesised, thanks to synergies, and complementarities between home and host R&D units and among foreign laboratories. R&D

productivity could also be the main objective of internationalisation when the knowledge production is at the core of the R&D internationalisation in intensive R&D industries.

Conversely, multiplying geographically disperse R&D activities abroad can produce an enhanced innovative capacity and more R&D outputs. However, without an efficient managerial organisation of R&D, dilution of knowledge or because of R&D redundancy in different units, the R&D productivity could decrease.

There is a need for empirical evidence to assess the effect of the R&D multinationality on the productivity of a firm's inventive activities. Our contribution, focused on R&D productivity, differs from existing literature where a wider view of firm productivity is used. We aim to study if the R&D productivity benefits from R&D relocation outside its home country.

We rely on patent data to measure the firm's innovative performance and use inventors' addresses to determine the R&D locations. We consider a relative valuation of the patent costs across technologies and use a technology-dependent weighted number of priority patents to proxy R&D output and the R&D investments and workers as the inputs. We adopt a twofold concept of internationalisation: the firm's degree of R&D internationalisation and its geographic diversification.

To empirically estimate the relationship described above, following Badin et al. (2012), we apply a flexible and innovative nonparametric *conditional* Data Envelopment Analysis (DEA) method, which does not require specifying a parametric assumption or an economic *a priori* relation between the performance and the variables of interest, in this case, the R&D internationalisation. This avoids the conceptual pitfalls of previous work, in particular, to determine in advance a (positive or negative) effect of internationalisation. Using a unique and comprehensive dataset, it estimates the R&D efficiency as the distance of each firm's R&D productivity from the estimated best practice frontier.

The paper is organised as follows. Section 2 provides a literature review of existing works related to multinationality and firm's performance and states our research questions. The modeling strategy is introduced in Section 3. Section 4 and Section 5 present respectively the data and the methodology. The results are reported in Section 6. It first describes the patterns of the firm's R&D internationalisation. Then it presents our core results on the R&D efficiency-R&D multinationality relationship as well as firm-related contextual elements to analyse the results. Section 7 discusses the results and section 8 concludes.

2- Literature review and research questions

Over the last thirty years, the local economies have become more and more interconnected, and the firms are now widely operating abroad. As R&D Multinational Enterprises (MNEs) were taking advantage of their geographical diversification, the understanding of the firms' improved performance through internationalisation needs to be clarified¹.

2-1- Rationales and trade-offs in multinationality and firm's performance

Internationalisation is not an unambiguous process. The relationship between the multinationality of the firm (foreign market penetration or foreign production presence) and the firm's (financial or operational) performance has been modeled as a positive, U-shape, inverted U-shape, or S-shape relationships (Ruigrok and Wagner, 2003; Thomas and Eden, 2004).

¹ For an extensive literature review on R&D internationalisation and innovation, we signal to the readers two excellent recent articles: Vrontis and Christofi (2021) and Papanastassiou et al (2020).

R&D multinationality is mainly driven by the largest R&D investors: 94% of the world's largest innovators now conduct R&D programs abroad in locations where their sales and manufacturing are growing fastest and where they can access the right technical talent (Global Innovation 1000 study, 2015). Following an “asset seeking” (or “home expanding”) strategy, the firms enhance their technological capabilities by gaining access to foreign localised knowledge spillovers (Kuemmerle, 1999). Adapting products to local foreign customers, the firms transfer internal knowledge assets to foreign sites to be exploited after adaptation (“asset exploiting” or “home exploiting” strategy).

The effect of R&D multinationality on the firm's R&D innovation performance has been the subject of empirical studies (Hsu et al., 2015; Singh, 2008; Lahiri, 2010; Chen et al., 2012; Rako, 2016). Most of them concluded that R&D multinationality was beneficial to firms. The benefit from US technology sourcing was identified (Griffith et al., 2006; Harhoff et al., 2014).

Anon Higon and Manjon Antolin (2012) and Castellani et al. (2017) reach similar results. But the relationship between internationalisation and performance is not always straightforward. The share of the firm's international subsidiaries increases labor productivity, but spreading subsidiaries in many countries is detrimental to it. However, when postulating that R&D intensity enhances productivity, they found an indirect overall positive effect of multinationality on productivity due to the positive effect of both internationalisation degree and geographical diversity on the firm's R&D intensity. Not all companies gain from R&D multinationality.

As technological knowledge is assumed to be a core asset, there are also motivations for the firms to keep a certain amount of R&D in the home country. It enables them to remain embedded in their national innovation system and prevents them from significant knowledge

spillovers. Moreover, the coordination of a network of several R&D sites abroad can become expensive and problematic in absence of the right infrastructure (Belderbos et al., 2013).

The Global innovation study considers that large firms have improved in managing disseminated R&D. Being “simultaneously a knowledge seeker and arbitrageur of comparative advantages, skilled in contracting and managing alliances as well as in coordinating global supply chains and innovation networks”, firms need to develop particular skills to offshore successfully (Contractor et al., 2010). The competencies rely on the capacities to optimise the degree of value chain disaggregation and to carefully select the locations and the chronology. Optimising global R&D is thus quite challenging and requires a learning process to develop a “capability to outsource internationally” (Mol et al., 2004). The learning process takes place when a firm starts to expand abroad or when a change of strategy occurs. Confronting liabilities of newness and foreignness, the firms need to learn how to operate. As a result, an increase or a change in multinationality can first induce a productivity decline. Then thanks to learning and adaptation, the firms enter into a phase of increasing productivity, at least up to a possible threshold (Chang and Wang, 2007; Steinberg et al., 2017).

The benefits of R&D multinationality also depend on the knowledge capability of the firm’s home country. Belderbos et al. (2015) has shown that only when the knowledge the firms need is lacking in the home country, firms benefit from R&D carried out abroad. Otherwise, domestic R&D remains the primary source of productivity growth.

2.2- The role of geography in R&D internationalisation

The geographical patterns of multinationality play a key role.

