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Follow the leader: Evidence of the Productivity catch-up of European firms

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Abstract

In this article we characterize Total Factor Productivity (TFP) frontier firms at the industry level within the European Union during the period 2003-2014, and explore the determinants of the firms' distance to the frontier. We find that larger, more capital-intensive, and more labour skilled firms are closer to the productivity frontier. In contrast, older firms are further away from the frontier. In addition, we obtain that a number of countries' economic and institutional factors, such as tertiary education, trade openness, R&D stock, easiness in getting credit and governance quality, affect positively the catching up of laggards towards the productivity frontier. We also examine the moderating effect of the Great Recession as well as the effect of productivity improvements at the frontier.

Keywords: TFP, frontier firms, laggard firms, Great Recession, European Union countries
JEL CODES: F43; O47; O52

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1 Introduction.

The presence of wide and persistent productivity gaps between countries, including within the EU, has been a long-debated issue. As a result, a vast literature has explored the evolution of these productivity differences over time and the extent to which they have been growing or shrinking, leading to divergence or convergence (Barro and Sala-i-Martin, 1992). A common feature of this literature has been the use of aggregated data, and hence, it has overlooked firm's heterogeneity. However, there is evidence that cross-country differences in aggregate productivity relate to differences in the within-industry productivity dispersion across firms (Bartlesman et al., 2013; Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009). Despite this evidence, few studies have examined the drivers behind convergence of laggards to the global productivity frontier in their industry (Andrews et al., 2016).

The aim of this paper is, therefore, to fill this gap by providing new evidence on the factors that allow firms to converge to the most productive in their industry at the European level. In particular, we analyse the factors determining the distance of laggard firms to their technological leader. With this aim, we test how firms' characteristics and countries' economic and institutional features may influence a firm's TFP relative position to the frontier. We also take into account the moderating effect of the Great Recession in the impact of these factors. Finally, we aim at providing guidance on how policy makers may further stimulate the productivity growth of firms lagging behind the productivity frontier. Fostering the productivity level of laggard firms within industries is an important policy issue, especially in countries with skewed industrial structures where more firms linger far from technological excellence. In this context, it is crucial to understand the

factors determining the distance-to-frontier of laggard firms, as a way to raise aggregate productivity.

Using European firm-level data from the AMADEUS dataset for the period 2003 to 2014, we identify the technological frontier firms by industry within the European Union and explore which firm and country-level characteristics determine the distance of other firms in the same industry to the EU frontier firms. To analyse the determinants of the within-industry distance to the TFP frontier we first provide a description of the characteristics of the most productive firms, that is, the frontier firms, in comparison with the non-frontier firms. We then analyse the determinants of firms' TFP gaps. To take into account the moderating effect of the Great Recession, we analyse two different sub periods, namely, the period prior to the last financial crisis, which we call pre-recession period, 2003-2007, and the recession period, 2008-2014.

This paper contributes to the scarce existing literature on the characteristics of firms operating at the productivity frontier and on the determinants of the distance to the frontier using firm-level data. Andrews et al. (2016) analyse productivity divergence from frontier firms using a dataset of firms in OECD countries. Other related papers using firm-level dada to analyse the catching up to the technological frontier are Bartelsman et al. (2008) for a group of five European countries and the US, Iacovone and Crespi (2010) for México, and Van der Wiel et al. (2012) for the Netherlands. However, to our knowledge there is no prior study attempting to capture the determinants of the catching up to the EU technological frontier, and the moderating role of the Great Recession.

Our main findings may be summarized as follows. The regression analysis of the determinants of the TFP gap between EU frontier and non-frontier firms within

industries suggests that, in general, larger, more capital-intensive and more labour skilled firms are closer to the frontier. In contrast, older firms are further away from the frontier. At the country level, there are a number of economic and institutional factors, such as tertiary education, trade openness, R&D, easiness in obtaining credit and governance quality, which play a significant role in reducing the distance of laggards to the frontier. As regards the role of the Great Recession in moderating the effect of these factors, we obtain differentiated patterns for the two considered sub periods. Additionally, our results show that in the pre-recession period laggard firms could benefit from knowledge spillovers from productivity improvements in the frontier firms. However, the presence of these spillovers vanished in the recession.

The rest of the paper is organized as follows. Section 2 presents the data we use and describes the measurement of firms' productivity. Section 3 provides a careful characterization of the best performing or EU frontier firms versus non-frontier firms. Section 4 presents a regression analysis of the determinants of TFP gaps, looking at firm specific and country level factors. Finally, section 5 concludes.

2. Data and measurement of productivity.

The data we analyse are drawn from AMADEUS, a database providing firms' balance sheet information, such as value added, assets, age, and number of employees, for all EU countries. We use this information to estimate TFP at the firm level in a cross-country setting.

Following Arnold et al. (2008), Gal (2013), and Andrews et al. (2015), we focus on the set of firms with more than 20 employees as this helps to obtain a better

coverage and a more balanced sample. Arnold et al. (2008) point out that AMADEUS does not have satisfactory coverage of firms with less than 20 employees; therefore, the resampling procedure targets the size-sector-country distribution of the true population of firms with 20 employees and more. Andrews et al. (2015) for ORBIS highlight a similar problem, and also exclude firms with less than 20 employees.[1]

Further, to ensure that the computation of TFP is feasible for the largest possible number of firms we follow Gal (2013), who suggests an imputation methodology, improving the original coverage of AMADEUS. Our working sample is largely coherent with that in Gal (2013) for the overlapping countries. In addition, following Gal (2013), currency conversion based on PPPs and deflation are applied to ensure comparability of productivity measures across countries and over time.

