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THE MOTORWAY SECTOR**

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PERSISTENT AND TRANSIENT EFFICIENCY ON THE STOCHASTIC PRODUCTION AND COST FRONTIERS – AN APPLICATION TO THE MOTORWAY SECTOR

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Abstract

This paper implements both stochastic production and cost frontier analyses to estimate the efficiency of toll motorway companies in Spain, the country with the largest number of private concessionaires in this economic sector. Our dataset includes 32 concessionaires with different features for a time span of 26 years (1988-2014). The results support the existence of scale and density economies, showing that an increase in vehicle-kilometers is more important for cost efficiency than extending the motorway. The differences between transient and persistent efficiency are significant, so that we can test for regulatory and ownership differences. The price cap regulation seems to increase management technical efficiency. Regional governments grant better projects than central governments and, as shareholders, they also perform better. However, their performance is not significantly differently from that of full private concessionaires. We also find limited evidence of efficiency gains from privatization. These results help us provide new insights to evaluate policy and regulatory reforms aimed at enhancing technical efficiency in the sector.

Keywords: Motorways; Efficiency; Stochastic Frontier, Concessions, Infrastructure.

JEL Codes: D22; D24; D78; H4; H54; L25; L32; L33; L5; L9.

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1. INTRODUCTION

Road transport is a major means of transportation with a significant influence on all areas of economic, political and social development since earliest times. Indeed, its role in public infrastructure investments and its link with economic growth, productivity and employment have been extensively studied, most notably in the economic literature since Aschauer (1989).¹ However, beyond their obvious economic impact, roads have been at the heart of transportation, mobility and communication from Roman times, and they continue to be so with the growing provision of high capacity motorway infrastructure (Albalate, 2014). Road transport today is dominant among transport modes: in terms of total passenger-km, its share in 2014 (latest available data) stood at 82.2 and 86.4% in the European Union and the United States, respectively. In the case of freight, the modal split also favored road transport accounting for 49.0% of all transport modes in the EU in 2013 (latest available data) and for 74.9% of total inland freight transport (based on tonne-kilometers performed) (European Commission, 2016). In the US, the tonne-km share moved by road was slightly lower (47.8%), but still much higher than that moved by the second most important mode, rail (28%). Road transport also has a huge influence in developing countries, whose railway networks are often undergoing a sharp decline and which typically lack other types of transport infrastructure. In short, roads have become their main axis of mobility (see Hilling, 1996; ADB, 2015).

Given these figures and the resources mobilized to build, maintain and operate this infrastructure, high capacity roads (motorways, expressways, highways, etc.)² clearly play a key role in our economy, which makes their efficient management essential. Yet, very little is known about the efficiency and productivity of motorway management. In some countries, the motorway network is managed directly by the State (or by a publicly owned corporation operating under private law), while in others, private companies

¹ See Matas, Raymond and Roig (2015) for recent studies on the link between road investments and productivity; See Jiwattanakupaisarn et al. (2009) and Albalate and Fageda (2015) for recent studies on the link between motorways and employment.

² As in Albalate (2014, p. 10), we define motorways as “a road that has been specially designed and constructed for motor traffic, and which is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other either by a dividing strip not intended for traffic or, exceptionally, by other means”. In English, several terms might be used to define such high-capacity roads: expressways, freeways, superhighways, parkways, highways, thruways, motorways, etc.

manage the motorways under concession contracts, especially when they are tolled as a return on their investment, maintenance and operation. These Public-Private Partnership contracts are designed and awarded in the expectation of improving efficiency and facilitating private financing, above all, in the hope of encouraging the collaboration of the private sector in the management of this capital-intensive infrastructure.³ However, toll regulation is usually unrelated to the degree of productivity or efficiency of the concessionaires (Albalade, Bel and Fageda, 2009), especially if price-cap regulation is not implemented (Iossa, 2015),⁴ and satisfying uncertain demand in the long run is the main factor determining the outcome of the standard fixed-term concession contract (Engel, Fischer and Galetovic, 1997; 2001).⁵ Even if motorway managers seem to have little scope for improving their overall cost efficiency given the overriding importance of capital costs (investment) in their cost structure, or they “can do little to increase demand”, as Engel, Fischer and Galetovic (2002, p. 22) claim, the empirical literature remains scarce and overly limited to allow us to draw any general conclusions regarding efficient management and its determinants.