The dispersion of R&D units enables the firms to achieve proximal access to external knowledge pools in different countries, to access ideas from diverse contexts, and to facilitate knowledge recombinations (Alonso-Martínez, 2018). But beyond a point, the costs of utilising knowledge over distributed R&D overrides the benefits of access to new knowledge sourced from different locations. The firms distributing their R&D activity too widely lower the quality of innovation (Athukorala and Kohpaiboon, 2010; Kafouros et al., 2008). Hurtado-Torres et al. (2018) show that the degree of R&D internationalisation and international geographic diversification increases the MNE's innovative output in the energy sector but deteriorates the innovative performance at very high levels.

The performance effects of international expansion can be expected to be different depending upon the level of geographic diversification across foreign countries (Verbeke and Brugman, 2009). As specified by the extensive and in-depth review done by Papanastassiou (2020), what appears to be indeed new in more recent research, and which still needs further investigation, is the complementarity between internal and external networking.

So, both the degree of internationalisation (internationalisation depth) and the geographic diversification (geodiversity or internationalisation breadth) should be analysed separately.

2-3 Relationship between R&D productivity and R&D internationalisation

The impact of R&D internationalisation on the firm innovative performance has been most often analysed in terms of innovation capacities considering R&D outputs, such as the number of patents (Awate and Mudambi, 2018; Cantwell and Noonan, 2002; Criscuolo et al, 2005; Dachs and Pyka, 2010; Picci, 2010; Huang and Li, 2019). Most studies have concluded that R&D internationalisation improve innovation performance (Ambos, 2005; Papanastassiou and Pearse, 2009; Wang et al., 2018; Belderbos et al., 2015; Hurtado-Torres et al., 2018)

The geographic dispersion of R&D units enables firms to access to external knowledge and ideas in different countries, to capture the externalities in areas of excellence and to facilitate knowledge recombination (Athukorala & Kohpaiboon, 2010; Cloudt et al., 2006). The degree of R&D internationalisation and the R&D geographic diversification increase the MNE's innovative output (measured by the number of patents for each billion of sales), but at very high levels, the costs of utilising knowledge across increasingly distributed R&D may overrides the benefits and deteriorate innovative performance (Lahari, 2010; Hurtardos-Torres, 2018).

However, to our knowledge no study has ever evaluated the impact of the R&D internationalisation on the R&D productivity. Does the positive impact of the R&D internationalisation on the innovative performance result from a gain of the R&D productivity? An enhanced R&D productivity could be hypothesised when the R&D internationalisation induces a rationalisation of the R&D function production thanks to synergies, complementarities between home and host R&D units, access to more valuable internal or external knowledge. This could be expected when knowledge production is a key firm asset at the core of the R&D internationalisation (Home based knowledge augmenting) in intensive R&D industries. In home base exploiting strategies, the adaptation of home product or home process could produce incremental innovation at limited R&D cost.

However, multiplying delocated R&D activities without an efficient rationalisation can indeed enhance the innovative capacity but decrease the R&D productivity because of a dilution of knowledge, R&D redundancy, lack of coordination or a low degree of managerial involvement or skills of the headquarters in R&D activities (Mani et al., 2014; Beugelsdijk and Jindra, 2018). This could be the case when R&D activities are not an essential target in

the R&D internationalisation in the case of mergers and acquisition in low tech industries.

Many variables may moderate the relationship of the R&D internationalisation and R&D productivity. To succeed, companies must develop R&D strategies that are carefully aligned with overall strategy and appropriate for the business environments in which they operate. Besides high and low tech sectors, i.e. the firm R&D intensity, the size of the firm as well as the characteristics both home and host countries (market size, national innovation system) matter (Martinez-Roman, 2019).

Based on the above literature, we frame our work to analyse how the R&D productivity of the top actors of the R&D worldwide internationalisation (the North American firms and the European firms) with the largest R&D investments benefits from R&D relocation out of their home country². We identify the following two research questions:

Question 1: Does the pattern of the R&D internationalisation influence (positively or negatively) the firm's R&D productivity?

Question 2: Do we identify different trends among R&D actors when analysing the R&D productivity-R&D multinationality relationship?

3- Methodology

To answer our research questions, we implement a robust efficiency analysis with a nonparametric approach to estimate the impact of conditioning variables on the production

² Top R&D performers headquartered in Asian countries were discarded from this study because of the very low R&D internationalisation level of most of Asian firms. The overall R&D internationalisation level of Asian firms was 3.5% and it was below 1% for 60% of the Asian firms. Similar results were obtained in Laurens et al. 2015.

process. It is based on a flexible nonparametric regression model suggested by Badin et al. (2012).

The inventive activity of multinational firms is modeled within an Activity Analysis Framework, according to which a set of inputs $X \in \mathbb{R}_+^p$ is used to produce a set of outputs $Y \in \mathbb{R}_+^q$, with $Z \in \mathbb{R}^d$ representing influencing variables, which are neither inputs nor outputs but may affect the performance of the production process.

According to Cazals et al. (2002) as well as Daraio and Simar (2007), the set of technically feasible combinations of firms (x, y) (*unconditional production set*) is

$$\Psi = \{(x, y) \in \mathbb{R}_+^{p+q} | x \text{ can produce } y\}$$

This can be characterised in a probabilistic way (Daraio and Simar, 2007). The unconditional (marginal) output-oriented Farrell–Debreu technical efficiency of a firm (x, y) is defined as:

$$\lambda(x, y) = \sup \{\lambda | (x, \lambda y) \in \Psi\} = \sup \{\lambda | S_{Y|X}(\lambda y | x) > 0\}$$

where $S_{Y|X}(y|x) = \text{Prob}(Y \geq y | X \leq x)$ is the nonstandard conditional survival function of X given that $X \leq x$.

Daraio and Simar (2005) introduced the conditional output-oriented technical efficiency of a production plan $(x, y) \in \Psi^z$, where z is the conditioning factor and $\Psi^z = \{(x, y), x \text{ can produce } y \text{ facing condition } z\}$ as:

$$\lambda(x, y|z) = \{\sup \lambda | (x, \lambda y) \in \Psi^z\} = \sup \{\lambda | S_{Y|X,Z}(\lambda y | x, z) > 0\}$$

where $S_{Y|X,Z}(y|x, z) = \text{Prob}(Y \geq y | X \leq x, Z = z)$.