The data we analyse correspond to the period 2003 to 2014. The coverage of EU member states is subject to data availability in AMADEUS. Thus, our data cover 23 EU Member States. Cyprus and Lithuania are excluded as there is no information. Luxembourg, Malta, and Latvia are also excluded due to insufficient observations. The industry classification is based on NACE Rev. 2, limited to the market sectors and excluding agricultural, mining, real estate and financial sectors.[2] These sectors are more prone to issues in accurately measuring output and they are more affected by lack of information. As for the financial sector, since AMADEUS does not generally include banks, the coverage would not be representative of this sector at the European level and, therefore, it is excluded.

[1] A drawback of ORBIS and AMADEUS is that it is a selected sample of larger and more productive firms, which tends to result in smaller and younger firms being under-represented in some economies.

[2] See Table A.1 in the Appendix for a classification of the industries used.

After cleansing the data from missing values in relevant variables and keeping company accounts with valid information for our analysis,[3] we have a sample of 1,032,516 observations, corresponding to 102,405 firms.

In order to estimate productivity, we first estimate a Cobb-Douglas value added production function using the methodology proposed by Wooldridge (2009) and the demand for intermediate materials as a control function as proposed by Levinshon and Petrin (2003). We consider the log version of the production function as follows:

$$y_{iptc} = \beta_{0p} + \beta_{Lp} l_{iptc} + \beta_{Kp} k_{iptc} + \omega_{iptc} + \eta_{iptc} \quad (1)$$

where y_{iptc} is the natural log of value added for firm *i* in sector *p* at time *t* and in country *c*, l_{iptc} is the natural log of labour and k_{iptc} is the natural log of capital. As for the unobservables, ω_{iptc} is the firm productivity (not observed by the econometrician but observable or predictable by firms) and η_{iptc} is a standard i.i.d. error term that is neither observed nor predictable by the firm.[4]

The production function in (1) is estimated separately for each 2-digit industry *p* but pooled across all countries, controlling for country and year fixed effects. This implies the estimation of time constant and sector-specific coefficients for labour and capital that are common across all countries. This allows for technological differences across industries, while simultaneously facilitating both international and over time comparability of the resulting productivity levels. We obtain estimates of firms' TFP as the residuals from the estimated production functions:

[3] We closely follow Kalemli-Ozcam et al. (2015) and Andrews et al. (2016) for filtering our data.

[4] Estimation of the above production function using the Wooldridge (2009) strategy has three advantages: it solves the problem of identification of the labour coefficient in the first stage of Levinshon and Petrin (2003) and Olley and Pakes (1996), noted by Ackerberg et al. (2007); it increases efficiency relatively to two-step procedures; and, finally, it makes unnecessary the use of bootstrapping for the calculus of standard errors.

$$\hat{\omega}_{iptc} = y_{iptc} - \hat{\beta}_{Lp} l_{iptc} - \hat{\beta}_{Kp} k_{iptc} \quad (2)$$

where $\hat{\omega}_{iptc}$ is the estimate of the log TFP for firm *i* belonging to the 2-digit industry *p* in period *t* and country *c*.

3 Descriptive analysis of EU frontier firms.

There is a renew interest in understanding the factors behind productivity growth and in particular the drivers of productivity convergence among EU countries. There are two main perspectives in the study of catching-up mechanisms to the frontier: the macroeconomic and the microeconomic approach. In the former, the unit of analysis is either the country or the region (Barro and Sala-i-Martín, 1992) and the objective is to identify the frontier at the country or region level, and to test whether productivity growth in other territories is related to the existing gap to the frontier (see Acemoglu et al., 2006; Aghion et al., 2008; Amable et al., 2010; Griffith et al., 2004a; Kneller and Stevens, 2006; Sala-i-Martí, 1996; among others). Under this approach, it is assumed that all firms in a given region catch-up and converge towards the frontier, disregarding heterogeneity across firms and ignoring the fact that growth may be influenced by mechanisms of selection and reallocation, as well as uncertainty (Jovanovic, 1982; Melitz, 2003).

The microeconomics approach, instead, aims at overcoming some of these limitations, and in particular the heterogeneity across firms (Acemoglu et al., 2007; Alvarez and Crespi, 2007; Andrews et al., 2015; Bartelsman et al., 2008; Bartelsman et al., 2015; Ding et al., 2016; Griffith et al., 2004b). The unit of analysis is the firm, and it is based on the identification of a best-practice frontier firm (or group of firms) reflecting the most advanced technology within an industry and country (or groups of countries). Although some micro studies based on a

single country are able to address the issue of firm-level heterogeneity, and they are potentially helpful in understanding whether catching up differs across types of firms, they may not be able to correctly identify the 'true' frontier, which in many industries may depend upon firms operating in neighbouring countries.

In light of these considerations, micro data for all (potentially relevant) countries within a given geographical area or development level is useful in identifying the "global" frontier, which may differ from the national frontier firms. The scarce literature using firm-level data in a multi-country analysis uses a small number of countries to identify the global frontier firms. For example, Bartelsman et al. (2008) focus on the United States and five European economies. Iacovone and Crespi (2010) and, Van der Wiel et al. (2012) analyse Mexico and The Netherlands, respectively, and use the data from Bartelsman et al. (2008) to identify the global frontier. However, a small sample of countries casts doubts about the correct identification of the global frontier. An exception to these studies are Andrews et al. (2015, 2016), who analyse the global frontier considering a sample of 23 OECD countries over the period 2001 to 2009 or 24 OECD countries over the period 1997 to 2014, respectively.