Analyses of the efficiency of regulated industries such as energy systems (Lin and Wang, 2014; Chen, Pestana and Borges, 2015; Ghosh and Kathuria, 2016) or water services (Phillips, 2013; Carvalho and Cunha-Marques, 2016), transport services, including buses (Filippini, Koller and Massiero, 2015; Bel and Rosell, 2016) and railroads (Couto and Graham, 2009) or transport infrastructures such as ports (Cullinane et al., 2006; Yan, Sun and Liu, 2009) and airports (Martin and Voltes-Dorta, 2011) have figured among the most frequent applications of frontier modeling. Recently, efficiency analyses have begun to distinguish between transient and persistent inefficiency, where the latter absorbs structural problems in the firm or systematic shortfalls in management, and the former is a time variant component that absorbs changes in a firm’s efficiency. Yet, the empirical literature has failed to pay sufficient attention to the distinction between these two

³Geltner and Moavenzadeh (1987) identified four potential economic justifications for privatizing motorways: higher revenues without higher taxes, improved highway use efficiency, production efficiency of maintenance, and quality of highway services.

⁴Banded rate of return, inflation adjustments and traffic fluctuation adjustments are some of the most common toll adjustment regulations that are unrelated to efficiency incentives.

⁵Some determinants of motorway demand beyond the control of the concessionaire include fuel prices, macroeconomic conditions, population growth, per capita income distribution, the existence of alternative cheaper roads or modes of transportation, changes in urbanization and land use, weather conditions and transportation technical change (Yescombe, 2007; Albalade, 2014; Iossa, 2015)

components of a firm's efficiency (Filippini and Greene, 2016). Recent analyses have focused on energy efficiency (Filippini and Hunt, 2015), banking (Mamatzakis et al., 2015) and the nursing home sector (Di Giorgio et al., 2015). All emphasize the importance of distinguishing between these two types of efficiency for policy analysis. Moreover, the literature dedicated to studying the efficiency of public utilities has largely neglected the motorway industry with just a few specific exceptions, most notably Benfratello, Iozzi and Valbonessi (2009) for Italy, and Odeck (2008) and Welde and Odeck (2011) for Norway.

This paper contributes to the literature by applying production and cost frontier models to the evaluation of the efficiency of toll motorway companies. We specifically study transient and persistent efficiency estimations as they allow us to isolate the sources of inefficiency when evaluating such public policies as regulatory and ownership reform. We use a new, self-constructed dataset for Spain, the country with the largest number of private concessionaires (for-profit) and with a longstanding tradition of public-private partnerships in this infrastructure sector (Albalade, 2014).^{6,7} A timespan of 26 years, covering the period 1988–2014, allows us to evaluate the efficiency of concessionaires during distinct periods (i.e. of economic growth and recession), and to take into consideration different regulatory changes (price cap schemes, privatizations, etc.) and different features of motorways (length, expansions, physical features, technological advances, etc.) that might have impacted on concessionaire efficiency. Thus, this paper is the first to evaluate cost and production stochastic frontiers for the same national toll motorway network, focusing on both sides of the efficiency phenomenon. Moreover, it does so for the longest period and with the largest sample of companies used to date in the literature of this kind.

⁶ The first toll motorway private concessions were awarded in 1967, during the dictatorship of Francisco Franco. He initiated a first wave of network construction under a PPP scheme of concession contracts, in which private companies, created as joint ventures, were responsible for building, maintaining and operating these new high capacity roads. These companies retained the right to charge tolls to users for a period of time established in the concession contract (typically around 30 years).

⁷ Note Norway has more toll collection companies but they are non-profit limited responsibility companies established by local governments.

The remainder of this paper is structured as follows. Section 2 describes the related literature on the efficiency of motorways. In section 3, we outline our technical approach by presenting the model implemented for both cost and production efficiency analyses. Our results are presented and discussed in section 4. Finally, section 5 provides our main conclusions and policy recommendations.

2. LITERATURE REVIEW

The literature on the efficiency of motorway management is scant. To the best of our knowledge, only two experiences of toll road concessions are examined in the literature: Norway and Italy. In the first, efficiency was first estimated by Amdal et al. (2007) and Odeck (2008). Since concessionaires are public companies under the ownership of the local authorities, the Norwegian case is unusual. As Estache and de Rus (2000) highlight, it uses dedicated non-profit companies to collect tolls, while the government road administration retains responsibility for road design, construction and maintenance (see Odeck, 2008).⁸ This makes Norway quite a unique case and one that is readily compared with other international experiences.