This is a measure of the performance that looks at the maximum expansion of the outputs that is feasible for the firm given the inputs it is using and the conditioning conditions it is facing.

Assuming that the truly attainable sets are convex and under free disposability of inputs and outputs, the DEA estimator of this conditional frontier can be written as (Daraio and Simar, 2007):

$$\Psi_{DEA}^z = \left\{ (x, y) \in R_+^p \times R_+^q \mid y \leq \sum_{j \in J(z)} \gamma_j y_j; x \geq \sum_{j \in J(z)} \gamma_j x_j; \gamma_j \geq 0 \text{ s. t. } \sum_{j \in J(z)} \gamma_j = 1 \right\}$$

where $J(z) = \{j = (i, v) \mid z - h_z < z_{i,v} < z + h_z\}$; h_z are bandwidths of appropriate size selected by data-driven methods (see Badin et al. 2019).

The effect on the boundary can be detected, following Badin et al. (2012), by analysing the ratios between conditional and unconditional efficiency measures, defined as follows:

$$R_O(x, y|z) = \frac{\lambda(x, y|z)}{\lambda(x, y)}$$

We refer to this ratio as the “DEA ratio” in this paper. Our study aims to analyse the effects of the external factors Z on these ratios. We use nonparametric estimators of the efficiency scores and explore the effect of Z by looking at the behavior of $R_O(x, y|z)$ as a function of Z (Figure 1).

Examining the behavior of the above ratios, we investigate if and how the environmental variables (z), in our case, the internationalisation level of inventive activities and the geodiversity of invention, affect the inventive production process of the firm (its R&D efficiency production). According to Badin et al. (2012), if the ratios as a function of z show an increasing trend, this points to a *positive* effect of z on the production process. On the contrary, a decreasing trend of the ratios shows a *negative* effect of z on the production process while a *flat* trend displays no effect of z on the production process.

The flexible approach described above is meaningful and proper because we did not need to assume *a priori* a positive or negative effect of internationalisation on the R&D production process: indeed, that is one of the main gaps of previous studies.

Through this methodology, we can fill the gap in the literature by obtaining a global overview of the effect of our conditioning variables, the degree of internationalisation and geodiversity. The latter is definitely among the most important variables for companies that carry out research and development.

4- Modeling strategy

Our model, displayed in Figure 1, explores the inventive activity of large firms from North America and Europe and assesses, through an efficiency analysis³, the effects of the level of internationalisation on the firm's R&D multinationality-productivity, studying the conditional and unconditional Data Envelopment Analysis scores.

Insert Figure 1

This paper adopts an innovation production framework and considers the R&D knowledge generation activity in each multinational firm as a production process.

This process includes observable measures as inputs, which are capital and labor, and an output, the results of the knowledge process.

³ We measure the performance in terms of efficiency, i.e., a measure of the distance from the best practice-benchmarking frontier in terms of output/input usage. Productivity and efficiency are often used as a synonym. We will use both terms to qualify the same measure of performance.

Following a well-established formulation, we define the conditional variables as something that is not an input or an output, but that can *condition* the (innovation) production process. Maintaining the input and output variables as the traditional production function models, we use the geographical diversity and the degree of internationalisation of patents as conditional variables.

Insert Table 1

5- Data Description

5-1- Analysed sample

The dataset consists of technological activities and the financial performance of 244 R&D-intensive firms: 126 firms are headquartered in Europe (54% in large European countries, that is Germany, France, United Kingdom, Italy, and 46% in small or medium-sized countries) and 118 firms in North America.

These firms are listed in the European Industrial R&D Scoreboard (2008 edition). They are among the top R&D-intensive firms worldwide across all industries and show a sustained inventive activity, i.e., they applied at least three transnational priority patents (patents applied in different countries) every year from 1997 to 2006.

The firm patent applications were identified by matching names of firms and their subsidiaries with the name of patent applicants in the Patstat database⁴.

The US and European firms show overall different sectoral distributions, more oriented towards Telecommunications and Technologies in North America and more centered on

⁴ See the details of the database construction in Laurens et al. (2015).

Industrials (including “Industrial goods and services” and “Construction and materials”) in Europe (Table 2).

Insert Table 2

5-2- Data description

Data and indicators are aggregated at the firm’s perimeter level and include the parent company and its subsidiaries.

The input variable Labor is represented by the number of workers, while R&D expenditure and Total Capital have been used as a proxy for the Capital variable.

In line with existing literature (Penner-Hahn and Shaver, 2005; Hsu et al., 2015), we proxy the innovative output of the firms by counting priority patent applications (weighting their number according to the technologies they cover). Of course, not all the R&D activities of the firm produce protected inventions, but patents are close to inventions and major inventions are often patented (Van Pottelsberghe et al., 2001). In order to give information on the inventive production of firms providing a patent quality threshold, we count the IP5 family priority patents, i.e., the priority patents extended at least in one foreign office and whose Inpadoc family contains one patent application in an IP5 office (EPO, USPTO, JPO, CNIPA, KINO). Similar indicators were used in many studies to account for innovative activities (de Rassenfosse et al., 2013; Rako, 2016; Squicciarini et al., 2015).

However, facing the issue of the heterogeneity across industry sectors, in particular concerning the costs of patents in firms covering different technologies, we assign a weight factor to patents. Recent studies have estimated the R&D investments per patent in different

sectors and showed that the cost per patent widely differs (Gkotsis and Vezanni, 2019; Neuhäusler et al., 2017). As the average costs in Gkotsis’s study were calculated on a set of firms very similar to ours, we use them to calculate the output of our production process. We are aware that such a weighted count of patents according to technology fields remains coarse. The *R&D output* of a firm is defined as a weighted volume of its patents applied during the period of time t per millions invested in R&D during the three previous years. We rely on the average value of the R&D investments per patent calculated by Gkotsis et al. (2019) for the 35 technological fields (WIPO classification), and the R&D efficiency for firm j is:

$$\text{R\&D productivity}_j = \sum_{i,j} (A_i \times N_i)_{\text{in 2005-2006}} / \text{R\&D expenditures}_{\text{in 2002-2004}}$$

where A_i is the average cost of a patent in the technological field i , and N_i is the fractional counting of the number of IP5 family priority patents of firm j in the technological field i .

