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THE EFFECT ON FIRMS' PRODUCTIVITY OF ACCESSIBILITY. THE SPANISH MANUFACTURING SECTOR

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ABSTRACT:

This paper evaluates the impact of accessibility on the productivity of Spanish manufacturing firms. We suggest the use of accessibility indicators to workers and commodities, integrating transport, land use, and individual components in their measurement, and computing real distances or travelling times using the Spanish full road network. The estimation is carried out in two steps. In the first one we estimate almost a hundred production functions using a panel of 155,937 firms along the 1999-2009 period from *SABI* database, applying Levinsohn and Petrin technique. From these estimations we derive the Total Factor Productivity level for 2009, which is then explained in the second estimation step as a function of the accessibility indicators and additional control variables. Results evidence the crucial role of the accessibility to commodities, and a smaller effect of the accessibility to workers on firms' productivity.

KEYWORDS: Accessibility, Firm Productivity, Transport Infrastructures, Instrumental Variables.

JEL: D24, R12, R40

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1. Introduction

From the 1990s, the positive effects of transport infrastructures on economic growth are well documented, although some controversy exists with regards to the magnitude of these effects[1]. However, only along last decade, papers have focused attention over the channels through which transport infrastructures affect firms' decisions (Banister and Berechman, 2001; Oosterhaven and Knaap, 2003; Anderson and Lakshmanan, 2007). The effects of infrastructures may be just temporary or permanent. The permanent ones last over the life span of the infrastructure, and can be classified in three types. (i) Direct (derived from the immediate improvement of transport conditions), (ii) externalities (noise, pollutant emissions and other environmental perturbations), and (iii) indirect, which take place over longer terms and affect the production and location decisions of firms and people, and condition the economic environment and thus the future generation of people's income and jobs (Rietveld and Nijkamp, 2000)[2].

The consequences directly derived from these effects can result, as pointed out by Prud'homme (2002), in firm location changes motivated by a reduction in logistic costs (Aschauer, 1992), allowing consideration of new forms of firm production, as the "just in time" one (Gillen, 2001)[3]. Furthermore, as firms' fields of actions are broadened (Limão and Venables, 2001; Vickerman et al. 1999; amongst others), the rising of specialisation and economies of scale is more likely to occur (Weisbrod and Treyz, 1998), which in turn provokes increases in competition pressure (Garrison and Souleyrette, 1996) and technological diffusion. All these effects generate in one hand, a reduction in firms' costs and thus productivity gains, and in the other, an

[1] To this respect one may refer to the literature revision on the impact of transport infrastructures on economic growth in Gillen (1996), Boarnet (1997), Jiang (2001), and more recently, the meta-analysis of Melo et al. (2012) and Nuñez and Velázquez (2013).

[2] When transport infrastructure investment policies pursue associated indirect effects, they are often referred as "active infrastructure policies", which are mainly oriented towards the induction of private investment.

[3] For instance, a new loading terminal may allow for inter-modality connections between trucks and railways, improving "just in time" production and diminishing maintenance costs of stock producers (Berechman, 2002). Furthermore, Gillen (2001) points out that this kind of organisational innovations may turn in additional product and process innovations.

increase in geographic concentration leading to the productivity effects associated to the economics of agglomeration (Berechman, 2002).

However, the increase in geographical concentration of economic activity may also generate some undesired effects on firms' performance, in the form of diseconomies of agglomeration. This is, as property and labour demand increases, so they do rents and wages. Similarly, road traffic growth may turn in network congestion and thus augment transport costs. In turn, a need for new transport infrastructures surges initiating again the mentioned effects sequence (Anderson and Lakshmanan, 2007).

Consequently, transport infrastructures modify the importance of agglomeration economies (Venables, 2007 and Graham, 2007a), which at the same time, reinforce the benefit of these type of infrastructures. Precisely, some authors following the literature on the effects of agglomeration on productivity have recently incorporated the role of infrastructures in spatial location decision theory. This is how the concept of accessibility gains relevance in both, the literature on agglomeration and that in infrastructure networks. The new challenges of this field of research have to do with the availability of information and the way measurement can be carried out.

From the macro perspective, several papers have shown a positive effect of agglomeration on productivity, using density of economic activity measures and different geographical areas as units of analysis (Melo et al., 2009). In some cases, the potential market is introduced as a proxy for economic agglomeration, as Combes et al. (2010), who analyse the impact over wages in French employment areas. In some other cases, the effect of accessibility on territories is studied, as Forslund and Johansson (1995) in Swedish municipalities, and Weisbrod and Treyz (1998) for Michigan districts.

Firm or plant level studies are only recent. Andersson and Lööf (2011) analyse the effect of agglomeration on Swedish firms' productivity. Grahan (2007a, 2007b) and Graham and Kim (2008) highlight the positive impact of potential markets in British firms, using the inverse of the Euclidean distance to compute the impedance function or disutility associated to distance. Graham (2007b) and Holl (2012) [4] measure road distances[5] although they use the same

[4] In this case, the study is carried out for the Spanish firms.

kind of impedance function. Lall et al. (2004), when analysing Indian firms, goes a step further by introducing a more complex function (negative exponential) in order to adjust for the observed utility loss. In fact, market potential is a measure standing between classical agglomeration variables and accessibility ones. Nevertheless, to the extent of our knowledge, these kinds of studies have not considered the individual features of economic agents in accessibility measures.

An additional relevant issue in this line of research is that many papers emphasise the role of accessibility to commodities or final markets, and only marginally, the studies consider accessibility to workers, and usually restricting the analysis to an aggregate level (Gibbons et al., 2010 and Melo et al., 2013).

To this respect, the present paper evaluates the effect of accessibility on the productivity of Spanish manufacturing firms using the System for Analysis of Iberian Balances (SABI) database, from the family of AMADEUS databases. Accessibility is measured for two components, workers and commodities, the first study in doing it jointly to the best of our knowledge. Accessibility measures are obtained according to Núñez (2012), and incorporate the specific locations of firms at the municipality level. The impedance function considers effective times and distances of travelling across the complete Spanish road infrastructure network (urban and intercity), and not just along the high capacity network as it is often the case. When estimating the loss in utility associated to travelling, the specific features of economic agents (workers and firms) are taken into account, as suggested by the available accessibility literature, which in turn constitutes a radical and important contribution of the present paper.

The paper is organised as follows. The next Section presents and examines employed accessibility indicators to workers and commodities. The third Section is dedicated to the formulation of estimated empirical models. We then describe followed measurement procedures for productivity, accessibility and remaining control variables. Section 5 offers and discusses obtained results and concluding remarks and policy recommendations are presented in Section 6.

[5] In fact, Graham's (2007b) approximation to the generalized cost of travelling is basically a time measure.

2. Accessibility Indicators

The economic literature offers a wide variety of accessibility measures[6]. These indicators should include four components: transport, land use, individual, and temporal (Geurs and Van Eck, 2001). The first component considers the availability and configuration of transport infrastructure networks, as well as the loss in utility associated to travelling. The land use dimension reflects the distribution of opportunities along the geographical territory and thus, the geographic concentration of economic activities. The individual component identifies economic agent characteristics to take advantages of available opportunities and make use of transport infrastructures. Lastly, the temporal dimension analyses changes in opportunities and in capacity or use of transport infrastructures along the different moments in time (e.g. morning, afternoon, night, summer, winter…).

The simplest measures of accessibility consider only partially the first mentioned component (for instance, considering the distance from the firm to the nearest transport infrastructure —Lutter et al., 1992—). The improvement in these indicators has been oriented to the full inclusion of the land use dimension, as it is the case of the potential measures of accessibility. Often, with regards to the transport component, these measures contemplate disutility associated to travelling (i.e. market potential identified through geodesic distance measures —Grahan, 2007a; Graham and Kim, 2008; amongst others—). More recent refinements evaluate travel distances or times along main road networks (Lall et al., 2004; Holl, 2012; Melo et al., 2013; amongst others). Only a few examples incorporate the individual component (for instance, workers' accessibility to jobs as a function of worker's qualification -Van Ham, et al., 2001 and Korsu and Wenglenski, 2010-). With the exception of very specific applications, the temporal component is usually omitted (Kwan, 1998).

[6] See for instance Bhat et al. (2000), Geurs and Van Eck (2001), Baradaran and Ramjerdi (2001), and Curtis and Scheurer (2007) amongst others, for a detailed analysis of these accessibility measures.

Therefore, this paper measures manufacturing firms' accessibility to the most relevant factors determining their costs and thus their productivity, (i) the accessibility to workers, and (ii) the accessibility to commodities.