Amdal et al. (2007) use panel data for 26 toll collection companies – including some toll cordons – with a time series that extends between two and seven years (1998 to 2004). They find evidence of important unexploited economies of scale in costs when estimating a translog cost function for traffic and other controls with a random effects estimator. Average costs were reported as being decreasing in traffic volume for low levels until they became flat for high-density traffic. Other controls, such as the number of lanes, competitive tendering and total debt, also provided interesting results. An increase in the number of lanes and total debt were both positively correlated with operating costs. However, the former appeared to be especially sensitive – probably due to its correlation with traffic – to model specification, becoming insignificant in the simplest models. In contrast, competitive tendering and the number of cars with on board paying units did

⁸ The Norwegian Public Roads Administration is responsible for planning, building and operating the road projects financed by toll money and for planning and building the toll collection systems. For each toll project, a dedicated toll company with limited responsibility is established by the local authorities, in order to operate the road toll system and to handle financial tasks.

decrease operating costs, which points to the importance of regulation and technological advances in toll collecting systems.

Odeck (2008) also evaluated this experience but employed a different methodological approach, namely, a non-parametric data envelopment analysis (DEA) to assess input technical inefficiency. The sample comprised 18 companies over a timespan of four years (2001-2004). Results also confirmed the potential for efficiency gains (of about 14%) and the existence of economies of scale, with larger companies being more efficient than their smaller counterparts. New electronic methods of collecting tolls seem to contribute to efficiency improvements, but represent sizable investments in the short run. Another result worth mentioning is the role of company age, found to be positively associated with efficiency.

Later, Welde and Odeck (2011) expanded their DEA to include a stochastic frontier analysis (SFA) for a production function. This study examined a six-year period (2003-2008) and considered 20 toll companies. The main finding once again was the significant potential for efficiency improvements and further evidence of the importance of technology advances in toll collection. Their results confirmed that electronic tolling is a source of efficiency gains with respect to manual toll collection. The introduction of this technology not only allows companies to reduce their costs but it enables them to be more efficient in their operations. The age of the toll company appears to be sensitive to the method used, given that it is significant according to SFA, but not according to DEA. However, the authors report the absence of economies of scale (contradicting the evidence presented in Odeck, 2008), a result that is consistent irrespective of the method applied. The paper's findings also contradict the results of Amdal et al. (2007) with regard to the contribution of competitive tendering, although the efficiency considered by the latter authors was based on average costs rather than on a production function.

The second experience to have been evaluated by the literature is the Italian motorway sector. Some early studies on productivity and operating efficiency were somewhat limited from a technical perspective and focused on the impact of privatization. Ragazzi (2008) found evidence of economies of scale, although the study links this result to the importance of *Autostrade* (the country's leading privatized concessionaire in what is a small sample), and the fact that its operation costs were much lower than the industry mean. Massiani and Ragazzi (2008) provide findings on the relationship between

privatization and efficiency. They report no statistically significant impact of the privatization of the network on productivity, finding no evidence that the privatization of *Autostrade* improved efficiency. The authors consider the use of productivity ratios based on traffic with respect to costs, or on traffic revenues with respect to total costs, as being invalid. Rather, they claim that productivity should be assessed by means of the sole consideration of operating costs, since amortization and financial costs depend upon historical investment costs and the length of the concession. Here, they found that operating costs largely depended on traffic and capacity, but they found no clear evidence of economies of scale.

A more technical, in-depth analysis of the Italian toll motorway sector was performed by Benfratello, Iozzi and Valbonesi (2009). This was the first paper to study a stochastic cost frontier function for the motorway sector. Their sample included 20 Italian concessionaires and a timespan of 13 years (1992-2004). Italy's experience is much more similar to that of Spain, with a large presence of private companies and, this makes it the closest paper to ours. Their empirical analysis based on SFA for a cost function concludes that the industry clearly exhibits scale economies for small- and medium-sized concessionaires operating in the Italian network. An equiproportional increase in traffic and network size causes a less than proportional increase in costs for networks up to 300 km. Besides scale economies, the authors also find large density economies and steady productivity gains over time. Interestingly, the authors find that privately owned concessionaires have a cost advantage of about 3 per cent over their publicly owned counterparts. By contrast, the introduction of a price cap – which in theory should serve as a productivity-enhancing mechanism – did not have any effect on efficiency. Unfortunately, given the nature of their dataset, they could not establish the size of the network at which the economies of scale are exhausted.

3. THE MODEL

The estimation of frontier functions is the econometric exercise of making the empirical implementation consistent with the underlying theoretical proposition that no observed agent can exceed the ideal (Greene, 2008). In practice, the frontier function model is a regression model that allows efficiency to be measured, that is, an empirical estimation of the extent to which firms achieve a theoretical ideal. Only a few firms typically manage

to operate at this frontier. Measuring the resulting inefficiency is the ultimate goal of stochastic frontier analysis.