The two *conditional* variables picturing the multinationality of the firm’s inventions are: a) the *internationalisation degree*, calculated using fractional counting to determine the share of patents invented outside the firm’s home country, and b) the *geographical diversity index*, calculated using the inventors’ country to proxy the invention’s location. In particular, we calculate the geodiversity = (1 - Herfindhal Index of the inventors’ country) to obtain an increasing measure of internationalisation in depth.

Table 3 summarises the definition and the sources of the data.

Insert Table 3

The variables were standardised and log-transformed. The summary statistics are resumed in Table 4.

Insert Table 4

On average, European and North American firms do not show statistically significant differences, but European firms are more multinational in their inventive activities than US firms (Table 4).

6- Results

In this section, we first characterise the European firms and the North American firms, contrasting the level of internationalisation and geodiversity of their inventions. Then, we present how the multinationality variables (internationalisation depth and breadth) influence the firms' R&D efficiency. The effects of the R&D multinationality on the R&D efficiency are not identical in all firms. Furthermore, a group of outperforming firms differs from the bulk, as they are not affected by internationalisation. We end by establishing the main characteristics, i.e., firms' internal factors, of this latter outperforming group.

6-1- The multinationality of the inventive activities

The R&D activities are more multinational in European companies than in the North American ones, both in terms of the internationalisation depth and the internationalisation breath: the level of internationalisation of EU firms (mean: 38,4%) is 11 points higher than the level of internationalisation of the North American firms (mean: 27,4%), and the geodiversity of the former (0.41) exceeds the diversity of the latter (0.34).

The internationalisation of European firms highlights very different patterns. Half of the EU firms have a level of R&D internationalisation below 28% (10 points below the mean value), but one-third of the EU firms are very internationalised and carry out more than half of their inventions outside their home country. In North America, the median and mean values are closer (respectively 22% and 27%); there is also a small group of very internationalised companies: 13% of North American firms have an internationalisation level above 50% (with a few outliers whose internationalisation levels are above 80%⁵).

Europe is by far the first destination of the internationalisation: European firms internationalise 27.2% of their inventions in European countries and North American firms internationalise 25.2% of them in Europe⁶. The attraction of European countries as a foreign location for R&D activities has already been described as a major trend of the early 2000s (Laurens et al., 2015).

The overall relationship between the level of internationalisation and the geodiversity of inventions for European and North American firms follows a global inverted U-shape⁷ (Figure 2).

Insert Figure 2

In a core set of firms, the level of internationalisation remains below 50%, and the internationalisation level and the geodiversity are linearly correlated. These firms rely first on national R&D facilities to develop new technological knowledge. When internationalising

⁵ They are discarded from further analysis.

⁶ By contrast, the European firms and the North American companies internationalise respectively 9% and 2.2% of their inventions in North America and 2.2% and 3.3% in Asia.

⁷ R-squared = 0.8823.

R&D activities, they simultaneously extend their internationalisation depth and breadth in order to access new competencies and/or new markets in a larger set of countries. This holds true for EU and US firms.

When the level of R&D carried out abroad dominates, a larger internationalisation depth is not always correlated with a wider internationalisation breadth. Most of the companies that carry out their R&D abroad, do it only where their markets are, i.e., in a limited number of countries. Structural reasons and organisational modes can also explain this situation: merging with foreign R&D entities, the acquisition of foreign R&D facilities, relocation of administrative units following financial incentives. Still, a few European firms do not comply with this mainstream mode of high level but low geodiversity R&D internationalisation. Their home countries (Northern European countries or Benelux) do not provide a large enough home market; in order to grow, they need to look beyond their domestic frontiers and become more globalised.

Using the theory of organisational learning, we interpret the above results in terms of learning phases in the process of R&D internationalisation (Ruigrok and Wagner, 2003, Mani et al., 2014). According to such a scheme, a firm starts to internationalise R&D by increasing both the internationalisation depth and breadth. However, as internationalisation is costly and requires managerial skills to benefit from foreign R&D, a firm gaining in maturity in its internationalisation development will optimise its R&D internationalisation. Different strategies could emerge depending upon the firms' own goals and strategies. This is why the mature firms could show diverging strategies and customised internationalisation scenarios.

6-2- The effects of the multinationality on the firm's R&D efficiency

From this evidence, we can gain insight into the dynamics of internationalisation effect on the production process, investigating the ratios of conditional and unconditional efficiency measures for full frontier. The full frontier ratios with respect to the geodiversity and the internationalisation depth are shown respectively in Figures 3 and 4.

The results show a heterogeneous behavior of the analysed firms.

The overall trend (dashed line) shows a slight and constant decreasing trend of the DEA ratios with respect to geodiversity (Fig. 3). This means that the R&D efficiency is weakly negatively affected by the geodiversity degree. This holds true on the whole range of internationalisation levels and applies to 87% of the North American firms and 80% of the European firms⁸.

Insert Figure 3

Insert Figure 4

Focusing now our attention on Figure 4, we see a different situation. First of all, we can see a nonlinear relationship, and this confirms that the nonparametric approach is appropriate for our analysis. Secondly, there is again a negative effect of the conditional variable (in this case, the internationalisation of patent) until the value of internationalisation level equals 0.6. Starting from this point, we see a positive trend. In general, the graph displays a U-shaped

⁸ A few very internationalised European firms diverge from the main trend: increasing the level of R&D internationalisation increases their DEA ratios.

relationship. The level of internationalisation equal to 0.6 is the same “changing point” as in Figure 2: it seems like a threshold beyond which the companies specialised their internationalisation strategy. Before this turning point, however, the strategy is common, and both indicators of internationalisation grow constantly, as already mentioned.