In this paper we use a microeconomic approach to derive the "EU frontier firms", considering the EU as a well-defined area to be analysed. Following Andrews et al. (2016), for the construction of the industry productivity frontier we use a fixed number of firms per industry over the sample period. More specifically, this fixed number of firms that will be part of the frontier in each industry corresponds to the top 5% of the median number of firms across all years within each 2-digit industry. This allows frontier firms to change over time, the frontier size to vary

across industries, and avoids potential problems that may arise as the coverage of firms by Amadeus expands over time.

Once the EU frontier firms for each 2-digit industries have been identified, we first characterize the EU frontier firms, analyse its composition by country of origin and, then, examine firms' persistence in the EU frontier.

3.1. A characterization of the EU frontier firms.

To analyse the EU frontier firms, we describe cross-sectional differences in key characteristics between EU frontier and non-frontier firms along a number of measurable dimensions. This part of the analysis is merely descriptive. The main dimensions considered include: TFP (measured as described in section 2), age, employment, value added, capital intensity, profits and wages per employee. A test of the difference in means over these dimensions determines the extent to which EU frontier firms differ significantly from non-frontier firms.

Table 1 reports these differences in average characteristics at aggregate level over the period 2003 to 2014. In addition, this table provides cross-sectional differences in average characteristics for the years 2006 (pre-recession) and 2013 (recession), respectively. Table 1 also shows these differences over the total period by three aggregate groups of industries: manufacturing, non-financial market services and other production.[5] In all cases the differences in means between frontier and non-frontier firms are based on the classification according to the TFP productivity measure.

[5] The industry classification is based on NACE Rev. 2, limited to the market non-farm/agricultural non-financial sectors (that is, excluding industries A, B, and O to P due to the lack of information). See the Appendix for a classification of industries.

[Insert Table 1 around here]

Over the period 2003 to 2014, firms at the EU frontier are on average four times more productive than non-frontier firms, indicating that the TFP gap between frontier and non-frontier-firms is considerable and, therefore, suggesting that the potential for catching up in TFP remains enormous.[6] In addition, EU frontier firms are on average older,[7] larger, more capital intensive, have higher value added, profits, and pay higher wages per employee than non-frontier firms (a similar characterisation is also obtained by Andrews et al., 2016, for the global frontier firms using a sample of 24 OECD countries). These features also hold when we look separately at manufacturing, non-financial market services and other production.

Comparing the reported statistics for the year 2006 (pre-recession) and the year 2013 (recession), we observe that there is a reduction in the average TFP of both frontier and non-frontier firms. Likewise, from 2006 to 2013 non-frontier firms experience a reduction in size, as measured by the number of employees, value added, and profits, while capital intensity and average wage per employee increase. In contrast, frontier firms increase in size, value added and capital intensity, whereas average profits and wages per employee decrease.

3.2. The EU frontier composition by country of origin.

Table 2 shows the percentage of firms in the EU frontier by country in the two selected years (2006 as pre-recession and 2013 as recession years). In

[6] Note that TFP is measured in logs, therefore, relative to non-frontier firms, frontier firms are on average *exp* (5.8-4.4)=*exp* 1.4=4.05 times more productive.
[7] Although the significant difference in age is lost over time.

particular, the figures presented in this table are calculated following the two steps procedure in Gal (2013): First, the percentage of EU frontier firms of a given industry from a given country (per year) is calculated.[8] Second, the average across industries of this percentage is calculated for each country. A higher value than 5 means the country is overrepresented in the EU top 5% of firms. For example, in 2013, on average across industries, 12.88% of firms in Germany are in the EU top 5%. Countries in the table are ranked according to their 2013 values, from the best to the worst. The information is provided separately for manufacturing, non-financial market services and other production, but also for the total of these sectors.

By looking at the country composition of the EU frontier in 2013 for the total of sectors, we observe that those countries with higher participation (above 5%) are Austria, the Netherlands, Belgium, Germany, Denmark, Ireland, and the UK, while firms in France, Sweden, Spain, Slovakia, Italy, and Hungary are less represented in the top 5% (from 3.29% for Hungary to 4.69% for France). The remaining countries are clearly underrepresented, with the last three being Romania, Greece, and Estonia.

By sectors, the general results hold with few exceptions. By 2013, France belongs to the group of countries overrepresented in the top 5% in manufacturing, the same happens to Sweden and Slovakia for non-financial market services, and to Spain for other production.

We also observe that from 2006 to 2013, the Netherlands enjoys a noticeable increase in its participation among the EU frontier firms (from 10.48% to 16.76%).

[8] More precisely, the percentage in top $5\%_{(country, year)}$ is calculated as the number of $firms_{(country, industry, year)}$ that belong to the $EU\text{-}frontier_{(industry, year)}$ over the total number of $firms_{(country, year)}$.

However, there are also relevant decreases for countries such as Spain, Hungary, Italy and Greece. The increase for the Netherlands comes both from manufacturing and non-financial market services. The decreases for Spain and Greece affect the three sectors. In Hungary the decrease comes from manufacturing and non-financial market services and, finally, in Italy from other production and especially from non-financial market services.