There are two approaches to estimating the frontier and measuring efficiency: parametric and non-parametric approaches. The parametric approach requires that the frontier functional and inefficiency form should be imposed, while in the non-parametric approach there are no functional form impositions. Frontier approaches do not necessarily observe the true (unobserved) technological frontier, only the best-practice reference technology. However, a non-parametric approach, such as DEA, does not distinguish between technical inefficiency and random noise. Here, the use of frontier models has become widespread for different reasons: First, either production or cost frontier behavior is consistent with economic theory of optimizing; second, deviation from the optimal frontier can be measured, which implies, in third place, that this deviation can have policy implications. The estimation of efficiency by the implementation of different models, therefore, seeks to identify which factors affect a firm's efficiency.

Parametric approaches can be subdivided into deterministic and stochastic models. Deterministic models allow the researcher to distinguish between technical efficiency and statistical noise, while the stochastic approach takes in to consideration both technical efficiency and random noise. On a stochastic frontier, one company can usually be assumed to operate at the efficiency level. Farrell (1957) was the first to measure productive efficiency empirically. This efficiency is evaluated by comparing best firm practice with the rest. In conclusion, the possibility of obtaining firm-specific estimates of efficiency has greatly enhanced the appeal and expansion of stochastic frontier analysis.

3.1. The cost function

The stochastic cost frontier (Aigner et al., 1977) is based on the idea that deviations from the cost "frontier" might not be entirely under the control of the firm. We adopt a stochastic cost frontier model for panel data in order to analyze the impact of different variables on a concessionaire's total costs. The cost function gives the minimum expenditure needed to produce a given output. In the case before us, the purpose of a motorway concessionaire is to maximize the total distance covered by the vehicles, assuming total costs to be a function of input prices. Thus, a motorway concessionaire uses its employees as labor force and its investment in the motorway as capital. As such,

the cost frontier provides a standard against which to measure the performance of the producers for whom the variable cost minimization assumption is appropriate. Aigner et al. (1977) and Meeusen and Van den Broeck (1977) propose the first estimation procedure for inefficiencies, an important derivative when estimating the frontier cost function. Based on previous studies, a cost function can be specified:

$$TC_{it} = f(Y_{it}, PL_{it}, PC_{it}, N_{it}, t_t) \quad (1)$$

where the total cost of concessionaire firm TC is assumed to be a function of output Y , factor prices P (labor and maintenance L , and capital C), network characteristics N and a time trend t_t . In this sector, just what should constitute the network characteristics that account for differences between motorway concessionaries is open to debate. Motorway length is one characteristic that has an impact on total costs. The number of accidents with victims is potentially another relevant motorway characteristic, given that a concessionaire seeks to minimize such accidents because of their associated costs and because of the negative effect they have on user perceptions regarding safety. The total number of accidents could be a substitute for accidents with victims, but there is a discontinuity in the way these variables are defined in the period analyzed here. A third network characteristic is the number of customer claims registered, which constitutes a motorway quality approximation.

The Cobb-Douglas and translog models overwhelmingly dominate the applications literature in stochastic frontier and econometric inefficiency estimation (Greene, 2008). The cost function should be non-negative, non-decreasing in input and output prices, linearly homogeneous and concave in input prices. We use a Cobb-Douglas (log-linear) cost function. The concavity assumption is automatically satisfied in the Cobb-Douglas production function. The linear homogeneity restriction can be imposed by dividing input prices and total costs by the price of one input price. A translog functional form is also suitable, but after several attempts, there is no convergence and the coefficient parameters obtained are counterintuitive, such as a significantly negative sign on the output variable. This problem, described by Farsi et al. (2005), is perhaps caused by multicollinearity between the several interaction and second order coefficients. Imposing the appropriate curvature on a translog model is generally a challenging problem in the production and cost frontier.

As a result, the stochastic cost frontier equation to be estimated can be expressed in the following double log form:

$$\ln \frac{TC_{it}}{PC_{it}} = \beta_0 + \beta_{PL} \ln \frac{PL_{it}}{PC_{it}} + \beta_Y \ln Y_{it} + \beta_{LEN} \ln LEN_{it} + \beta_{ACC} \ln ACC_{it} + \beta_{CLA} \ln CLA_{it} + \beta_T \text{Time_trend}_t + u_{it} + v_{it} \quad (2)$$

with $i = 1, 2, \dots, 32$ and $t = 1988, 1989, \dots, 2014$

where subscripts i and t denote the concessionaire firm and year, respectively. The total costs (TC) are the sum of labor, maintenance and capital costs, where the price of labor and maintenance (PL) and the price of capital (PC) are the two input factor prices. The output (Y) is the number of vehicle-kilometers. The network characteristics are the motorway length (LEN), the number of accidents with victims (ACC) and the number of customer claims (CLA). The random term is divided into a normally distributed error term v_{it} and the non-negative inefficiency term u_{it} following a truncated non-negative normal distribution $N^+(0, \sigma_v^2)$. Between both terms, there is an independent distribution assumption. Estimating a cost frontier allows us to compare the performance of the model on two sides: the cost function coefficients and inefficiency. There is some evidence of a trade-off between the coefficients estimated and inefficiency. The fixed-effects models perform well in estimating the coefficients, but a degree of bias appears in the inefficiency estimates.