The combined analysis of the three graphs (Fig. 2, Fig. 3, and Fig. 4) shows a clear result: the internationalisation follows a path of growth in both dimensions considered in the analysis (geodiversity and patent internationalisation), and this effort is detrimental for R&D efficiency. Starting from the turning point around the level of internationalisation equal to 0.6 (and geodiversity also equal to 0.6), each company chooses its own mix between geodiversity and patent internationalisation and, from this point, we can see a clearly positive effect of this last conditioning variable on R&D efficiency. These trends are similarly evidenced on both sides of the Atlantic in the shared range of internationalisation level (0% - 80%).

6-3- Characteristics of the two groups of outperforming and mainstream firms

Next to this strong trend, a small group of 28 outperforming firms (40% are Northern American firms, 37% originate from small or medium-sized European countries, and the other firms are from Germany or the United Kingdom) behave differently. They witness a DEA ratio equal to unity. Neither the internationalisation depth nor the geodiversity affects their R&D efficiency.

In this subsection, we aim to characterise the two groups of firms in order to find empirical evidence that could help us to explain why a group of firms is not affected by R&D multinationality. We analyse whether the internal features of outperforming firms differ from those of the mainstream group.

Singling out these outperforming firms from the mainstream firms on a level of internationalisation-geodiversity plot (Figure 5) did not permit us to identify a range of levels of internationalisation or geodiversity where such high performing firms are clustered. However, the average internationalisation depth and breadth were significantly higher in this group of outperforming firms (respectively equal to 0.59 and 0.54 in the outperforming group and respectively equal to 0.34 and 0.29 in the mainstream group)⁹.

Insert Figure 5

From a geographical perspective, the continent of the firm's headquarters is not a variable that determines if a firm is mainstream or outperforming: the share of North American firms is not significantly different in the outperforming group compared to the mainstream group (42% versus 48%).

It seems that the firm's industrial sector and the size of the firm's home market are factors that discriminate the two groups. The outperforming firms are more often active in the sector of 'Software and computer service', and in Europe, the outperforming firms are more often headquartered in small or medium-sized European countries where the reduced dimension of the home market encourages the firms to extend their activities beyond national borders.

The R&D multinationality is on average higher in the outperforming group (both in internalisation depth and breadth as shown in Figure 5), but the internationalisation depth is quite heterogeneous among the outperforming firms (mean = 0.59; standard error = 0.059). This shows that there is a variety of cases where modulating the R&D multinationality to an overall business strategic scheme does not deteriorate the R&D productivity.

⁹ P-values = 0.000 (Kolmogorov Smirnov test).

We believe that the level of R&D intensity, calculated by the total amount of R&D expenditure on the number of employees devoted to R&D activities, is a key parameter to determine the behavior of the firm in its internationalisation process. It is only when reaching a certain level of R&D intensity that firms can overcome the uncertainty inherent to R&D globalisation.

Due to innovation in products and production processes, the R&D intensity contributes to improving, first from an operational point of view, the firm's global performance. Indeed, R&D intensity positively affects the firm's labor productivity (Kotabe et al., 2002; Castellani et al., 2017). However, how the operational performance gains are distributed along the chain value is still under study. Our results confirm this theory: with such high investments dedicated to R&D activities (Table 5), the outperforming firms surpass the group of mainstream firms when dealing with variables related to the firm's R&D productivity, the weighted IP5 family patent/R&D ratio, and they can overcome the uncertainty of internationalisation. Indeed, the latter does not affect the production process of the outperforming firms' group.

Insert Table 5

Our overall findings can now be summarised as follows. By and large, in the mid-2000s, the western large R&D corporate producers still relied to a large extent on national R&D skills, and their R&D efficiency did not benefit from R&D multinationality. This is true for a small-medium level of internationalisation. Starting from a medium-high level of

internationalisation of patent (equal to 0.6), we see a positive effect of multinationality on R&D efficiency.

There are companies whose efficiency is not affected by internationalisation. In these outperforming firms, both the R&D intensity and the R&D production are above the average. These firms strongly rely on foreign R&D to produce inventions, and their R&D efficiency does not suffer from the costs of internationalisation. Being often located in small countries, such firms had to expand their markets internationally. Being smaller than the mainstream firms, these outperforming firms can be seen as more mobile and more agile to adapt to international opportunities. They are characterised by a high level of R&D intensity, which seems to cushion the turbulence of internationalisation.

7- Discussion

We frame our work in the broad Multinationality-Performance relationship. The literature review explored this well-known relationship with often conflicting and contradictory results, in great part mediated by R&D intensity. This means that the more important the R&D is for the future of the firm, the more important will be the role of the R&D internationalisation in its two critical dimensions: enlarged access to knowledge resources ('home expanding' strategies) and product adaptation to key markets ('home exploitation' strategies).

R&D is manpower-intensive while, at the same time, value chains are more and more fragmented. The implication is that the performance of R&D production becomes a more and more important issue for the firm's strategic management. This creates a growing interest in the productivity of R&D itself.

Our analysis confirms that the majority of both US and European firms are engaged in R&D

internationalisation (EU firms are on average more internationalised, in particular when located in small EU countries seeking for external markets) but that they may well be, at the time of the analysis, in a learning phase that negatively impacts their R&D performance. On average, home-based activities still represent the majority of R&D activities and the depth and the breadth of the R&D internationalisation are strongly correlated and play similarly on the deterioration of R&D performance.

Such results can be analysed, following conceptual works highlighting that the management of internationalised R&D bears network and governance costs, and this requires a learning process (Chen et al., 2015; Singh, 2008; Gammeltoft, 2006). This means that R&D productivity deteriorates until internationalisation becomes rooted in the firm. Both US and EU firms suffer from R&D internationalisation. Taking into account that European firms do massively internationalise R&D in Europe (about $\frac{3}{4}$ of their internationalised inventions), it is not easier for European firm to internationalise R&D nearby in Europe than for a US firm to internationalise overseas in Europe.

At higher levels of internationalisation, the R&D efficiency frontier sees diverging evolutions. The main trend remains negative concerning the geodiversity degree of the inventors' country but we witness European firms showing a reversal of the negative trend at high levels of internationalisation. Looking at such highly internationalised European firms, we have anecdotal evidence that there is a connection between the relative size of their markets (Martinez-Romàn et al. 2019) and the respective roles of the countries where their R&D internationalisation is carried out, with a combination of home expanding and home exploiting rationales (Laurens et al., 2015).