Accessibility measures in labour markets often cover insufficient or relatively small geographic areas of influence. In fact, most of the papers treating this aspect are based on the labour supply side, focusing attention on limited geographical areas such as municipalities, functional areas, industrial districts, local labour markets, etc. (Kawabata, 2003 from the perspective of demand and Gibbons et al., 2010; Melo et al., 2013 from supply; amongst others). However, these geographical limits unnecessarily impose fictitious impediments to objective measurement. For this reason, we select an accessibility measure from the competition typology, based on Shen (1998 and 2001) proposal, which takes the form of expression (1).

$$\mathrm{ACC}_{\mathrm{ij}}^{\mathrm{W}} = \sum_{\mathrm{k}} \frac{\mathrm{W_k} f_w\left(\mathrm{d_{jk}}, \mathrm{i}, \mathrm{w_k}, \mathrm{j}, \mathrm{k}\right)}{\sum_{\mathrm{p}} \mathrm{E_p}\, f_w\left(\mathrm{d_{kp}}, \mathrm{i_p}, \mathrm{w_k}, \mathrm{k}, \mathrm{p}\right)} \qquad (1)$$

Where $\mathrm{ACC}_{\mathrm{ij}}^{\mathrm{W}}$ is the accessibility indicator to workers of firm *i* located in municipality *j*. In the numerator, W_k registers the number of potential workers (labour supply) living in a generic municipality *k* located in the neighbourhood of municipality *j* (this neighbourhood also contains the reference municipality *j*). $f_w\left(\mathrm{d_{jk}}, \mathrm{i}, \mathrm{w_k}, \mathrm{j}, \mathrm{k}\right)$ is the impedance function for workers that accounts for the cost or disutility associated to travelling from *j* to *k*[7], and it depends on the travelling time or distance between *j* and *k* ($\mathrm{d_{jk}}$), the characteristics of both municipalities (*j* and *k*), the features of the potential workers living in *k* ($\mathrm{w_k}$), and the firm *i*.

The point realisation of this impedance function can be interpreted as the probability a potential worker living in municipality *k* has to work in firm *i* located in *j*. By symmetry, this measure can be also understood as the probability of firm *i* hiring this worker residing in municipality *k*. Therefore, the numerator of this indicator shows firm *i* expectations about hiring workers from the

[7] Impedance functions generally reflect the costs of transport. In this current case, these transport costs are measured in terms of the distance between *j* and *k* along the road network, measured either in Kilometres or time units, taking into account specific characteristics of involved municipalities (size, excess labour supply, etc.), as well as workers' features (sex, qualifications, etc.) and firms' attributes (type of labour demanded, size, etc.).

municipality where it is located and associated neighbourhood (opportunities)[8]. The denominator expresses firms' labour demand over workers residing in a given municipality (competition for the opportunities). Its construction is identical to that of the numerator. To this respect, workers' expectations on competition are measured by adding up the crossed product of labour demand over municipalities located across attraction radius of workers living in *k* —denoted here by *p*— and the probability that firms located in these municipalities *p* choose those available workers in *k*.

In order to successfully apply expression (1), it is absolutely necessary to have all required information at the municipality level, as well as having access to the impedance functions or the equivalent probability realisations between each firm and its associated municipalities. The indicator must be equal or greater than zero, and although it is not bounded from above, it does not usually take values greater than one.

With regards to accessibility to commodities, competition for available opportunities is not as relevant as in the labour market. Thus in this case the accessibility indicator is based on the potential economic activity and considers three different types of commodity flows to/from the firm, (i) intermediate consumption of goods by firms, (ii) intermediate uses, and (iii) final uses of firms' production.

Potential accessibility indicators, in contrast to potential market ones, consider as well as the spatial distribution of economic activity the individual component in the form of product required or obtained by firms. To this respect, firm's accessibility to intermediate consumption is defined as the ease with which the firm has access to available or potential production for intermediate use. The indicator takes the form of expression (2),

$$ACC_{ij}^{IC} = \frac{\sum_g IU_g \, f_M\left(d_{jg}, j, g, IC_i\right) SI_{ig}^{IC,IU}}{\sum_g IU_g} \qquad (2)$$

where ACC_{ij}^{IC} is firm's *i* (located in *j*) accessibility indicator to intermediate consumption. *g* denotes each one of all possible municipalities where

[8] If municipality *k* is far enough from municipality *j*, then, $f_L\left(\mathrm{d_{jk}}, \mathrm{i}, \mathrm{t_k}, \mathrm{j}, \mathrm{k}\right) = 0$, implying that municipality *j* is beyond the attraction or influence radius of firm *i*.

production is originated. *IU* registers manufacturing production available for intermediate use in each municipality. $f_M(d_{jg}, j, g, IC_i)$ represents the impedance function, which depends on distance, specific characteristics of the municipalities of origin and destination, as well as other features of firm's *i* intermediate consumption, mainly related to the type of required product. Once again, the interpretation of this function has to do with the probability that firm *i* is provided with commodities for intermediate use that have been produced by the firms located in *g*. In contrast to previous applications where this function is basically an inverse function of distance (Graham, 2007a; Holl, 2012; amongst others) or simply a parameter affecting distance in gravity functions, the proposed function is not determined *ad-hoc* but derived from available information. *SI* is a similarity index between commodities produced in *g* for intermediate uses and the intermediate consumption required by firm *i*. Thus the similarity index SI_{ig} reflects the potential intensity of flows between municipality *g* and firm *i*[9]. The flow is zero when production differs substantially, and increases as similarities in production arise. The intermediate consumption required by firm *i* can be obtained from all possible manufacturing locations, including the municipality where the firm is located.

Analogously, accessibility to firm's final production from the perspective of remaining firms demanding intermediate consumption is defined by expression (3).

$$ACC_{ij}^{IU} = \frac{\sum_g IC_g \, f_M(d_{jg}, j, g, Y_i) SI_{ig}^{IU,IC}}{\sum_g IC_g} \qquad (3)$$

Where $\mathrm{ACC}_{\mathrm{ij}}^{IU}$ is the accessibility indicator to firm's *i* production that is demanded for the intermediate uses of other firms. In this case, the impedance function depends on the characteristics of final production.

Somewhat different is the accessibility indicator to final uses of firm's production destined to final consumers. Homogeneity in tastes across locations is assumed, and accessibility depends solely on markets' size, which in turn is

[9] The specific definition of this similarity index is $SI_{ig} = 1 - 0{,}5 \sum_j \left| S_{ij}^{IC} - S_{gj}^{IU} \right| = \sum_j Min\left(S_{ij}^{IC}; S_{gj}^{IU}\right)$, where $S_{.j}$ is the share of commodity *j* in corresponding total production.

affected by population and purchasing power. The indicator is defined in expression (4).

$$ACC_{ij}^{FU} = \frac{\sum_g R_g \, f_M\left(d_{jg}, j, g, Y_i\right)}{\sum_g R_g} \qquad (4)$$

Where ACC_{ij}^{FU} is the accessibility indicator to the production of firm *i* located in *j*, destined to meet final demand, and *R* denotes the income of municipality *g*. The accessibility indicators to commodities are normalised according to country totals and hence, they are all defined in the closed interval [0,1].

The global accessibility indicator in expression (5) is therefore defined as the firm-level weighted average of the accessibility indicators to each type of commodity flow.

$$ACC_{ij}^{M} = \alpha_{1i} ACC_{ij}^{IC} + \alpha_{2i} ACC_{ij}^{IU} + \alpha_{3i} ACC_{ij}^{FU}; \quad \sum_{z=1}^{3} \alpha_{zi} = 1 \qquad (5)$$

3. The empirical model

In order to analyse the effect on manufacturing firms' productivity of the degree of accessibility, we assume that technology can be described by a Cobb-Douglas production function with two factor inputs[10] of the form described by expression (6).

$$Y_{it} = A_{it} L_{it}^{\beta_l} K_{it}^{\beta_k} \qquad (6)$$

Where Y_{it} is firm's *i* value added in period *t*, *L* and *K* are labour and capital, respectively, and *A* is the efficiency level or total factor productivity (TFP) of the firm. Taking logarithms in expression (6) we have the linear function in (7).

[10] We choose a value added function instead of a production function, which would require intermediate consumption as an additional production factor. Sims (1969) and Arrow (1972) point out that the elasticities obtained from this specification are equivalent to those in which the dependent variable is production, whenever underlying gross production is weakly separable in value added and intermediate consumption, and efficiency only affects value added.

$$y_{it} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + v_i + \varepsilon_{it} \qquad (7)$$

Where β_0 is an estimate of the average level of firms' efficiency in corresponding industry, v_i is the individual component of firm *i* and captures differences in efficiency between each firms' averages and the average level in the sector. Finally, ε_{it} registers efficiency differences by year with respect to industry average plus firm average. Thus each firm's TFP can be estimated according to expression (8).

$$\ln(A_{it}) = \beta_0 + v_i + \varepsilon_{\mathrm{it}} = y_{it} - \beta_l l_{it} + \beta_k k_{it} \qquad (8)$$

A two-step approach is followed in order to evaluate the impact of accessibility on firms' productivity. In the first step we estimate the production function of expression (7) and in the second, we explain TFP as a function of specific firms' characteristics or the strategies they follow. One of these characteristics may well be the degree of accessibility the firm benefits from. Berndt and Hansson (1992) and Barro and Sala-i-Martin (1995) argue that infrastructure endowments enhance productive efficiency, since for a given combination of private factor inputs, a higher level of potential production may be attained. Meade (1952) refers to these type of public factors as "the creation of the atmosphere", which are beyond control of individual firms, suggesting the two-step estimation process[11].