The cost inefficiency measures how much a motorway concessionaire is able to reduce its costs while maintaining the same level of output. In a context in which demand is determined and cannot be stored, as is the case of the motorway sector, this is especially relevant. We can account for two sources of inefficiency: technical and allocative inefficiency. Technical efficiency can be achieved using fewer inputs for the same output level, whereas allocative efficiency can be achieved through a different input combination. Utilities were alleged to be wasting money on excessively capitalized facilities, so allocative efficiency refers to the extent to which the input choices fail to satisfy the marginal equivalences for cost minimization. In our case, it is difficult to achieve efficiency from the allocative perspective because it is difficult to change capital during a concession period after it has been assigned at the beginning. We use input-oriented inefficiency, that is, a concessionaire objective is to produce a given level of output with the minimum possible cost. This view is useful if the output, i.e. the vehicle-

kilometers, is exogenously given. After all, on the cost side, any errors in optimization, technical or allocative, must show up as higher costs.

The first application of panel data models to stochastic frontier analysis was undertaken by Pitt and Lee (1981) in the form of a random effect model. To estimate the inefficiency term – one of the main aims in estimating this model, a two stage-approach is taken. The authors assume that the inefficiency term u_i is constant in time and that it captures firm inefficiency; concessionaire specific inefficiency is the same in each time period. This might represent quite a strong assumption for a long panel, although it might be plausible when a firm operates in a non-competitive environment, such as that of motorway concessions. In a regulated industry, all firms might be operating under excess capacity, which could be reflected in high inefficiency values. Another limitation of this model is that no correlation is assumed between the explanatory variables and inefficiency. In these models, any individual-specific or unobserved heterogeneity is captured by the inefficiency term u_i ; or α : the Pitt and Lee model (1981) underestimates the level of efficiency.

The Pitt and Lee (1981) model cannot disentangle a firm's inefficiency from cost differences due to the unobserved characteristics of the concession area. Usually, such companies cannot control for such concession characteristics as the terrain slope, viaducts or tunnels needed, etc., that cannot simply be attributed to concessionaire performance. To overcome this problem, Greene (2005a and 2005b) proposes a model that captures invariant unmeasured unobserved heterogeneity in a specific term, besides a firm-specific inefficiency term and a random noise term. The true fixed effects (TFE) model captures the unobserved heterogeneity in the cost function. In the true random effects (TRE) specification, unobserved cost differences across firms that remain constant over time are driven by unobserved characteristics rather than by inefficiency. The basic difference between the TFE and TRE models is that in the former any correlation between the effects and explanatory variables is allowed. Thus, time invariant inefficiency is interpreted as concessionaire specific heterogeneity, as it is not captured by the inefficiency term. This time invariant unobserved characteristic not absorbed by the inefficiency term is beyond the control of the concessionaire due to the concession characteristics.

Recently, models have focused on separating productive efficiency into its persistent and transient parts. The initial implementation difficulties in the Colombi et al. (2011)

estimation procedure were solved on Colombi et al. (2014), Tsionas and Kumbhakar (2014), Kumbhakar, Lien and Hardaker (2014) and Filippini and Greene (2016). The persistent term is related to the presence of structural problems in the organization of the production process of a concessionaire or to the presence of systematic shortfalls in managerial capabilities. This cost inefficiency does not vary over time, and can be caused by structural problems in the motorway concession, by structural factors that have not been well allocated or by long-term management mistakes, among others. In contrast, the transient term is related to the presence of non-systematic management problems that can be solved in the short term. This is a more plausible assumption regarding concessionaire capabilities to reduce inefficiency – whereas a persistent inefficiency due to input allocations is difficult to remove, organizational changes or the elimination of short-run rigidities improves a concessionaire’s transient efficiency. This part is time varying, reflecting temporal management mistakes or temporal events affecting the concession. The Pitt and Lee (1981) model tends to reflect the persistent part of the time-invariant values. In Greene’s TRE and TFE models, any persistent component of the inefficiency is absorbed in the individual-specific constant term. In industries in which certain sources of efficiency result in time-invariant excess of inputs, the estimated inefficiency could be relatively small. Filippini and Greene (2015) find that the TRE model tends to estimate the transient part of efficiency, whereas the Pitt and Lee (1981) model does not capture persistent efficiency well. Kumbhakar, Lien and Hardaker (2014) propose a model that splits the error term in four components in order to capture these effects and to overcome Colombi et al.’s (2011) estimation difficulties.⁹ Total technical efficiency, therefore, can be obtained from the product of the persistent and transient technical efficiency terms.