At last, the analysis also showed that a subgroup of mature internationalised firms did not witness a change in their efficiency due to R&D internationalisation. These 'outperforming' firms are not gathered in the expected quadrant of both high depth and high breadth. On the

contrary, they display a rather high level of geodiversity and cover a broad range of levels of internationalisation.

Overall, our results raise several questions for future developments. First, we show that the internationalisation of R&D activities that answers overall strategic goals whether to look for complementary knowledge resources or to adapt products to new geographical markets is conducted despite a loss of productivity of R&D activities. Is that deterioration a lasting feature, compared to R&D centralised in the ‘home’ country of multinational firms? It does not seem so, as we have nearly one quarter of firms, that have not witnessed such a movement. These firms bear two dominant characteristics: they are more R&D intensive and they witness a large geographical spread of their R&D activities.

Moreover, the internationalisation of R&D activities is a long learning process to achieve institutional and organisational proximities (Boschma, 2005) that can counterbalance the deterioration of R&D performance. This raises two questions: what speeds up this process (R&D intensity seems a potential core factor) and what may define a maturity stage (geodiversity of R&D activities compared to the markets of the firms seems also a good candidate).

At last, there may be multiple stable situations of productive R&D internationalisation, as is witnessed by the few ‘mature’ cases in our sample. This remains an open interrogation that may find elements in a similar analysis made on firms one decade later, anticipating a far greater number of mature firms. But one may well also consider, in the achievement of a stable productive R&D situation, the role of fragmentation in value chains and the relative importance of R&D activities in the firm added value. These questions pave the way to future works on the one hand including a larger sample of firms with more recent data and also to in-depth analysis of individual cases. Questions related to the R&D internationalisation and

its influence on the R&D productivity in a pandemic time is of interest. Very preliminary evaluations indicate that R&D investment drops were limited and the location of the industrial sites across countries remains stable among top R&D investors (Grassano et al., 2021).

At last, we have shown that US firms and European firms seems to behave quite similarly in their loss of R&D productivity when internationalising. Investigating this relationship in set of firms that do internationalise more slowly (Japanese firms for example) or more recently (firms from emerging countries) would also be a highly relevant.

8 - Conclusion

Overall, we show that there is not a unique best way for internationalisation, for ‘mature’ internationalised firms, but a variety of situations dealing both with the level of internationalisation and the geographical diversity of the countries where R&D is undertaken (von Zedtwitz et al., 2004; Vrontis and Christofi, 2019).

The variety is also well illustrated with the outperforming firms. Being very effective when internationalising R&D, they witness different key characteristics. Mobilising twice as large assets as the mainstream firms, the outperforming firms are more R&D productive and more R&D intensive: this is what characterises and differentiates them.

Other studies have shown how the R&D intensity weighs on the multinationality-performance relationship (Kirca et al., 2011; Castellani et al., 2017). Kotabe et al. (2002) have shown that companies tend to enjoy operational improvement (i.e., positional strengths) from foreign expansion before financial improvement as they increase their R&D intensity. Similarly, we believe that the R&D intensity also plays a role in the R&D efficiency - R&D internationalisation relationship. Below a certain level of R&D intensity, the R&D

productivity is lowered by the internationalisation of R&D activities but that companies may enjoy R&D productivity improvements from foreign expansion as soon as their R&D intensity is high enough to overcome the challenges of R&D internationalisation. The level of R&D intensity that allows firms to reduce instability of and benefit from internationalisation certainly depends on the firm's internal factors, but we are not able to further specify this issue. We do not have a large enough sample to test whether there are typical situations of productive R&D internationalisation and assess the role of the firm's external parameters (industry, country). This calls for further analyses, in particular considering the situation one decade later.

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Footnotes:

¹ For an extensive literature review on R&D internationalisation and innovation, we signal to the readers two excellent recent articles: Vrontis and Christofi (2021) and Papanastassiou et al (2020).

² Top R&D performers headquartered in Asian countries were discarded from this study because of the very low R&D internationalisation level of most of Asian firms. The overall R&D internationalisation level of Asian firms was 3.5% and it was below 1% for 60% of the Asian firms. Similar results were obtained in Laurens et al. 2015.

³We measure the performance in terms of efficiency, i.e., a measure of the distance from the best practice-benchmarking frontier in terms of output/input usage. Productivity and efficiency are often used as a synonym. We use both terms to qualify the same measure of performance.

⁴See the details of the database construction in Laurens et al. (2015).

⁵They are discarded from further analysis.

⁶ By contrast, the European firms and the Northern American companies internationalise respectively 9% and 2.2% of their inventions in North America and 2.2% and 3.3% in Asia.

⁷ R-squared = 0.8823.

⁸ A few very internationalised European firms diverge from the main trend: increasing the level of R&D internationalisation increases their DEA ratios.

⁹ P-values = 0.000 (Kolmogorov Smirnov test).

Table 1: Model of the production of inventions.

ble	Measures
Inputs	R&D expenditures Capital Number of Employees
Output	Weighted number of IP5 family priority patents
Conditional factors	Geographical diversity Level of internationalisation of patents

Table 2: The distribution of firms by industrial sectors.

Industrial sector (ICB industry)	Europe	Northern America	Total
Basic Materials, Oil & Gas	22	18	40
Industrials	51	32	83
Consumer Goods & Services	27	21	48
Health Care	13	14	27
Technology and Telecommunications	13	33	46
Total	126	118	244

Table 3: The description of the variables used in the analysis.