[Insert Table 2 around here]

3.3. Persistence of EU frontier and non-frontier firms.

An additional feature we are interested in is the analysis of firms' persistence in the EU frontier. In Tables 3 and 4 we present the percentages of firms remaining at the frontier and lagging behind the frontier, respectively, after one, two and five years. We report the results for all sectors and separately for manufacturing, non-financial market services and other production. The information in these tables corresponds to three different samples. Sample 1 follows (frontier and non-frontier) firms from 2003 onwards. Sample 2 follows (frontier and non-frontier) firms from 2006 onwards and, therefore, minimizes potential coverage problems of Sample 1 due to the expansion over time in the number of firms in AMADEUS. Finally, Sample 3 follows firms (frontier and non-frontier) from 2006 onwards but restricting the sample to a balanced panel of firms that remain in AMADEUS from 2006 to 2013. As compared to Samples 1 and 2, Sample 3 eliminates the effect of firms' exit from AMADEUS in the computation of persistence.[9] The purpose of

[9] For several countries, there is a relevant drop in observations and coverage in AMADEUS from the year 2013 to 2014 (also highlighted by Andrews et al. 2016). For this reason, the criteria for balancing the sample in Sample 3 considers the year 2013 but not the year 2014. However, data corresponding to 2014 are included in the estimations.

examining these three samples is to provide a robustness check as regards the analysis of firms' persistence.

[Insert Table 3 around here]

Table 3 reports firms' persistence in the EU frontier. We observe that the degree of persistence according to Samples 1 and 2 is quite similar, although persistence is higher according to Sample 3 as expected. As mentioned above, persistence is higher due to the fact that balancing the sample we avoid the effects of attrition in the AMADEUS database. In Sample 3, results indicate that on average 51.78% of firms remain at the EU frontier after five years (the percentages are 66.05 and 74.88 after two and one years, respectively). In general, persistence is higher among frontier firms in non-financial market services than among firms in manufacturing and other production.

[Insert Table 4 around here]

Table 4 reports persistence in the non-EU frontier. According to our Sample 3, the average percentage of firms that remain at the non-EU frontier after one year is 93.97%, and after five years is 70.45%. By sectors, in Samples 1 and 2, the highest persistence in this status is for firms in manufacturing, whereas in Sample 3 the highest persistence corresponds to firms in other production and non-financial market services.

Another proxy for persistence in the frontier (non-frontier) status is the average number of years a firm remains at the frontier (away from the frontier). We have

calculated these mean values for frontier (non-frontier) firms during the period 2006-2014 using only information on firms belonging to Sample 3. We find that those firms at the frontier (for at least one year) remain there for around 61.65% of the years analysed, and the mean number of years they remain leaders is 3.31 years. Furthermore, we find that non-frontier firms (for at least one year) remain at the non-frontier status around 97% of the years analysed, and the mean number of years they remain there is around 5.24 years.

4. Determinants of the distance to the frontier.

In Table 5 we report the evolution of the average TFP for all firms, and also for frontier and non-frontier firms during the period analysed. We observe that the average TFP gap between frontier and non-frontier firms is approximately equal to 4 during the sample period (ranging from the lowest, 3.71 in 2005, to the highest, 4.18 in 2009). This means that, on average, frontier firms are four times more productive than non-frontier firms.

[Insert Table 5 around here]

In this section we analyse the factors determining the distance-to-frontier of laggard firms. With this aim, we test how firms' characteristics and country's economic and institutional features may influence a firm's TFP relative position to their frontier. As stated earlier, frontier firms are identified at the EU level (within each industry and year). We estimate a model with the distance to the frontier (or technology gap) on the left-hand side and firms' and country's characteristics and

other controls (such as industry, country and year dummies) on the right-hand side, as follows:

$$\ln \frac{TFP_{icpt}}{TFP^{F}_{pt}} = \alpha + \beta' Z_{icpt} + \delta' X_{ct} + \gamma_p + \gamma_c + \gamma_t + \varepsilon_{icpt} \quad (3)$$

where subscript *i* denotes firm, subscript *c* country, subscript *p* 2 digit-industry and *t* the time period. The distance to the frontier of a particular laggard firm is calculated as the log of the ratio of its own TFP over the average TFP of the firms at the frontier of the same industry and year. Firms' characteristics are captured by Z_{icpt} (including size –measured by the number of employees–, age, capital intensity, and skilled labour –proxy by wage per employee).[10] X_{ct} is a vector of variables capturing economic and institutional characteristics at the country-year level. The γ's are industry, country and year dummies, respectively, and ε_{icpt} is a standard i.i.d. error term.

Among the variables at the country-year level we include the following. First, we include a measure of human capital, which is the percentage of 15-64 years old population with *Tertiary Education*, drawn from *Eurostat*. We expect this variable to be related to the ability of the country to absorb ideas and knowledge from the technological frontier and, therefore, to have a positive impact on the technological catching up of laggards. Second, as knowledge is expected to play a crucial role in explaining the distance of firms to technological frontiers, we consider a knowledge-related variable such as the percentage of researchers in R&D per million people (*R&D*) obtained from the World Bank Development Indicators. The advantage of this type of variable is that it represents a stock

[10] We use wages as a proxy for skills at the firm level. Although we acknowledge this is far from perfect, this is the best available measure in the AMADEUS database for this purpose. We are also aware of papers that use information on wages to control for differences in the quality of the workforce (Gopinath et al., 2017).

measure of knowledge. We also include a measure of *Trade Openness* (calculated as the ratio of the sum of imports plus exports over GDP) from the World Bank Development Indicators. According to Melitz (2003), exposure to trade is an important driver contributing to a better resource allocation, thereby affecting within-industry productivity dispersion.[11]

In addition, from the World Bank's dataset *Doing Business* we use an indicator capturing the distance to frontier (DTF) between a particular country's performance and the world' best practice regarding the ease in getting credit (*DTF getting credit*). This indicator tries to capture two types of related issues: the strength of credit systems and the effectiveness of collateral and bankruptcy laws in facilitating lending.[12] By construction, higher values of this indicator imply greater ease in conducting business, thereby we expect this variable to positively affect TFP growth.