The two-step estimation has nevertheless some practical advantages due to data availability. The time horizon, for which data on factor inputs and infrastructure endowments and thus accessibility is available, does not usually coincide, especially if considering the complete road network and not just the high capacity one. Whilst firms' panel data is available for a large time horizon, the information on transport infrastructure endowments is only recent.

[11] Nonetheless, Arrow and Kurz (1970) suggest that these elements contributing to firms' production should be included in the production function as an additional factor input, as they show features of a private good. However, Núñez and Velázquez (2013) show through a meta-analysis of almost 2000 results provided by nearly 150 different papers, that there are no statistical significant differences from the results derived from either of the two mentioned procedures, as theory predicts for the Cobb-Douglas production function.

Additionally, the cost associated to this kind of geodatabases often obliges to use only a cross-section[12]. Consequently, the TFP function is specified as described by expression (9).

$$\ln(A_i) = \alpha_0 + \sum_j \gamma_j lnACC_i^j + \gamma_Z Z_i \qquad (9)$$

Where ACC_i^j refers to each of the used accessibility measures and Z_i is a vector of control variables identifying those firms' characteristics or strategies that may affect their productivity levels.

A first group of control variables recognises firms' internationalisation strategies. International trade strategies (exports and/or imports) have been shown to be related to larger productivity levels (Fariñas and Martín-Marcos, 2007; Andersson et al., 2008; Vogel and Wagner, 2010; Aw et al., 2011; amongst others). The same occurs with foreign investment (Damijan et al., 2007; Tomiura, 2007; Yeaple, 2009; to mention some recent ones) and foreign capital participation on firms' social capital, which positively affect productive efficiency (Harris and Robinson, 2003; Weche, 2013). Additionally, the inclusion of a variable indicating the presence of firms' subsidiaries in the country, may capture a positive relation with productivity, as it may identify internal reorganisation of production in relation to domestic outsourcing strategies.

A second group of control variables identifies state features of firms, such as age, market exit and human capital. The variable age captures knowledge accumulation and learning by doing processes (e.g. Audretsch, 1995; Huergo and Jaumandreu, 2004). In order to detect the relationship indicated by Jovanovic (1982) and Hopenhayn (1992), i.e. exiting firms exhibit lower productivity levels just before abandoning activity, we introduce a variable to reveal market exit. In fact, Fariñas and Ruano (2005) show for the Spanish manufacturing sector that firms exiting the market return lower productivity scores. Finally, the introduction of human capital enables to recognise the fact that higher human capital endowments are usually associated to higher levels

[12] In the case of Spain, the complete road network is only available for year 2006 and is especially dear.

of innovations in management, processes and product, and thus productivity (Bartelsman and Doms, 2000).

Estimation of expression (9) is not trivial due to the possible presence of endogeneity between firms' productivity and the degree of accessibility they face. If workers' propensity to change place of residence depends on wage differentials, and these wage differentials are linked to productivity, as expected in competitive markets, a simultaneity problem arises between workers' accessibility and productivity. Whilst consideration of sector effects partially mitigates this problem (Combes et al., 2008), accessibility is a peculiar firm characteristic that depends on a variety of effects such as agglomeration, firm location, and infrastructure endowments, and thus high labour concentration is expected to influence policy makers' decisions on the execution of new infrastructure projects.

Furthermore, Holl (2012) claims that there is a simultaneity problem between the accessibility to commodities and firm productivity. Specifically, positive productivity shocks attract new firms and workers that derive in firms' accessibility improvements, thus generating causality between accessibility and market growth, and in turn productivity (Graham et al., 2010 and González-Val et al., 2013). A documented simultaneity source is due to location, as shown by Baldwin and Okubo (2006) amongst others, which influences productivity through market size and qualified human capital endowments. The way in which policy oriented towards construction of new infrastructures is executed also constitutes an important source of simultaneity, as infrastructure plans aim to anticipate future infrastructure demand through expected economic and productivity growth. Consequently, expression (9) must be estimated consistently by means of instrumental variables procedures.

4. Data

In order to fulfil the defined two-step estimation strategy, we must estimate first the production function from a firm panel data and derive TFP, and then, using estimated TFP and accessibility data, we need to identify the productivity function. For the first step, we use the information available in *SABI* database, System for Analysis of Iberian Balances, elaborated by Informa and

Bureau Van Dijk, and belonging to the group of European firms databases integrated in AMADEUS. An unbalanced panel along the period 1999-2009 is available, with a total of 155,937 manufacturing firms[13]. The second step estimation, i.e. the productivity function, is restricted to 2009 cross-section, due to the lack of a panel of geodatabases with Spanish full road network. The firm information required for control variables in the productivity function, is also derived from *SABI* database.

A. TFP calculation

Although the origin of TFP calculation is due to Solow's (1956) seminal paper, many empirical and theoretical studies have risen along past few decades, proposing statistical techniques to improve the estimation processes for newly available firm databases[14].

The ordinary least squares estimation, OLS, in (7) requires that firms' efficiency levels must be independent of factor inputs. In this sense, if firms know their level of efficiency at the moment when they decide upon their factor input endowments, then simultaneity occurs between input factors and production (Olley y Pakes, 1996; Ackerberg, et al, 2007)[15]. A solution to this problem may consist of within-group estimation procedures (Pavcnik, 2002; Levinsohn and Petrin, 2003). However, these methodologies result in extremely low values for the income elasticity of capital, and impose strict exogeneity of factor inputs conditioned to firm heterogeneity, therefore implying that the election of factor inputs does not react to productivity shocks (Wooldridge, 2009).

An alternative procedure to guarantee consistency in the production function parameter estimates is through instrumental variables techniques (Griliches y Mairesse, 1995), although finding appropriate instruments may be

[13] The analysis is constrained to continental Spain, excluding the Canary Islands, the Balearic Islands, Ceuta and Melilla. SABI coverage for the manufacturing sector amounts to 30% in terms of firms and 66.7% in terms of employment. An intense process of data depuration is previously required, detailed information on it can be found in Martín et al. (2011).

[14] See Van Beveren (2012) for a more detailed explanation.

[15] A positive productivity shock leads to a lesser utilisation of firm inputs in the short term, and this introduces upward bias in coefficients (De Loecker, 2007).

somehow problematic[16]. Other possibility is General Method of Moments, GMM, procedures (Wooldridge, 2009), although factor input quantities are often too persistent in time and hence, they provide weak endogeneity corrections. Blundell and Bond (1999) propose an extended GMM estimator (system-GMM) that uses lagged values of first finite differences as instruments in levels' equations, and vice versa, also incorporating both in estimations, and thus attaining more reasonable results.

A preferred substitute for previously described methods corresponds to semi-parametric estimation procedures, which offer consistent and better behaved estimators (Van Beveren, 2012). Olley and Pakes (1996) are pioneers in using an algorithm that solves the simultaneity problem, and takes also into account firm dynamics. They use firms' investment decisions as a proxy for unobservable productivity shocks and they also control for firm exit. Nonetheless, this procedure does only generate consistent estimations if and only if there exists a strict monotonic relationship between the proxy and the output.

However, very often, there are no available variables measuring firms' investment. For this reason, Levinsohn and Petrin (2003) offer a similar estimation procedure that uses intermediate inputs (raw materials and energy) instead of investment as a proxy for unobservable productivity shocks, as they are usually available in most databases, they tend to achieve the monotonicity condition more often, and they provide very similar results (Levinsohn et al. 2004).

The information required to estimate the production functions using Levinsohn and Petrin methodology—production, employment, net tangible fixed assets (as a proxy for capital), raw materials, main activity of the firm to 4 digits (NACE rev. 1.1)— is obtained from *SABI* database. Production is deflated using the Index for Industrial Prices available at the Spanish National Institute of Statistics (INE)[17]. Intermediate consumption and capital are deflated according to the different intermediate goods and capital goods components, respectively, available in the Index for Industrial Prices. Value added is deflated applying a

[16] If markets were perfectly competitive, prices could be appropriate instruments (Ackerberg, et al, 2007). Nevertheless, firms often operate in imperfect markets and exhibit certain market power, and thus prices cannot be valid instruments.

[17] This Index for Industrial Prices is available to 3 digits NACE rev. 1.1.

double deflation criterion. As the panel is unbalanced, upward biases in TFP estimations associated to the exclusion of firms exiting the market are attenuated (Jovanovic, 1982 and Hopenhayn, 1992). In order to estimate the production functions by type of productive activity, each firm is assigned to its sector of primary activity defined at 4 digits, with a final total of 93 different activities[18].