Summing up, in Table 1 we summarize the econometric specifications of the total cost stochastic frontier. The firm’s inefficiency is estimated using the conditional mean of the inefficiency term proposed by Jondrow et al. (1982) adapted to each model.

⁹This model can be implemented following Kumbhakar et al. (2015)

Table 1: Econometric specifications of the Stochastic Cost Frontier

	Pitt and Lee (1981)	True Fixed Effects (TFE)	True Random Effects (TRE)	Kumbhakar, Lien and Hardaker (KLH, 2014)
Model	c_{it} $= \alpha + \beta'x_{it}$ $+ u_i + v_{it}$	c_{it} $= \alpha_i + \beta'x_{it} + u_{it}$ $+ v_{it}$	c_{it} $= \alpha + w_i + \beta'x_{it}$ $+ u_{it} + v_{it}$	c_{it} $= \alpha + w_i + \beta'x_{it}$ $+ \mu_i + u_{it} + v_{it}$
Concessionaire component	None (α)	α_i	$\alpha + w_i$ $w_i \sim N(0, \sigma_w^2)$	$\alpha + w_i$ $w_i \sim N(0, \sigma_w^2)$
Composed error	$\varepsilon_{it} = u_i + v_{it}$ $u_i \sim N^+(0, \sigma_u^2)$ $v_{it} \sim N(0, \sigma_v^2)$	$\varepsilon_{it} = u_{it} + v_{it}$ $u_{it} \sim N^+(0, \sigma_u^2)$ $v_{it} \sim N(0, \sigma_v^2)$	$\varepsilon_{it} = u_{it} + v_{it}$ $u_{it} \sim N^+(0, \sigma_u^2)$ $v_{it} \sim N(0, \sigma_v^2)$	$\varepsilon_{it} = \mu_i + u_{it} + v_{it}$ $\mu_i \sim N^+(0, \sigma_\mu^2)$ $u_{it} \sim N^+(0, \sigma_u^2)$ $v_{it} \sim N(0, \sigma_v^2)$
Efficiency	$E[-u_i \varepsilon_{it}]$	$E[-u_{it} \varepsilon_{it}]$	$E[-u_{it} \varepsilon_{it}]$	Transient $E[-u_i u_i + v_{it}]$ Persistent $E[-\mu_i \mu_i + u_i + v_{it}]$

A derivative from this approach is the possibility it affords of calculating the economies of density and scale. The economies of density are defined as the inverse of the elasticity of costs with respect to output; the relative increase in total costs resulting from an increase in vehicle-kilometers, holding input prices and the network characteristics fixed:

$$ED = \left(\frac{\partial \ln TC}{\partial \ln Y} \right)^{-1} = (\beta_Y)^{-1} \quad (3)$$

Economies of density (ED) imply that the average total costs of a motorway concessionaire fall as vehicle-kilometers increase. These economies exist if ED is greater than one; diseconomies of density are present for values less than one; while values equal

to one indicate that the firm is operating at the optimal level, holding all other factors constant.

Economies of scale (ES) measure the reaction recorded by total costs when the output and the network length increase in the same proportion, holding other network characteristics and input prices fixed:

$$ES = \left(\frac{\partial \ln TC}{\partial \ln Y} + \frac{\partial \ln TC}{\partial \ln LEN} \right)^{-1} = (\beta_Y + \beta_{LEN})^{-1} \quad (4)$$

Thus, economies of scale exist if ES is greater than one, that is, the average total costs of a motorway concessionaire decrease as the vehicle-kilometers and motorway length increase in the same proportion, holding all other parameters constant. Economies of scale exist if ES is equal to one and diseconomies of scale exist if ES is less than one. It is important to assume that any increase in the network length raises the output level in the same proportion (Caves et al., 1984).

3.2. The production function

The production function assumes that each company seeks to maximize output from a given set of inputs. We suppose that motorway output can be described in terms of the production function:

$$Y_{it} = f(L_{it}, K_{it}, N_{it}, t_t) \quad (5)$$

where subscripts $i= 1, 2, \dots, N$ refers to the concessionaire firm and $t= 1, 2, \dots, T$ to the year. The total concessionaire output firm Y is assumed to be a function of inputs, including labor force L , the amount of capital K , the network conditions N and a time trend t_t .