Finally, from the *Worldwide Governance Indicators* we use different indicators in order to obtain a summary measure of each country' *Governance Quality:* Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. Government effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. Regulatory Quality reflects the perceptions of the ability of the government to formulate and

[11] It has been documented that more exposure to trade implies selection of the most productive firms into the export markets and market share reallocation by the exit of less efficient firms (Amiti and Konings, 2007; Fernandes, 2007).

[12] In particular, this indicator measures two types of institutions and systems that may facilitate access to finance and improve its allocation: (i) Legal rights of borrowers and lenders in secured transactions and bankruptcy laws. (ii) Coverage, scope and quality of credit information available through credit registries and bureaus.

implement sound policies and regulations that allow and promote private sector development. Rule of Law captures the perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. Finally, Control of Corruption captures perceptions of the extent to which public power is exercised for private gain, including both minor and grand forms of corruption, as well as "capture" of the state by elites and private interests. Given the high correlation among these four variables, we apply factor analysis to obtain a synthetic measure, *Governance Quality*, which is a weighted sum of the original indicators.

The estimation results obtained by linear regression are presented in Table 6. All regressions are run only with non-frontier firm distances. Results were similar when also including frontier firms in the regressions, in which case the corresponding log value for the dependent variable for frontier-firms was set to zero. Coefficient estimates for the regressors at the firm-level have the interpretation of elasticities since both the dependent variable and firm-level regressors are in log form.

[Insert Table 6 around here]

In Column (1) of Table 6 we estimate the regression in expression (3) above. Regarding firms' characteristics, we find that larger, more capital intensive, and more skilled-labour firms decrease the distance to the frontier. For instance, a one per cent increase in size (as measured by the number of employees) reduces the distance to the frontier by 0.182 per cent, and a one per cent

increase in capital intensity reduces the distance to the frontier by 0.026 per cent. In addition, age increases the distance to the frontier. These results are consistent with the findings of Andrews et al. (2015) for OECD countries, and also with Conway et al. (2015) for New Zealand, who find that frontier firms are more likely to be younger.

As regards to country-level economic and institutional factors, we find that they play an important role as determinants of firms' distance to the EU TFP frontier. In particular, we obtain that tertiary education, R&D stock, trade openness, easiness in getting credit, and quality of governance significantly and positively affect the technological catching up of laggards to the frontier. These results are in line with existing literature. For instance, Iacovone and Crespi (2010) provide evidence on the role of trade openness in the catching up of laggards towards the frontier. Arnold et al. (2001) document how product market regulations that restrain competitive pressure negatively affect firms' productivity, implying that a weak market and institutional framework may impose a burden on productivity growth of firms. In addition, though from a macroeconomic perspective, Añón Higón et al. (2018) obtain a positive impact of R&D in fostering countries TFP growth in a study on productivity convergence across the EU countries.

In Column (2) we include the same regressors and controls than in Column (1), but we also interact the regressors with a dummy variable taking value 1 for the recession years (2008-2014). Hence, the estimates for non-interacted regressors in this column correspond to the reference category, pre-recession years (2003-2007).[13] For pre-recession years we obtain both for firm-level and country-level

[13] For recession years we should add the coefficients for interacted regressors to the corresponding ones for the reference category (pre-recession).

variables the same patterns than in Column (1), with only two exceptions: both governance quality and R&D are non-significant. For recession years, results indicate that size and skilled-labour decrease the distance to the frontier more than in the pre-recession period. Differently, capital intensity reduces the gap less than in the pre-recession years. As for age, it increases the gap more than in the pre-recession period. In addition, regarding country-level economic and institutional factors, we find that they also play an important role in reducing firms' distance to the TFP frontier during the recession period, although the effect is weaker for tertiary education, slightly stronger for trade openness, equal for easiness in getting credit and, interestingly, we uncover that the overall effect of governance quality and of R&D in reducing the gap is driven by the effect of these variables in the recession years (as in the pre-recession period their effect is statistically non-significant).

Finally, in columns (3) and (4) of Table 6 we perform a robustness analysis of our results by estimating equation (3) with an extra variable among regressors. This additional control measures the TFP growth (from period *t-1* to *t*) of the industry frontier to which a given firm belongs to. The objective of this robustness check is to eliminate the effect in our analysis of a movement of the frontier (frontier-shift effect). By conditioning on the frontier TFP growth, we are able to identify more precisely the catching-up process of laggard firms towards their industry frontier. Our estimation equation is in this case as follows:

$$\ln\frac{TFP_{icpt}}{TFP^{F}_{pt}} = \alpha + \beta' Z_{icpt} + \delta' X_{ct} + \theta\left(\ln TFP^{F}_{pt} - \ln TFP^{F}_{pt-1}\right) + \gamma_p + \gamma_c + \gamma_t + \varepsilon_{icpt} \qquad (4)$$

Importantly, the estimate for parameter θ will inform whether the growth rate of the industry technological frontier encourages or discourages the catching-up

process of laggard firms. If this process is enhanced, this may suggest that there are positive knowledge spillovers from frontier to non-frontier firms in an industry and, hence, laggard firms benefit from them.

The results obtained in columns (3) and (4) of Table 6, both for firms' characteristics and for economic and institutional features at the country level, are qualitatively and quantitatively similar to the ones obtained from estimation of equation (3). Interestingly, in column (3) we observe that the TFP growth of the frontier contributes to increase the gap between laggards and frontier firms in an industry for the whole period. However, this result is strongly determined by what happens in the recession period (see column 4). In contrast, during the pre-recession period the sign of the coefficient from the frontier TFP growth variable is positive. This suggests that in the pre-recession period, laggard firms in an industry could benefit from positive technological spillovers from advances in the frontier. Hence, productivity improvements in frontier firms were allowing laggard firms to reduce the productivity gap.