B. Accessibility

Impedance functions are required to compute accessibility indicators. These functions can be approximated through a collection of probability functions[19]. In the case of workers, they adopt the form of expression (10).

$$D_{ij}(T) = \alpha_0 + \beta X_i + \gamma X_I + \delta X_j + \theta X_J \quad (10)$$

Where $D_{ij}(T)$ refers to the commutation probability of worker *i* over the interval *T* (where *T* is measured either on time or distance units), worker *i* living in municipality *I* and commuting to municipality *J* where firm *j* is located. X_i incorporates worker's subjective characteristics, X_I refers to the features of the municipality where the worker resides, X_j includes the attributes of the hiring firm, and X_J describes the municipality where the firm is located.

The information needed to estimate the probabilities for each *T* (time intervals dedicated to commutation) comes from a 5% sample extracted from the microdata of the Spanish Population Census for year 2001 and published by *INE*. Individuals not working, those classified as freelancers, and workers employed either in more than one municipality or abroad are excluded from the sample, as they have no associated commuting times. Additionally, workers living or employed outside the Spanish Peninsula are also excluded.

Commuting information is grouped in five different time intervals, (i) less than 10 minutes, (ii) between 10 and 20 minutes, (iii) 20 to 30 minutes, (iv) 30 to

[18] When there are less than 2000 observations along the complete time horizon (firms and years) in one of the primary activities, available information is assigned to the most closely related activity, in terms of technology, chosen from the secondary activities declared by the firms.

[19] A brief summary on the calculation of accessibility indicators and impedance functions is presented here. For a detailed explanation on adopted procedures refer to Núñez (2012).

45 minutes, and (v) more than 45 minutes. This last time interval is nonetheless excluded as it comprises anomalous information[20]. The final sample covers about 600,000 commuting observations.

The probability of travelling along each time interval required to estimate the equations of expression (10) is computed as follows. (i) All individuals are able to travel along the minimum time interval (up to 10 minutes), i.e. the probability here is degenerated. (ii) Individuals prepared to commute along a given time interval would do it as well along the previous ones. (iii) The probability of commuting over a 45 minutes time interval is zero. (v) Estimations include all individuals commuting, though assigned probabilities vary according to the estimated probability function[21].

Information on the characteristics of firms, municipalities and individuals is also due to the available Census microdata. In relation to workers, subjective characteristics include sex, age and education level. With respect to the municipality where the worker inhabits, we consider the province, size (measured in intervals), and municipality's unemployment rate. In terms of the firm hiring the worker, we reflect the sector of economic activity, size interval[22], and qualification level of employed workers. Lastly, regarding to the municipality where the firm is located, the province, size, and municipality's unemployment rate are considered.

We estimate three probit functions, one for each of the commuting time intervals, 10-20 minutes, 20-30 minutes, and 30-45 minutes[23]. For known values of the probability function parameters, and incorporating the information for year 2009 obtained from the data sources detailed in Núñez (2012), the specific probabilities establishing connection between each firm and all Spanish municipalities can be computed.

Year 2009 distances and minimum commuting times between the Spanish municipalities (8116 municipalities) across the urban and intercity road networks have been computed implementing Google Maps enquiries. Firms and

[20] In fact, only 9.4% of individuals commute over the 45 minutes threshold.
[21] For instance, a worker commuting over the 20 to 30 minutes time interval would have a degenerated probability along this time interval and the previous one (i.e. 10 to 20 minutes), and a zero probability for the interval 30 to 45 minutes.
[22] This variable comes from *SABI* database for year 2001.
[23] When travelling time is less than 10 minutes, a degenerated probability is assumed.

workers are thus assumed to be located in municipalities' centroids[24]. The location of the firms is obtained from *SABI* database[25]. The information on resident labour force for each municipality is acquired from the Spanish Labour Force Survey and the municipal Census, whilst jobs are derived from affiliation statistics to the National Social Security Service.

From all this information workers' accessibility indicators can be computed for each firm, by substituting the impedance function by the probability value obtained for the corresponding commuting time interval in each of the available iterations between firms and municipalities, i.e. the one associated to real travelling time across centroids obtained from Google Maps enquiries.

The probability functions for commodity transport take a similar form, although the range of considered attributes is far less compared to the previous case due to the availability of information. They are calculated according to expression (11).

$$P_{JG}(T) = \alpha_0 + \beta CAO_J + \gamma CAD_G + \sum_k \delta_k M_k \qquad (11)$$

Where $P_{JG}(T)$ is the probability that firm *j*, located in in *J*, moves its production to municipality *G*, located at a distance within the range *T*. CAO_J refers to Origin *Comunidad Autónoma* (i.e. the one where municipality *J* is located), CAD_G is the Destination *Comunidad Autónoma* (i.e. the one where municipality *G* is located) [26], and *M* contains several qualitative variables describing the type of transported commodity.

These probability functions are estimated using microdata from the Permanent Survey on Road Commodity Transport of the Ministry of Infrastructures along the time horizon 2002 to 2009. Transport of commodities

[24] Geographical coordinates for municipality centroids are obtained from the Spanish National Geographical Institute.

[25] *SABI* database offers information on manufacturing firms located in 4036 different municipalities, although workers and consumers are placed in 8112 Spanish municipalities along year 2009.

[26] Note that expression (11) refers to firm's *i* production. In the case of intermediate consumption, the Origen *Comunidad Autónoma* corresponds to that of municipality *g*, and the Destination one to the *Comunidad Autónoma* where firm *i* is located.

being imported or exported are excluded from the sample, as well as those corresponding to trade between third party countries and the ones done by empty trucks. The sample is therefore constrained to the commodity transport in the domestic market (80% of transported commodities) and only those made using the road network (94% of the total), amounting to 1,241,495 observations.

Expression (11) is estimated for nine different distance intervals, which are defined according to the observed distribution of transported commodities: 20-40 km, 40-70 km, 70-100 km, 100-150 km, 150-200 km, 200-250 km, 250-350 km, 350-500 km, and more than 500 km. The initial assignation of probabilities (0 or 1) is carried out in a similar way to that applied for workers' commutations. The probability is degenerate in the case of less than 20 km long transportations, and firms transporting commodities to a given distance are also willing to do so in all inferior distance intervals. Additionally, probabilities are estimated applying weights which depend on the load transported in each journey.

Firms' intermediate consumption and production for year 2009 are obtained from *SABI* database. The composition and distribution of commodities in each intermediate consumption is assumed to be equal to the one revealed by the corresponding sector of economic activity, registered in the Use Table[27] of the Input-Output framework of Spanish National Accounts for year 2007. With respect to commodities' structure of final production, the procedure is identical, nonetheless, the distribution is computed from the Supply Table[28] for year 2007. In order to quantify the proportion of each commodity dedicated to intermediate use (intermediate demand) or final use (final demand), we calculate the average of the shares in each of the producing sectors observed in year 2005 Symmetric Input-Output Table, whilst the distribution in a given product is estimated from the year 2007 Use Table[29]. The classification of manufacturing products in the Use and Supply Tables, has been aggregated to 11 groups of homogenous

[27] The rows of the Destination of Production Table informs about the economic destination of each product, whilst the columns show the sector of economic activity where the good is destined. Thus the columns give the distribution by products of the intermediate consumption in each sector of economic activity.

[28] The rows of the Origin of Production Table report the sectors of economic activity producing each good, and the columns, the products obtained by each sector. Thus each row offers the distribution by product of production.

[29] All deflated according to 2009 Index of Industrial Prices.

commodities between the Revised Nomenclature for Transport Statistics (NST/R) used by the EPTMC, and the National Classification of Products by Activity (*CNPA*-96) of National Accounts.

The intermediate consumption, the production, and associated commodities' distributions in each municipality are obtained by aggregation of the firms located in them, and applying the corresponding elevation coefficients.

The probability of each commodity's transportation between each firm and municipality is computed substituting the average distribution of firms' commodity flows (in terms of intermediate consumption and final production) and corresponding municipality. Municipalities' income is calculated multiplying the number of inhabitants declared by *INE*'s Municipality Census (year 2009) by the Province per capita income derived from *INE*'s Regional Accounts of the same year[30].

The accessibility indicators of expressions (2) to (4) are computed by substituting each firm-municipality iteration of the impedance function, by the previously estimated probability of commodities' transportation in the distance interval associated to the real distance between centroids of the corresponding municipalities. These distances are calculated in the same manner as for workers' accessibility.