The concessionaire's production objective is to ensure the maximum number of vehicles use the motorway and travel the maximum distance. Obtaining this output requires certain inputs. Capital represents the total investment in the motorway by the concessionaire each year. A large proportion of the total capital invested during the concession is invested in the first few years, but a non-negligible sum also has to be invested by the concessionaire in subsequent years to improve motorway conditions. A second input is the labor required

to carry out maintenance and to operate the toll collection system. Network length is directly related to the construction and maintenance costs and the use of the network is a key element in the scale and density economies of the infrastructure. This means the concessionaire has incentives to attract traffic. By improving motorway quality, the concessionaire can maximize the output given the large fixed and sunk costs associated with motorway construction. Other network condition variables include the number of accidents and the number of customer claims. A time trend is included to capture technical progress. Technical change refers to a change in the production technology associated with improved methods for using existing inputs.

A particular transformation of production function 5 is that of the Cobb-Douglas function, and its stochastic frontier can be described as:

$$\ln Y_{it} = \beta_0 + \beta_L \ln L_{it} + \beta_K \ln K_{it} + \beta_{LON} \ln LEN_{it} + \beta_{ACC} \ln ACC_{it} + \beta_{CLA} \ln CLA_{it} + \beta_T \text{Time_trend}_t - u_{it} + v_{it} \quad (6)$$

with $i = 1, 2, \dots, 32$ and $t = 1988, 1989, \dots, 2015$

where subscripts i and t denote the concessionaire firm and year, respectively. A supposition in the Cobb-Douglas function is that all observations share the same production technology. The composed error term is formed by u_{it} and v_{it} . The random variable v_{it} is the idiosyncratic error component and is assumed to be identically and independently distributed $N(0, \sigma_v^2)$, being either positive or negative. This term is independent of u_{it} , the one-sided non-negative random variable. Different distributional assumptions for u_{it} are made in the different model specifications.

In the production function we only have a technological relation, while in the cost function economic behavior emerges. A production firm is technically inefficient if a higher level of output is technically achievable for the same inputs (output-oriented) or if the observed output level can be produced with fewer inputs (input-oriented). A supposition in this model is that all firms share the same technology production function. This is a plausible assumption for the same country and for the same sector; however, in a cross-country or in a competitive environment comparison it is a much less plausible supposition. In our analysis, we do not discuss allocative efficiency, that is, whether the observed combination of inputs is the best.

Using panel data allows us to disentangle persistent and time-varying inefficiency for firms, and to determine if the firms' effects are fixed parameters or the realizations of a random variable. The same model specifications are used as in the cost function, namely, Pitt and Lee (1981), true fixed and true random effects models (Greene, 2005a and 2005b) and Kumbhakar, Lien and Hardaker (2014).

4. DATA

The Spanish motorway industry forms part of the country's national road network, providing public service infrastructure. The dataset used in this paper is extracted from the annual reports published by the Secretary-General of Infrastructure and Transport at the Spanish Ministry of Transportation. The first year included is 1988, given that in years prior to that date the majority of variables are unavailable. The result is an unbalanced data panel, where the total number of observations through to 2014 is 437. In the initial years, between eight and ten companies are compared, while by the end of the period the number of concessionaires amounts to thirty-one. The dataset includes all of Spain's tolled motorways, with the exception of some of the Basque country's motorways for some years. The Basque *foral* regime (specific fiscal arrangements) means that public firms are under no obligation to report data to the central government. The sample, however, represents 96% of the total motorway observations.

The information available for any given year includes total costs, structural costs, capital costs, vehicle-kilometers, number of employees, motorway lengths, number of accidents and customer claims. The cost function includes one output, two inputs, three network variables and a time trend. The production function includes two inputs and the same cost function variables: three network variables and a time trend.

On the cost function side, the total cost (TC) is the dependent variable and includes labor, maintenance and capital costs.¹⁰ The price of labor and maintenance (PL) is given by the ratio between total salaries and motorway maintenance costs, on the one hand, and the

¹⁰All costs are adjusted for inflation using the Spanish CPI, measured in 2002 euros. Before 2001, financial data have been converted from the former Spanish currency (pesetas) to euros.

total number of full-time equivalent workers, on the other. It is not possible to break these costs down into subcategories (i.e., such as labor or maintenance costs). The price of labor and maintenance should be positive. The price of capital (PC) is obtained by amortizing the costs of all concessionaire investments related to motorway length. This variable divides the other price input and the total costs.