5. Concluding remarks.

In this paper we have analysed the determinants of within-industry distance to the TFP frontier firms across EU economies. We first provide a description of the characteristics of the best performing firms in terms of productivity, that is, the frontier firms, in comparison with the non-frontier firms. We further analyse the determinants of firms' TFP gaps between frontier and non-frontier firms, including factors at the firm and country levels.

The analysis of the determinants of the TFP gap between frontier and non-frontier firms within industries shows that larger, more capital intensive and more labour

skilled firms are closer to the frontier. In contrast, older firms are further away from the frontier. At the country level, in general, trade openness, tertiary education, R&D, easiness of getting credit and governance quality play a positive role in reducing firms' distance towards frontier firms.

In addition, our results indicate that it is important to consider the moderating role of the recession when analysing the effects of the determinants of the distance to the TFP frontier. In this respect, for firm characteristics the direction of the effects is the same in the recession period than in the pre-recession one, but their magnitude becomes larger or smaller depending on the considered variable. Hence, the effect of size and skilled-labour in the catch-up process becomes stronger during the recession period, while this effect becomes weaker for capital intensity. Furthermore, the effect of age in increasing firms' distance to the frontier is stronger in the recession years. As for countries' economic and institutional factors, the effect of trade openness in approaching towards the frontier is slightly larger in the recession period, while this effect for tertiary education becomes weaker. For easiness of getting credit the effect is similar in both periods. A quite differentiated effect is found for governance quality and R&D, since their role in decreasing the distance to the frontier is only relevant during the recession period (before it is statistically non-significant).

Finally, and interestingly, our results are robust to controlling for the intertemporal shift of the frontier. The inclusion of this additional control in the analysis allows us to disentangle the effect of the movement of the frontier in either facilitating or hampering the capacity of laggard firms to converge. The results show that in the pre-recession period laggards benefited from technological spillovers from the

frontier, which facilitated their catching-up process but, contrarily, during the recession this possibility has vanished.

Although it is difficult to provide a well-targeted policy guidance, our findings suggest a number of implications. First, given the characteristics of firms at the technological frontier, it seems advisable to pursue active policies promoting size growth, labour quality and capital intensity at the firm level. Second, macroeconomic policies towards the increase in human capital and the promotion of trade openness, by helping at absorbing advanced technologies and a better reallocation of resources, may also serve to enhance the technological catch-up of laggards towards the frontier. The results on the importance of the easiness in getting credit also point towards the need to implement policies that stimulate a more competitive banking system, with a reduction in informational asymmetries between lenders and borrowers (eliminating borrowing constraints). In addition, our findings also suggest that improving the quality of governance seems to be an important institutional factor, especially relevant in the recession period, which policy makers should consider. Finally, it is also relevant during downturns that governments pay attention to the increase of the stock of knowledge, as a facilitating factor to reach the frontier. This is even more relevant if we consider the fact that something has emerged with the recent financial crisis that makes firms less able to benefit from technological spillovers from the frontier, with the consequence that the higher the TFP growth of the frontier, the higher the gap between laggards and frontier firms in an industry.

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Appendix.

Table A.1. Industry classification.

Manufacturing
Manuf. of food, beverages and tobacco
Manuf. of textiles, wearing apparel, leather
Manuf. of wood, paper, printing
Manuf. of coke and refined petroleum prod.
Manuf. of chemicals and chemical prod.
Manuf. of pharmaceutical products
Manuf. of rubber, plastic and non-metallic
Manuf. of basic and fabricated metal prod.
Manuf. of computer, electronic and optical
Manuf. of electrical equipment
Manuf. of machinery and equipment n.e.c.
Manuf. of motor vehicles, trailers
Manuf. of furniture; jewellery, musical prod.
Non-financial market services
Wholesale and retail trade of motor vehicles
Wholesale trade, except of motor vehicles
Retail trade, except of motor vehicles
Transport and storage
Postal and courier activities
Accommodation and food service activities
Publishing, motion picture, video, television
Telecommunications
Computer programming, consultancy
Professional, scientific and technic. activities
Other production
Electricity, gas, steam and air cond. supply
Water suppl.; sewerage, waste management
Construction

Table 1. Means and differences in means of firm characteristics: EU frontier firms vs. non-frontier firms.

	TFP		*Age*		*Employment*		*Value Added*		*Capital intensity*		*Profits*		*Wage p.e*	
	NF	***F***	***NF***	***F***	***NF***	***F***	***NF***	***F***	***NF***	***F***	***NF***	***F***	***NF***	***F***
Average 2003-2014:	4.44	5.93***	24.1	31.9***	107.5	857.3***	4422	70157***	43.7	122.6***	338	14149***	30.9	57.6***
Pre-recession: 2006	4.49	5.93***	23.4	30.5***	109.7	789.4***	4558	66895***	39.4	120.8***	381	14366***	31.1	65.2***
Recession: 2013	4.44	5.92***	26.6	34.9***	105.2	855.8***	4383	67638***	49.4	130.7***	307	13431***	31.8	59.7***
By sectors (2003-2014):														
Manufacturing	4.45	5.88***	25.7	36.2***	107.0	662.6***	4639	66638***	43.6	82.8***	376	13232***	30.2	54.5***
Non-financial market services	4.42	5.94***	22.9	28.5***	89.9	499.2***	4463	66950***	62.8	253.8***	420	15992***	33.5	58.1***
Other production	4.40	6.11***	22.9	28.9***	113.1	1134.4***	4210	74267***	38.5	123.1***	279	14482***	30.7	60.5***

Note: To identify the EU frontier firms, we obtain the median number of firms in an industry over time, we calculate on it the 5%, this gives us the fixed number of firms per year that are at the frontier in that industry. F is the average of frontier firms; NF is the average of non-frontier (all other) firms. TFP is measured in logs, employment by the number of employees. Value added, capital, profits and wages measured in thousands of euros. Test in mean differences with *** significant at 1%, ** significant at 5%, and * significant at 10%.