Variable	Definition	Source
R&D expenditure	R&D expenditure (only investments funded by, and performed for, the companies themselves) (2002-2004)	Industrial R&D Investment Scoreboard
Capital	The total amount of capital (2002-2004)	Orbis Database
Employees	The total number of employees (2002-2004)	Industrial R&D Investment Scoreboard
IP5 family priority patents	The total number of priority transnational patents applied for which the extended family includes a patent filed in one of the IP5 offices (2005-2006)	CIB Database
Internationalisation degree	The share of IP5 family patents with inventors, who are located outside of the firm's headquarters (fractional counting) (2005-2006)	CIB Database
Geographical diversity	Invention's geographical diversity at the country level (1-Herfindhal Index on inventors' countries) (2005-2006)	CIB Database

Table 4: Summary statistics

Variables	Mean	Std. Err.
Employees (avg)	51 263	4 595
R&D expenditures (avg) (M€)	556	67
Capital (avg) (M€)	16 354	37 100
The number of IP5 family patents (unweighted) (avg)	91	12
The number of IP5 family patents (weighted) (avg)	289	39
The level of internationalisation of inventions (avg)		
- Northern America:	0.27	0.0225
- Europe:	0.38	0.0283
The geodiversity of inventions (avg)		
- Northern America:	0.34	0.0182
- Europe:	0.41	0.0219

Table 5: The characteristics of firms that differ in the mainstream group and the outperforming group.

Variables	Mainstream firms	Outperforming firms	Kolmogorov Smirnov test (p value)
Weighted IP5 family patents/R&D	0.76	1.22	0.002
R&D intensity	12.3	20.5	0.000

Figure 1: An overview of the analysis carried out.

Figure 2: The evolution of the geographical diversity of inventors' location with the degree of internationalisation.

Figure 3: The evolution of the DEA ratios with the geodiversity.

Figure 4: The evolution of the DEA ratios with the level of internationalisation.

Figure 5: The identification of outperforming and mainstream firms with respect to the R&D internationalisation depth and breadth.