C. Control variables in productivity function

The remaining variables included in the productivity functions are obtained from *SABI* database. In the case of firm foreign trade activity, where only qualitative variables are available, the possibilities are four, (i) no foreign trade activity, (ii) firm exports, (iii) firm imports, and (iv) firm exports and imports. If the firm is associated with foreign owners controlling more than 50% of social capital (OECD control criterion), the firm is assumed to have foreign capital. If a firm participates in more than 50% of social capital of other Spanish or foreign firms, the firm is assumed to have Spanish and/or foreign affiliates, respectively. The age of the firm is calculated by subtracting from 2009 the year when the firm is first incorporated. The firm exit variable is obtained from *SABI*'s State

[30] Municipal income is only available for some *Comunidad Autónoma*. A common methodology for all municipalities is preferred.

variable. If the firm state in year 2009 is different to active and related to an exit scenario, the firm is assumed to exit in year 2009. Lastly, firm's qualification level of workers is derived through a complex mechanism which compares firm's mean wage with that observed in the Province where the firm is located in the corresponding sector of economic activity[31].

D. Instruments

Choosing appropriate external instruments is a complex task. Combes et al. (2010) argue that in the context of agglomeration and market accessibility analysis, these exogenous variables can come from the geographical-geological and historical fields. In the case of accessibility and given that this variable has agglomeration, infrastructure endowments, and geographical location components, it seems reasonable to look for exogenous instruments identifying these particular aspects. Additionally, endogeneity can take place also in the accessibility to workers variable, so exogenous instrument determination for both variables is required.

We start by considering mean municipal altitude and ruggedness computed in Goerlich and Cantarino (2010). They calculate these variables from the NASA SRTM data, which exhibit a resolution of the raw data for Spain of three arcsecond (90 meters) and 4 to 6 meters in terms of elevation precision. The ruggedness index corresponds to that proposed by Riley et al. (1999), and basically measures differences in elevation through neighbouring areas.

With regards to the historical dimension, we have constructed two instruments. It is common that lagged values of a given variable are used as instruments. If the variable shows an important degree of persistence, its lagged values may behave as weak instruments. For this reason, the economic geography literature often considers a very broad time displacement (sometimes over a century) so that the spatial distribution is different enough to eliminate endogeneity. Consequently, we use year 1900 population density and the accessibility to final markets using 1857 road network. This last one

[31] The complete procedure is described in the Annex.

combines information on population density and the road and path network of mid-19th century, in the way Duranton and Turner (2012) do when considering the planned high capacity network of year 1947 and the 1898 railway network to instrument 1983 infrastructure stock. Similarly, Combes et al. (2010) calculate French market potential indicators for year 1831 to instrument contemporary values, and Holl (2012) does the same for Spain with data on 1760 roads and 1900 population.

The year 1857 accessibility measure is based on the accessibility to final markets defined in expression (4). Municipal income is nonetheless substituted by year 1857 population and the probabilities are calculated according to the estimated coefficients of expression (11), but considering the distances in year 1829 transportation network associated to minimum travelling time. Population data is computed from all available population censuses [32], implementing recursive procedures so that the adopted municipal definition (i.e. that of year 2009 with 8116 municipalities) is preserved throughout the time series. Population in year 1857 is used to compute the firm level accessibility indicator, whist population density is intentionally calculated using year 1900 information. Allowing for wide time gaps between years 1857 and 2009 we intend to avoid possible collinearities amongst considered instruments.

With regards to the road and path network, we draw and build a network geodatabase (see Figure 1) that allows network analysis using GIS exploiting the map [33] provided by Cabanes (1830). This generated road network represents the original basis of the actual Spanish road network, and contrary to the one used by Holl (2012), it includes not just the postal routes, but the remaining main roads and pathways in Spain[34]. We consider up to four different road categories, two main roads where carriage transit was possible, and two

[32] The first proper Population Census corresponds to year 1857. There exists previous information on population at the municipal level from the Census "*Censo de la Matrícula Catrastral"*. Nonetheless it had no statistical rigor as information was generated by imputation procedures. Documentation on this information is disperse along Pascual Madoz's Dictionary *"Diccionario Geográfico-Estadístico-Histórico de España y sus posesiones de Ultramar"* published in 1850 (García, 1991).

[33] *Mapa Itinerario de los Reinos de España y Portugal*.

[34] The pathway network detailed in Cabanes (1830) incorporates improved and new routes constructed under Spanish Royal Order of 10 June 1761, which as stated by Jovellanos (1775), it contemplated a genuine Road Plan. The map in Cabanes (1830) also includes the unification process defined in the Spanish Royal Order of 8 October 1778, in charge of integrating the road and guest houses network (*Superintendencia General de Caminos y Posadas*) with postal routes and customs (*Correos y Postas*), as well as assignation of some of the tax revenues to the construction and maintenance of roads.

more path categories denoted as general and second order ones[35]. A different velocity is assigned to each of these four categories [36], thus allowing determination of the distance associated to the fastest route between two points [37]. These distances, when introduced in expression (11), permit calculation of the probability of commodity transportation conditional on past infrastructure network.

(Figure 1 around here)

Table 1 shows the pairwise correlations between chosen instruments and the endogenous variables, as well as some of the results derived from the univariate regressions between them. Although R^2 values are in some cases relatively low, taking into account the complete set of instruments and the statistical significance of correlations, it seems that chosen instruments have certain explanatory power over endogenous variables. Specifically, we can expect that commodities' accessibility will be better explained by the accessibility indicator to final markets according to 1829 road infrastructures, followed by population density and to a lesser extent, municipal ruggedness. In the case of workers' accessibility, population density and municipal altitude should behave better.

(Table 1 around here)

5. The effect of accessibility on productivity

Table 2 presents the OLS results of expression (9), which relates firms' productivity with the different accessibility indicators and mentioned control variables. Additionally, all estimations include sector of economic activity

[35] The first two categories correspond to the postal and customs network.

[36] Specifically, the Treaty on Postal and Custom Network of 1826 establishes the speed limit in 32 Castilian *leguas* (1 Castilian *legua* = 5,572.7 meters) per day. This is equivalent to 7.5 km per hour if taking into account horse resting and time dedicated to horse switching. In computed network geodatabase, we establish a velocity range from 7.5 km per hour to 4.0 km per hour, depending on the quality of considered roads and paths.

[37] Distances between neighbouring municipalities were traditionally lower, due to the existence of quite straight pathways between them. These paths were not necessarily easy and thus may result slower than longer routes.

(NACE-2 digits) indicators of firms' primary activity. The dependent variable corresponds to the logarithm of TFP estimated using Levinsohn and Petrin procedure. The first four columns of Table 2 refer to estimation results when accessibility indicators are introduced in an isolated manner, i.e. one by one. The fifth column registers results when only the aggregated accessibility to commodities is included. The sixth and final column reports estimation results when both accessibility indicators are considered, i.e. the aggregated accessibility indicator to commodities and the one to workers.

(Table 2 around here)

All of the accessibility indicators, both to workers and commodities, show a positive effect over the TFP, being far larger in the case of commodities. Additionally, results do not change drastically when both accessibility indicators are jointly introduced.

In terms of workers' accessibility, a lower but statistically significant effect is obtained (.016-.024). Results in this dimension are less conclusive and comparison is not as straightforward, nonetheless they are in line with previous results highlighting a moderate impact over TFP (Gibbons et al., 2010 and Melo et al., 2013).

The observed effects over TFP of commodities' accessibility reveal that the accessibility to final consumers (.191) is more important than to intermediate uses (.097), probably due to the existence of previous contracts and business networks ensuring higher client fidelity than in the case of final consumers. Higher volatility with respect to consumers possibly generate larger logistic and distribution costs to firms, and hence, accessibility to final markets gains relevance in firms' performance. The observed elasticity for intermediate consumption is between the two already mentioned values (.122). These estimated values at least double in magnitude those recently available results in the literature analysing the effect of agglomeration or market potential on productivity (Combes et al., 2009; Melo et al., 2009; Puga, 2010; Combes et al., 2011; Holl, 2012; amongst others), and they are only slightly higher than those provided by Brülhart and Mathys (2008). The relatively high (low) elasticity estimated for commodities' (workers') accessibility can be explained according

to three factors, (i) the existence of simultaneity problems between these variables and productivity, (ii) the nature of used accessibility indicators, and (iii) the specific characteristics of the Spanish economy.

In order to assess robustness of these results and amend possible endogeneity problems, expression (9) is estimated consistently using the two-step least squares estimator. Table 3 registers results when the accessibility to workers and commodities are introduced separately and Table 4 when the specifications consider both indicators simultaneously.