Table 2. Percentage of firms in the EU frontier by country of origin in selected years.

	Total		Manufacturing		Non-financial Market Services		Other Production	
Country	**2006**	**2013**	**2006**	**2013**	**2006**	**2013**	**2006**	**2013**
Austria	--	22.82%	--	29.73%	--	18.86%	--	12.50%
Netherlands	10.48%	16.76%	13.04%	19.44%	10.75%	16.67%	--	--
Belgium	11.75%	13.10%	14.12%	16.98%	10.65%	9.95%	9.53%	14.96%
Germany	14.01%	12.88%	16.28%	14.89%	13.84%	12.53%	8.67%	8.36%
Denmark	--	12.60%	--	11.37%	--	12.23%	--	17.65%
Ireland	--	9.89%	--	15.00%	--	7.46%	--	25.00%
UK	9.27%	9.55%	8.40%	7.23%	9.14%	10.53%	13.51%	12.92%
France	4.21%	4.69%	4.30%	5.33%	3.84%	4.51%	5.12%	4.02%
Sweden	3.28%	4.61%	3.56%	4.09%	3.43%	5.30%	2.35%	4.04%
Spain	9.92%	3.64%	10.18%	3.48%	8.87%	3.11%	15.28%	7.86%
Slovakia	3.50%	3.61%	2.33%	2.29%	4.79%	5.53%	4.14%	2.40%
Italy	5.01%	3.57%	4.99%	4.16%	5.03%	2.83%	5.05%	3.00%
Hungary	5.35%	3.29%	5.70%	2.95%	5.74%	3.67%	2.94%	2.89%
Croatia	1.71%	2.52%	1.44%	2.41%	2.38%	3.23%	0.98%	1.06%
Slovenia	2.40%	2.28%	1.28%	1.23%	4.15%	3.23%	0.84%	2.13%
C Republic	1.94%	1.88%	1.81%	1.08%	2.65%	2.96%	0.00%	0.44%
Poland	1.92%	1.87%	1.34%	1.99%	2.70%	1.79%	0.89%	1.83%
Finland	2.63%	1.83%	3.24%	2.06%	2.38%	1.80%	1.72%	1.32%
Portugal	--	1.66%	--	1.06%	--	2.15%	--	2.75%
Bulgaria	2.65%	1.54%	1.66%	1.34%	3.53%	1.36%	3.23%	3.85%
Romania	0.59%	0.89%	0.43%	0.65%	0.84%	1.34%	0.81%	0.93%
Greece	3.57%	0.85%	3.62%	0.56%	3.51%	0.99%	4.17%	2.38%
Estonia	1.58%	0.72%	0.75%	0.35%	2.40%	0.90%	1.04%	1.32%

Notes:

1. Austria, Denmark, Ireland and Portugal have no coverage in AMADEUS for the year 2006 in the sample used for TFP measurement. The Netherlands has no coverage in AMADEUS for both years in the sample used for TFP measurement for the sector other production.
2. The percentages are calculated in two steps: First, the percentage of EU frontier firms of a given industry in a given country (per year) is calculated. Second, we calculate the average across industries of these percentages for each country. A higher value than 5 means the country is overrepresented in the EU top 5% of firms. Countries are ranked according to their 2013 values, from the best to the least well-represented one in the EU top 5%.

Table 3. Persistence in the EU frontier.

Percentage of firms staying in the frontier after several years

	Sample 1			Sample 2			Sample 3		
	Number of years			*Number of years*			*Number of years*		
Industry	**1**	**2**	**5**	**1**	**2**	**5**	**1**	**2**	**5**
Total	71.61%	51.33%	31.12%	66.03%	51.28%	32.96%	74.88%	66.05%	51.78%
Manufacturing	69.05%	50.82%	30.48%	67.12%	51.57%	33.54%	74.25%	61.04%	47.32%
Services	74.89%	53.54%	33.59%	67.37%	53.25%	33.64%	77.64%	72.27%	56.71%
Other Production	69.01%	44.44%	23.68%	57.44%	43.04%	28.48%	66.17%	62.41%	51.13%

Notes: To identify the EU frontier firms, we obtain the median number of firms in an industry over time, we calculate on it the 5%, this gives us the fixed number of firms per year that are at the frontier in that industry. Sample 1 follows frontier firms from 2003 onwards. Sample 2 follows frontier firms from 2006 onwards. Finally, Sample 3 follows frontier firms from 2006 onwards but restricting the sample to a balanced panel of firms that stay in AMADEUS database from 2006 to 2013.

Table 4. Persistence in the non-EU frontier.