Figure 1

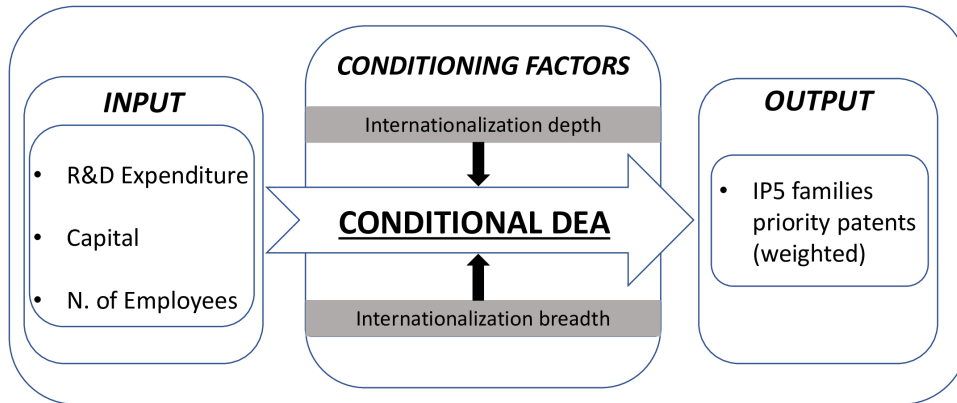


Figure 2

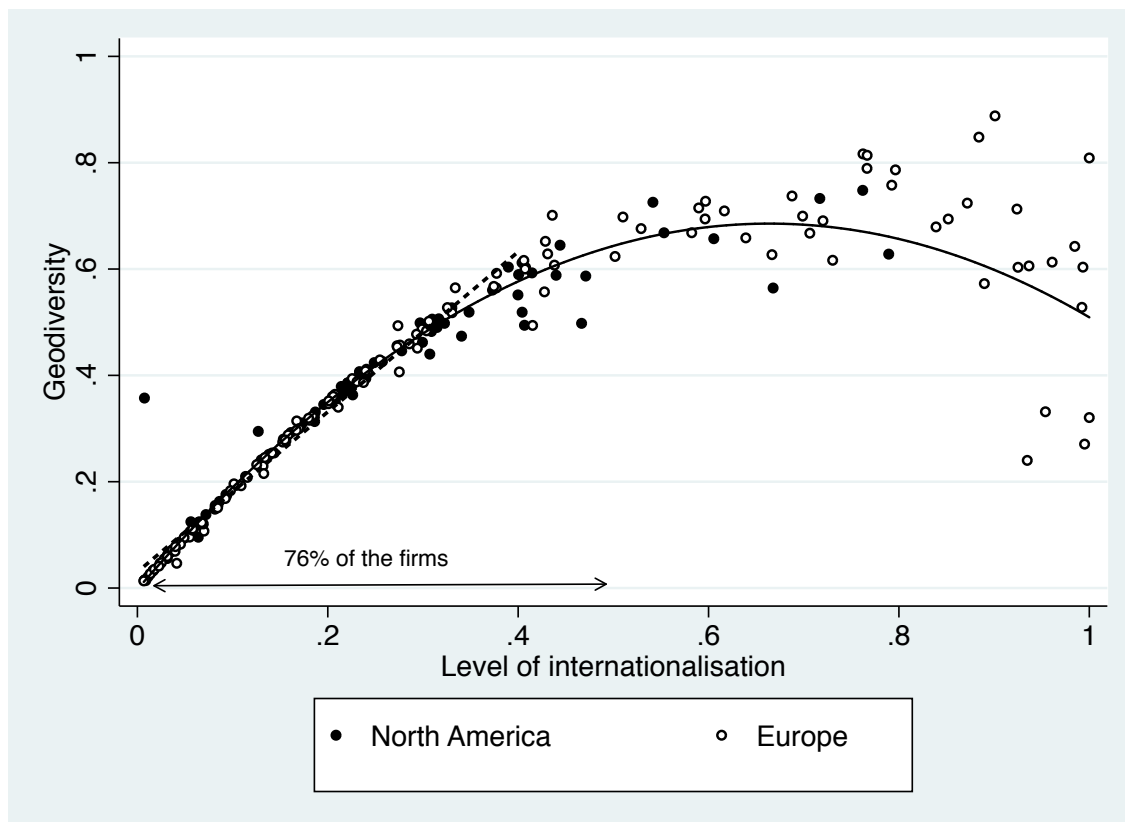


Figure 3

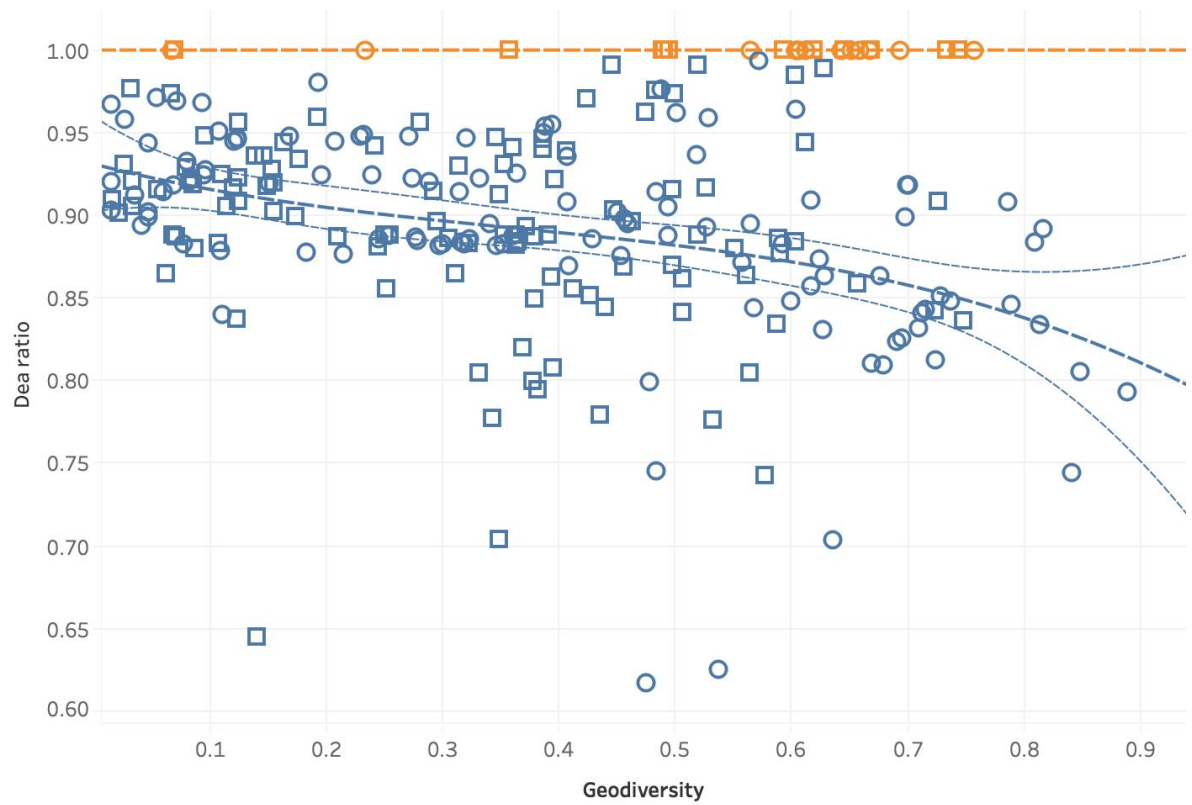


Figure 4

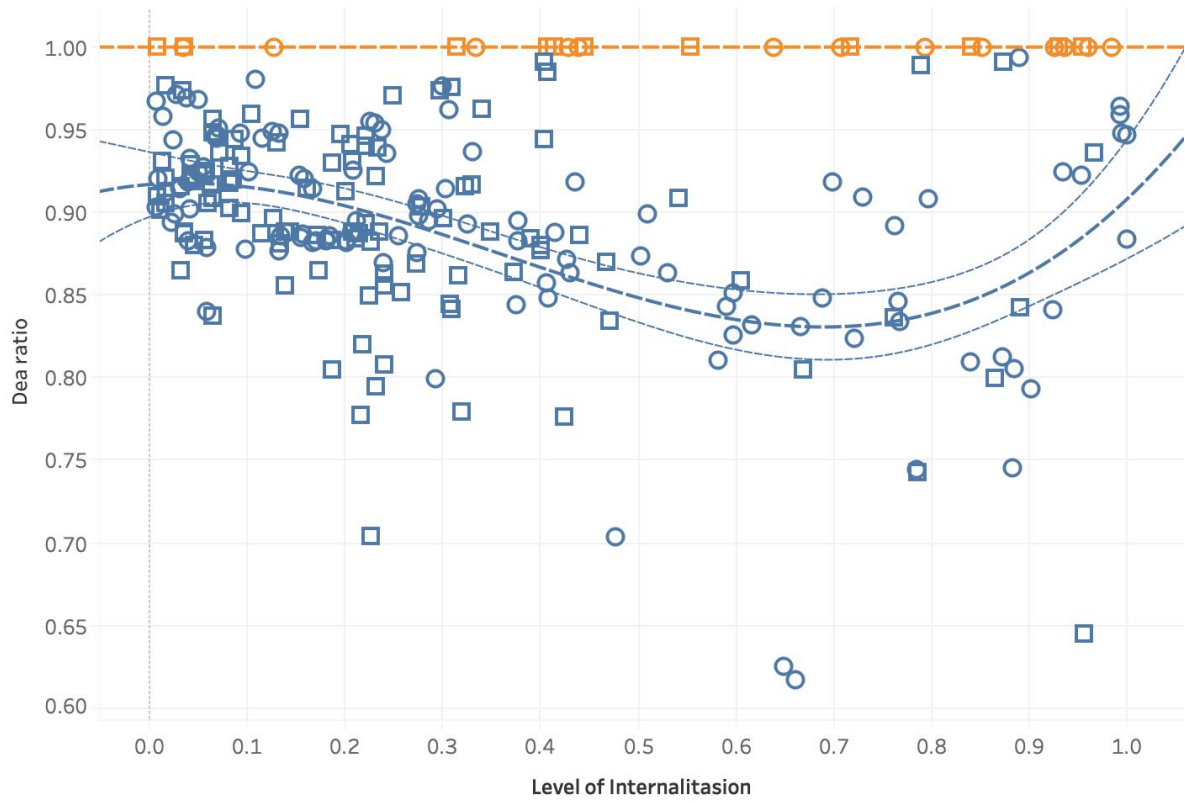


Figure 5