(Table 3 around here)

(Table 4 around here)

To ensure instrument validity we compute and report a wide range of test statistics (*cf*. Tables 3 and 4). Endogeneity of accessibility indicators is confirmed by means of a control-function approach, testing for statistical significance of predicted residuals from first-stage OLS regressions when included as additional explanatory variables in the OLS estimation of expression (9). The null hypothesis of exogeneity of the accessibility indicator to commodities is rejected at the 99.9 per cent significance level in all considered cases. Endogeneity of the accessibility indicator to workers is also confirmed systematically, and only in one of the specifications, rejection of the null is not possible at the 95 per cent significance level (column 4 in Table 4). Nonetheless, residuals are statistically significant at the 90 per cent level and thus verify endogeneity of workers accessibility in the TFP regression. Considered instruments are jointly significant at the 99.9 per cent significance level thoroughly in first-stage regressions, as reported by first-stage regression F-tests' statistics. The majority of computed estimations include more instruments than endogenous variables, so instrument validity is explored further through Sargan-Hansen test of overidentifying restrictions. The null joint hypothesis stating that the instruments are valid is accepted at the 99.9 per cent significance level in three out of eight cases (columns 2 and 5 of Table 3, and column 5 of Table 4), and it cannot be rejected at the 90 per cent level in the remaining ones. According to these overidentification tests, workers' accessibility is best instrumented with the ruggedness index and 1900

population density, whilst in the case of the accessibility to commodities indicator, the accessibility to final markets in 1857 and the ruggedness index are well behaved. When including worker and commodity accessibility indicators in the same regression, a combination of the instruments (i) accessibility to final markets in 1857, (ii) municipal mean altitude, and (iii) the crossed product of accessibility to final markets in 1857 and year 1900 population density, offers best results in terms of Sargan-Hansen test statistics. The null hypothesis of underidentification is rejected systematically at the 99.9 per cent significance level as shown by the value of the Anderson LM statistic for underidentification. Comparison of Cragg-Donald Wald F statistics with Stock and Yogo (2005) critical values, discards weak identification problems related to poor correlation of the chosen instruments with the endogenous variables, as the null hypothesis of weak identification is always rejected. Lastly, endogenous regressors in the structural equations are jointly significant in all considered specifications, as shown by the set of the three provided test statistics robust to the presence of weak instruments. The null hypotheses of valid overidentifying restrictions, i.e. the coefficients of the endogenous variables are statistically equal to zero in the structural equations, are systematically rejected at the 99.9 per cent significance level.

The magnitude of consistently estimated elasticities is corrected in the expected direction, returning lower values in the case of commodities (14-15 per cent) and significantly higher ones in the case of workers' accessibility (4 per cent).

Obtained elasticities are nonetheless particularly high in the case of commodities. Precisely, the nature of the accessibility indicators here computed can explain the differences in magnitude between provided and already available results. In one side, the inclusion of the individual component of accessibility provokes that certain firm's characteristics, as its size, affect not just productivity but the accessibility indicator itself. On the other, the substantial differences on variance's magnitude between delivered indicators and those market potential ones grounded on inverse distance formulations of the impedance functions (Holl, 2012). Consideration of probabilities estimated from real travelling times or distances incorporates in the impedance function the highest propensity to supply larger markets even from those poorly

communicated locations. This results in a relatively lower variance of our indicators and therefore higher elasticity levels.

The differences on the results obtained for the two types of evaluated accessibility are somehow surprising, and they may be possibly caused also by the degree of volatility of the accessibility indicators. In order to objectively evaluate the impact of accessibility over TFP, Table 5, based on the average elasticities listed in Table 4, evaluates the increase in productivity associated to changes in firm's accessibility calculated according to their year 2009 real locations. Moving from percentile 10 to 90 in terms of commodities' accessibility causes a 17.8% increase in productivity, and an 8.1% increase if the accessibility improvement is equivalent to a shift from percentile 25 to percentile 75. In terms of workers' accessibility, the increases in productivity are much more moderate although still relevant, a 12.7% and a 6.1% increase in productivity when accessibility improvements are associated to shifts from the percentiles 10 to 90, and 25 to 75, respectively.

(Table 5 around here)

The differences in obtained results can also be interpreted in terms of the cross-sectional and temporal variation. Although only the former dimension is exploited in the estimated regressions, it is important to notice that there has been a substantial improvement in Spanish urban and metropolitan infrastructure endowments along the recent years, which has led to notorious progress in workers' commuting time. The efficiency gains associated to better infrastructures are already taken into account by firms' productivity, and therefore, cross-sectional variation in workers' accessibility has been reduced. However, commodities' accessibility is more influenced by agents' location and thus the structure and quality of the full road network, where there may still be important connexion problems in certain territories.

Additionally, high unemployment rates in Spanish labour markets erode workers' bargaining power, so labour commuting costs are often undertaken by workers and not shared by hiring firms. Conversely, commodities' transportation costs enter the costs function of the firm, directly affecting its productive efficiency.

Lastly, the productive structure of the Spanish economy may also help in understanding observed differences in estimated elasticities. Spanish manufacturing firms generally produce goods of medium-low technological content, thus the demand for qualified labour is relatively low. This provokes that firms' benefits associated to suitable matching between labour specialisation and required level of qualifications are rather limited. Additionally, labour intensive manufacturing activities will tend in one hand to hire labour located nearby production locations, and in the other, to position their plants in the neighbourhood of large labour markets. This in turn reduces the impact of workers' accessibility on firm's productivity.

With respect to control variables, they are all statistically significant and show the expected signs. Foreign trade activities positively affect firm productivity, the effect being higher if firms engage jointly in both exports and imports. Having affiliates either in Spain or abroad is also associated to better firm performance, and estimated effects are as expected larger than those observed for foreign capital participation. Experienced firms and those hiring higher proportions of qualified labour perform better than the firms exiting the market during the study year.

Obtained results highlight the important role played by infrastructures on firms' productivity. No wonder firms prefer their locations across best endowed territories in terms of road transport infrastructures. Furthermore, accessibility to commodities reveals, at least in the specific case of Spanish, more important to enhance firms' productivity improvements than the accessibility to workers[38].

6. Conclusions

This paper measures the impact on firms' productivity of accessibility goodness to labour markets and commodities. In order to attain it, we estimate a productivity function which includes accessibility indicators as well as those control variables determining differences in the level of productivity across firms.

[38] For robustness check of obtained results, firm size (in four different size classes) was included in regressions. Given that this particular variable is highly correlated with the rest of regressors, results, which did not show significant differences, have not been included in the paper.

We consider two accessibility measures, one to workers and other to commodities.

One of the contributions of this paper is the way in which accessibility is measured. First in terms of the impedance functions, approximated through the estimation of probability functions using microdata, to properly identify the individual features of both, workers and firms. Furthermore, the measurement is at firm level, providing the indicators for more than 60,000 firms and evaluating the distances (or journeys' times) between firms and workers or firms and territories across the full urban and intercity road network. The estimation of the TFP functions uses Levinsohn and Petrin methodology and is carried out for almost a hundred different manufacturing activities.

Obtained results confirm that the impact of accessibility on firms' productivity is positive, elasticities ranging from .1393 to .1584 in the case of commodities, and from .0295 to .0592 in terms of labour markets. An accessibility improvement to commodities equivalent to a shift from percentile 10 to 90 increases productivity in almost 17%, and 8% if the accessibility correction is from percentile 25 to 75. The impact on productivity in terms of workers' accessibility is lower, an approximate 25% reduction is observed with respect to commodities. This is possibly due to the fact that in one hand, workers run with commuting costs instead of hiring firms, and in the other, the relatively less important role played by proper matching between labour demand and supply in Spanish labour markets, as a consequence of the specialisation in manufacturing of medium-low technological content goods.

Obtained results should not be mistaken for policy recommendation purposes. Although the positive role of road infrastructure in firms' productivity is confirmed, this does not necessarily mean that any type of transport infrastructure investment is going to generate indicated effects on productive efficiency. For this to occur, new infrastructures should increase connection between firms, firms and final consumers, and to a lesser extent, between firms and workers. Productivity improvements are expected to be larger, the most oriented they are to the productive sector, the higher is the number of firms affected by them, and rather than concentrating in particular territories, they should transform the complete infrastructure network by means of increasing connectivity. Precisely, given provided results, infrastructure policy in Spain

should concentrate further on the improvement of commodity transport infrastructures, which will definitely deliver efficiency gains to Spanish productive system.