Percentage of firms staying away from the frontier after several years

	Sample 1			Sample 2			Sample 3		
	Number of years			*Number of years*			*Number of years*		
Industry	**1**	**2**	**5**	**1**	**2**	**5**	**1**	**2**	**5**
Total	85.78%	57.43%	40.64%	81.91%	64.98%	47.18%	93.97%	83.40%	70.45%
Manufacturing	85.80%	59.54%	44.64%	85.46%	68.39%	51.85%	94.11%	81.80%	68.42%
Services	85.64%	55.93%	37.73%	78.92%	62.08%	43.61%	93.50%	84.42%	72.12%
Other Production	86.19%	55.90%	38.02%	80.68%	63.84%	44.30%	95.05%	85.59%	72.02%

Notes: To identify the EU frontier firms, we obtain the median number of firms in an industry over time, we calculate on it the 5%, this gives us the fixed number of firms per year that are at the frontier in that industry. Sample 1 follows non-frontier firms from 2003 onwards. Sample 2 follows non-frontier firms from 2006 onwards. Finally, Sample 3 follows non-frontier firms from 2006 onwards but restricting the sample to a balanced panel of firms that stay in AMADEUS database from 2006 to 2013.

Table 5. Evolution of TFP of EU frontier and non-frontier firms.

Year	**All firms**		**Frontier firms**		**Non-frontier firms**		**TFP gap**
	Mean	s.d.	Mean	s.d.	Mean	s.d.	
2003	4.50	0.66	6.04	0.27	4.42	0.60	5.03
2004	4.53	0.67	6.02	0.25	4.44	0.61	4.83
2005	4.55	0.68	5.86	0.28	4.45	0.61	4.09
2006	4.57	0.67	5.93	0.28	4.49	0.61	4.24
2007	4.58	0.66	5.95	0.27	4.50	0.59	4.27
2008	4.53	0.65	5.92	0.27	4.45	0.58	4.35
2009	4.44	0.68	5.89	0.28	4.36	0.62	4.58
2010	4.54	0.64	5.94	0.28	4.46	0.58	4.39
2011	4.53	0.64	5.93	0.28	4.46	0.57	4.38
2012	4.51	0.66	5.92	0.26	4.43	0.60	4.44
2013	4.53	0.66	5.92	0.26	4.44	0.60	4.36
2014	4.52	0.67	5.81	0.28	4.42	0.59	4.04
Average 2003-2014	4.53	0.66	5.93	0.27	4.44	0.60	4.41

Notes: To identify the EU frontier firms, we obtain the median number of firms in an industry over time, we calculate on it the 5%, this gives us the fixed number of firms per year that are at the frontier in that industry. TFP is measured in logs. Values corresponding to 2014 should be taken with caution given the smaller number of observations in the sample. TFP gap is calculated as the difference in average TFP of frontier and non-frontier firms. Note that TFP is measured in logs, so that, for instance, the TFP gap in 2003 is *exp*(5.78-4.36)=4.14, i.e., in 2003 frontier firms are on average 4.14 times more productive than non-frontier firms.

Table 6. Distance to the EU frontier.

Dep. Variable: $\ln \frac{TFP_{icpt}}{TFP^{F}_{pt}}$	(1)	(2)	(3)	(4)
Firm Size	0.182***	0.152***	0.183***	0.151***
	(0.001)	(0.001)	(0.001)	(0.001)
Firm Size 2008-2014		0.044***		0.046***
		(0.001)		(0.001)
Firm Age	-0.009***	-0.007***	-0.024***	-0.020***
	(0.001)	(0.001)	(0.001)	(0.001)
Firm Age 2008-2014		-0.002**		-0.005***
		(0.001)		(0.001)
Firm Capital Intensity	0.026***	0.041***	0.028***	0.043***
	(0.001)	(0.001)	(0.001)	(0.001)
Firm Capital Intensity 2008-2014		-0.022***		-0.022***
		(0.001)		(0.001)
Firm Skilled-Labour	0.849***	0.826***	0.881***	0.848***
	(0.003)	(0.003)	(0.003)	(0.004)
Firm Skilled-Labour 2008-2014		0.036***		0.055***
		(0.003)		(0.003)
Country Tertiary Education	0.014***	0.0160***	0.016***	0.018***
	(0.001)	(0.001)	(0.001)	(0.001)
Country Tertiary Education 2008-2014		-0.005***		-0.004***
		(0.000)		(0.000)
Country R&D	0.135***	0.004	0.132***	0.026
	(0.014)	(0.016)	(0.014)	(0.016)
Country R&D 2008-2014		0.049***		0.058***
		(0.015)		(0.016)
Country Trade Openness	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Country Trade Openness 2008-2014		0.0001***		0.0002***
		(0.000)		(0.000)
Country DTF Getting Credit	0.0002***	0.0012***	0.0002*	0.0014***
	(0.000)	(0.000)	(0.000)	(0.000)
Country DTF Getting Credit 2008-2014		0.00001		0.0002**
		(0.000)		(0.000)
Country Governance Quality	0.047***	-0.005	0.038***	-0.006
	(0.004)	(0.004)	(0.004)	(0.004)
Country Governance Quality 2008-2014		0.038***		0.033***
		(0.004)		(0.004)
TFP Growth of Frontier Firms			-0.098***	0.041***
			(0.006)	(0.008)
TFP Growth of Frontier Firms 2008-2014				-0.546***
				(0.012)
Constant	-5.659***	-5.601***	-5.760***	-5.679***
	(0.017)	(0.019)	(0.018)	(0.020)
Observations	1,032,516	1,032,516	844,669	844,669
R-squared	0.773	0.774	0.787	0.789

Notes: To identify the EU frontier firms, we obtain the median number of firms in an industry over time, we calculate on it the 5%, this gives us the fixed number of firms per year that are at the frontier in that industry. Size refers to the number of employees. All specifications include industry, country and year dummies. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.