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Annex

In order to obtain the level of qualification of the labour demanded by firms (i.e. the one deduced from the type of activities carried out by employees), we carry out a rather complex measurement procedure as the information is not directly available in *SABI* database for considered time horizon. Several data statistical sources and time periods are considered depending on the availability of information. For each firm included in *SABI* we calculate the average wage for years 2001 and 2009 (w_i^{2001} and w_i^{2009}), as the ratio between labour expenditures and the number of employees. We then obtain a weighted average for the wage (considering firms' size defined in employment) by province (w_p^{2001} and w_p^{2009}) and by activity and province for both years (w_{sp}^{2001} and w_{sp}^{2009}). Additionally, from the microdata 5% sample of the *INE* 2001 Population Census, we calculate by province (h_{jp}^{2001}) and by province and sector (h_{jsp}^{2001}) the number of workers in each of the three available educational levels, primary (j = 1), secondary (j = 2), and tertiary (j = 3). Next we compute the average number of workers' years of schooling in each province (H_p^{2001}) and each activity and province (H_{sp}^{2001}) according to expression (A.1).

$$H_{\cdot}^{2001} = 6 \times h_{1\cdot}^{2001} + 12 \times h_{2\cdot}^{2001} + 17 \times h_{3\cdot}^{2001} \qquad (A.1)$$

Assuming that the differences in relative wages observed across activities within each province with respect to the provincial average are due to qualification differences, expression (A.2) can be estimated.

$$\frac{w_{sp}^{2001}}{w_p^{2001}} = \alpha + \beta \frac{H_{sp}^{2001}}{H_p^{2001}} + \varepsilon \qquad (A.2)$$

Rearranging expression (A.2) and assuming that the relationship holds in time, we obtain by expression (A.3) the average level of education (average

number of schooling years) for workers in a given activity and province in year 2009[39].

$$\widehat{H_{sp}^{2009}} = \left(\frac{w_{sp}^{2009}}{w_{p}^{2009}} - \hat{\alpha}\right)\frac{H_{p}^{2009}}{\hat{\beta}} \qquad (A.3)$$

Similarly, wage disparities amongst firms engaged in a given activity and located in a particular province must be originated from differences in the level of employees' qualifications. Expression (A.2) can be rewritten to obtain expression (A.4) for year 2009.

$$\frac{w_{spi}^{2009}}{w_{sp}^{2009}} = \hat{\alpha} + \hat{\beta}\frac{H_{spi}^{2009}}{\widehat{H_{sp}^{2009}}} \qquad (A.4)$$

Where w_{spi}^{2009} and H_{spi}^{2009} are respectively the wage and the average number of schooling years for firm's *i* employees working in province *p* and activity *s*. Rearranging expression (A.4), the level of qualification of firm's *i* employees can be estimated by expression (A.5) [40]

$$\widehat{H_{spi}^{2009}} = \left(\frac{w_{spi}^{2009}}{w_{sp}^{2009}} - \hat{\alpha}\right)\frac{\widehat{H_{sp}^{2009}}}{\hat{\beta}} \qquad (5)$$

[39] Note that w_{sp}^{2009} and w_{p}^{2009} are known in expression (A.2) from *SABI*. H_{p}^{2009} is obtained from human capital database of IVIE.

[40] w_{spi}^{2009} and w_{sp}^{2009} are obtained from *SABI* database, whilst $\widehat{H_{sp}^{2009}}$ is estimated from expression (A.3).

TABLES AND FIGURE

TABLE 1. PAIRWISE CORRELATIONS, COEFFICIENTS AND R^2 OF UNIVARIATE REGRESSIONS

	Ln (accessibility to workers)	Ln (accessibility to commodities)
Ln (altitude)	.0284***	-.2555***
	.0139***	-.1842***
	.0008	.0652
Ln (ruggedness)	-.1122***	-.1045***
	-.0882***	-.1253***
	.0125	.0109
Ln (Accessibility to final markets in 1857)	.8166***	.1143***
	.8784***	.1874***
	.6669	.0131
Ln (population density)	.1631***	.3954***
	.0625***	.2306***
	.0266	.1563

Note: First row is the pairwise correlation, second row presents the coefficient of the univariate regression, and third row accounts for the R^2.

TABLE 2. ACCESSIBILITY EFFECTS ON THE PRODUCTIVITY OF SPANISH MANUFACTURING FIRMS.

Dependent variable	TFP 2009					
Accessibility to workers	.0231*** (0.003)					.0151*** (0.003)
Accessibility to commodities					.1938*** (0.008)	.1890*** (0.008)
Accessibility to intermediate consumption		.1233*** (0.007)				
Accessibility to firms' intermediate uses			.0996*** (0.005)			
Accessibility to final markets				.1929*** (0.007)		
Control Variables						
Only exports	.340*** (0.010)	.339*** (0.010)	.337*** (0.010)	.337*** (0.010)	.338*** (0.010)	.338*** (0.010)
Only imports	.307*** (0.012)	.309*** (0.012)	.307*** (0.012)	.305*** (0.011)	.308*** (0.011)	.307*** (0.011)
Exports and imports	.431*** (0.008)	.433*** (0.008)	.430*** (0.008)	.428*** (0.008)	.431*** (0.008)	.430*** (0.008)
Has Spanish affiliates	.335*** (0.009)	.336*** (0.009)	.336*** (0.009)	.335*** (0.009)	.336*** (0.009)	.335*** (0.009)
Has foreign affiliates	.345*** (0.017)	.342*** (0.017)	.344*** (0.017)	.341*** (0.017)	.340*** (0.017)	.338*** (0.017)
Foreign social capital	.320*** (0.019)	.296*** (0.019)	.303*** (0.019)	.298*** (0.019)	.294*** (0.019)	.292*** (0.019)
Firm exits	-.167*** (0.016)	-.167*** (0.016)	-.171*** (0.016)	-.173*** (0.016)	-.171*** (0.016)	-.173*** (0.016)
Firm age	.102*** (0.003)	.098*** (0.003)	.097*** (0.003)	.095*** (0.003)	.096*** (0.003)	.095*** (0.003)
Employees qualification level	.654*** (0.006)	.670*** (0.006)	.662*** (0.006)	.667*** (0.006)	.671*** (0.006)	.668*** (0.006)
N	64034	61443	61443	61443	61443	61440
R2	0.333	0.340	0.341	0.344	0.343	0.343

All estimations are carried out by OLS. All variables, except qualitative ones, are evaluated in logarithms. All estimations include a sector of activity indicator, 2 digits NACE-93. Significance levels are denoted as follows: 99.9% (***), 99% (**), 95% (*), 90% (†).

TABLE 3. ACCESSIBILITY EFFECTS ON THE PRODUCTIVITY OF SPANISH MANUFACTURING FIRMS. 2SLS ESTIMATIONS
Accessibility to workers and commodities included separately

Dependent variable	**TFP 2009**				
Accessibility to workers	.0425*** (.008)	.0487*** (.008)	.0450*** (.008)		
Accessibility to commodities				.1584*** (.012)	.1561*** (.012)
Instruments					
Acccessibility to final markets in 1857	N	N	N	Y	Y
Average municipal altitude	Y	N	Y	N	N
Average municipal ruggedness index	N	Y	Y	N	Y
Municipal population density in year 1900	Y	Y	Y	N	N
Endogeneity test. Parameter value and standard error over first-stage regression residuals	-.0223** (.009)	-.0295*** (.008)	-.0255** (.008)	.0641*** (.016)	.0641*** (.016)
First-stage regression F-test (·)	4,978.59***	5,127.78***	3,549.82***	51,003.88***	26,676.17***
Sargan-Hansen Overidentification $\chi^2(\cdot)$	5.29*	.17	7.12*	-	1.61
Anderson Underidentification $\chi^2(\cdot)$	8,629.35***	8,852.2***	9,143.76***	27,894.99***	28,582.18***
Weak Identification Cragg-Donald Wald *F*	4,978.59	5,127.78	3,549.82	51,003.88	26,676.17
Anderson-Rubin Wald F(·) Weak-Instrument-Robust inference	16.83***	19.26***	13.65***	181.16***	90.93***
Anderson-Rubin Wald $\chi^2(2)$ Weak-Instrument-Robust inference	33.72***	38.58***	41.00***	181.47***	182.16***
Stock-Wright LM S $\chi^2(2)$ Weak-Instrument-Robust inference	33.71***	38.56***	40.98***	180.93***	181.62***
Degrees of Freedom first-stage regression F-tests	F(2, 63930)	F(2, 63930)	F(3, 63929)	F(1, 61340)	F(2, 61339)
Degrees of Freedom for Sargan-Hansen Overidentification $\chi^2(\cdot)$	1	1	2	-	1
Degrees of Freedom for Underidentification and Weak-Instrument-Robust inference $\chi^2(\cdot)$ statistics	2	2	3	1	2
Control Variables					
Only exports	.340*** (.010)	.340*** (.010)	.340*** (.010)	.338*** (.010)	.338*** (.010)
Only imports	.306*** (.012)	.306*** (.012)	.306*** (.012)	.308*** (.011)	.308*** (.011)
Exports and imports	.430*** (.008)	.430*** (.008)	.430*** (.008)	.431*** (.008)	.431*** (.008)
Has Spanish affiliates	.333*** (.009)	.333*** (.009)	.333*** (.009)	.336*** (.009)	.336*** (.009)
Has foreign affiliates	.341*** (.017)	.340*** (.017)	.341*** (.017)	.342*** (.017)	.342*** (.017)
Foreign social capital	.317*** (.019)	.316*** (.019)	.317*** (.019)	.297*** (.019)	.297*** (.019)
Firm exits	-.170*** (.016)	-.170*** (.016)	-.170*** (.016)	-.170*** (.016)	-.170*** (.016)
Firm age	.102*** (.003)	.101*** (.003)	.101*** (.003)	.096*** (.003)	.096*** (.003)
Employees qualification level	.651*** (.006)	.650*** (.006)	.651*** (.006)	.668*** (.006)	.668*** (.006)
N	64,034	64,034	64,034	61,443	61,443

All estimations are carried out by 2SLS. All variables, except qualitative ones, are evaluated in logarithms. All estimations include a sector of activity indicator, 2 digits NACE-93. Significance levels are denoted as follows: 99.9% (***), 99% (**), 95% (*), 90% (†).

TABLE 4. ACCESSIBILITY EFFECTS ON THE PRODUCTIVITY OF SPANISH MANUFACTURING FIRMS. 2SLS ESTIMATIONS

Accessibility to workers and commodities included simultaneously

Dependent variable	**TFP 2009**					
Accessibility to workers	.0592***	.0348***	.0412***	.0295***	.0466***	.0335***
	(.011)	(.009)	(.008)	(.008)	(.008)	(.009)
Accessibility to commodities	.1393***	.1473***	.1420***	.1452***	.1417***	.1439***
	(.012)	(.012)	(.012)	(.012)	(.012)	(.012)
Instruments						
Acccessibility to final markets in 1857, (a)	Y	Y	Y	Y	Y	Y
Average municipal altitude	Y	N	Y	N	Y	N
Average municipal ruggedness index	N	N	N	Y	N	N
Municipal population density in year 1900, (b)	N	Y	Y	Y	N	Y
(a) · (b)	N	N	N	N	Y	Y
Endogeneity test. Parameter value and standard error over first-stage regression residuals, workers	-.0455***	-.0207*	-.0282**	-.0147†	-.0341***	-.0192*
	(.012)	(.009)	(.009)	(.009)	(.009)	(.009)
Endogeneity test. Parameter value and standard error over first-stage regression residuals, commodities	.0650***	.0644***	.0715***	.0725***	.0686***	.0723***
	(.016)	(.016)	(.016)	(.016)	(.016)	(.016)
First-stage regression F-test (·) (workers)	2,258.18***	4,398.04***	3,283.77***	3,272.95***	2,938.16***	2,959.71***
First-stage regression F-test (·) (commodities)	26,008.73***	25,518.52***	17,501.78***	17,802.55***	17,365.14***	17,583.39***
Sargan-Hansen Overidentification $\chi^2(\cdot)$	-	-	4.88*	5.08*	2.60	5.99*
Anderson Underidentification $\chi^2(2)$	4,077.34***	7,327.02***	8,284.76***	7,901.68***	7,583.91***	7,351.12***
Weak Identification Cragg-Donald Wald *F*	2,180	4,153	3,187	3,017	2,879	2,779
Anderson-Rubin Wald F(·)	97.90***	100.16***	68.31***	67.06***	68.17***	66.82***
Anderson-Rubin Wald $\chi^2(2)$	196.13***	200.65***	205.27***	201.53***	204.87***	200.81***
Stock-Wright LM S $\chi^2(2)$	195.50***	200.00***	204.58***	200.87***	204.18***	200.16***
Degrees of Freedom for first-stage F-tests (workers)	F(2, 61336)	F(2, 61336)	F(3, 61335)	F(3, 61335)	F(3, 61335)	F(3, 61335)
Degrees of Freedom for first-stage F-tests (commodities)	F(2, 61336)	F(2, 61336)	F(3, 61335)	F(3, 61335)	F(3, 61335)	F(3, 61335)
Degrees of Freedom for Sargan-Hansen Overidentification $\chi^2(\cdot)$	-	-	1	1	1	1
Degrees of Freedom for Underidentification and Weak-Instrument-Robust inference $\chi^2(\cdot)$ statistics	1	1	2	2	2	2
Control Variables						
Only exports	.339***	.338***	.339***	.338***	.339***	.338***
	(.010)	(.010)	(.010)	(.010)	(.010)	(.010)
Only imports	.305***	.306***	.306***	.307***	.306***	.307***
	(.012)	(.011)	(.011)	(.011)	(.011)	(.011)
Exports and imports	.430***	.430***	.430***	.431***	.430***	.431***
	(.008)	(.008)	(.008)	(.008)	(.008)	(.008)
Has Spanish affiliates	.330***	.333***	.332***	.333***	.332***	.333***
	(.009)	(.009)	(.009)	(.009)	(.009)	(.009)
Has foreign affiliates	.332***	.336***	.335***	.337***	.334***	.336***
	(.017)	(.017)	(.017)	(.017)	(.017)	(.017)
Foreign social capital	.290***	.293***	.292***	.294***	.292***	.293***
	(.019)	(.019)	(.019)	(.019)	(.019)	(.019)
Firm exits	-.177***	-.174***	-.175***	-.173***	-.175***	-.174***
	(.016)	(.016)	(.016)	(.016)	(.016)	(.016)
Firm age	.095***	.095***	.095***	.096***	.095***	.095***
	(.003)	(.003)	(.003)	(.003)	(.003)	(.003)
Employees qualification level	.657***	.662***	.660***	.662***	.659***	.662***
	(.007)	(.006)	(.006)	(.006)	(.006)	(.006)
N	61,440	61,440	61,440	61,440	61,440	61,440

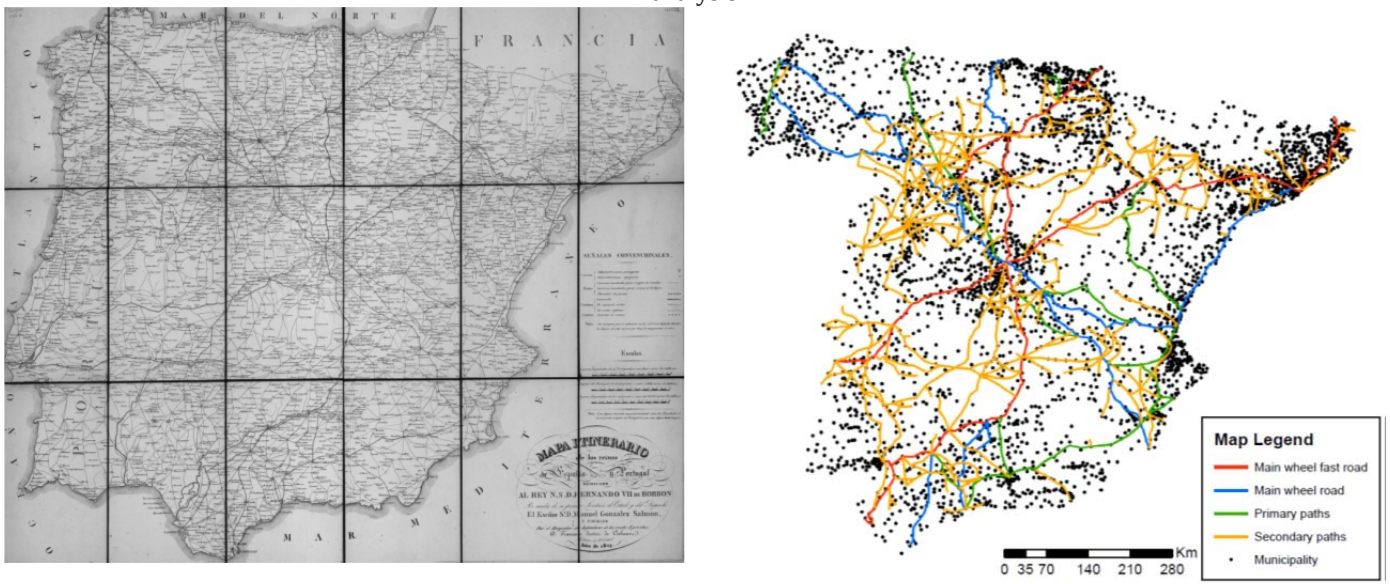
All estimations are carried out by 2SLS. All variables, except qualitative ones, are evaluated in logarithms. All estimations include a sector of activity indicator, 2 digits NACE-93. Significance levels are denoted as follows: 99.9% (***), 99% (**), 95% (*), 90% (†).

TABLE 5. PERCENTAGE CHANGES IN PRODUCTIVITY DUE TO ACCESSIBILITY IMPROVEMENTS EXPRESSED IN PERCENTILES

Accessibility to commodities				
	Percentile 25	**Percentile 50**	**Percentile 75**	**Percentile 90**
Percentile 10	7.15	9.33	15.43	18.19
Percentile 25		5.10	8.28	11.04
Percentile 50			4.18	5.94
Percentile 75				2.76

Accessibility to workers				
	Percentile 25	**Percentile 50**	**Percentile 75**	**Percentile 90**
Percentile 10	5.66	9.78	12.49	14.30
Percentile 25		4.12	6.84	8.64
Percentile 50			2.71	4.52
Percentile 75				1.80

Figure 1. Road and Pathway map of Spanish and Portuguese Kingdoms and computed network geodatabase map for network analysis



Source: Cabanes (1830) and own elaboration.