On the output side, the literature considers two main groups: supply- and demand- related measures. Supply measures, such as network length multiplied by the number of lanes, are the most suitable. However, the relative homogeneity of motorways and the absence of available data mean this is not an option available to us. On the demand side, the number of vehicles is a key determinant. However, several concessionaires have more than one motorway, or there can be marked differences on the same motorway in terms of average daily traffic, depending on the measurement point. For this reason, the output (Y) variable opted for is vehicle-kilometers, which accounts for the distance travelled by every vehicle. It should be noted that this demand indicator reflects consumer preferences, above and beyond the objectives of the concessionaire under control. The expected sign is positive, that is, an increase in the number of vehicles and in the distance travelled should result in higher total costs for the concessionaire. However, we call into question whether the addition of more vehicles would result in a stronger relation with total costs.

As for the network characteristics, total motorway length (LEN) captures the network size. We expect a positive relation between motorway length and total costs. One variable of network quality is the number of accidents suffered by the concession (ACC). The concessionaire has incentives to minimize the number of road accidents since they result in emergency costs, traffic jams and a lower user-perceived quality. A second variable of network quality is the number of customer complaints received by the concession (CLA) over the years, the majority of customer claims are related to traffic congestion, the toll system, road signs, and the toll tariff, among others. We expect a positive sign for both quality indicators; that is, total costs should increase if the number of accidents increases or the quality of the motorway service is poor.

The time trend should capture technological progress. Here, we would expect a negative sign because, although this sector is not characterized by significant changes in production technology, after several years a certain technical progress can be expected.

On the production function side, the dependent variable is vehicle-kilometers. The concessionaire minimizes inputs in order to achieve maximum output. We consider the total number of full-time equivalent workers as labor input (L) and motorway investment as capital (K), adjusted using the Spanish CPI. The network characteristics – the motorway length (LEN), number of accidents with victims (ACC), and the number of customer complaints (CLA) – and the time trend are as defined in the cost function.

Table 2 reports summary statistics for the concessionaires. Information for total costs, inputs, vehicle-kilometers, network length, number of road accident victims, and the number of claims includes the mean, standard deviation, and first and third quartiles. Two large concessionaires (ACESA and AUMAR) can be characterized as outliers (there being a close coincidence between their mean and third quartile values).

Table 2: Summary statistics

Variables	Mean	Standard deviation	1 st quartile	3 rd quartile
Total costs (€)	28.5·10 ⁶	37.4·10 ⁶	8·10 ⁶	30·10 ⁶
Number of workers	206.35	271.35	69.5	220
Capital invested (€)	596·10 ⁹	591·10 ⁹	229·10 ⁹	832·10 ⁹
Vehicle-kilometers (km)	846·10 ⁶	1440·10 ⁶	121·10 ⁶	805·10 ⁶
Length (km)	124.89	138.68	43.1	112.6
Number of accidents with victims	77.06	130.37	6	83
Customer complaints 100 million veh-km	26.24	63.32	4.67	19.16

Note: All monetary values are in 2002 euros

5. RESULTS

5.1. Cost function results

The regression results of the model specified in Eq. 6 are presented in Table 3. Since all variables are expressed in logarithms and normalized on the mean, the coefficients can be interpreted as elasticities. The original values of the monetary variables are deflated by a price index.

Table 3: Stochastic estimates of total cost function parameter

Variables	Pitt and Lee (1981)		True Fixed Effects		True Random Effects		Kumbhakar, Lien and Hartaker (2014)	
	Coefficients	Standard error	Coefficients	Standard error	Coefficients	Standard error	Coefficients	Standard error
β_{PL}	0.575***	(0.0082)	0.458***	(0.0120)	0.454***	(0.0113)	0.566***	(0.0086)
β_Y	0.145***	(0.0419)	0.206***	(0.0291)	0.215***	(0.0186)	0.195***	(0.0359)
β_{LEN}	0.486***	(0.0461)	0.464***	(0.0821)	0.516***	(0.0170)	0.502***	(0.0360)
β_{ACC}	0.0142	(0.0201)	-0.003	(0.0127)	-0.003	(0.0108)	0.011	(0.0209)
β_{CLA}	0.046**	(0.0206)	0.0141	(0.0116)	0.0141*	(0.0074)	0.038**	(0.0184)
β_T	-0.002	(0.0014)	-0.006***	(0.0007)	-0.006***	(0.0007)	-0.004***	(0.0013)
Constant	-0.424***	(0.0476)			-0.086***	(0.00996)	-0.0001***	(0.0347)
σ_u	0.440***	(0.0707)	0.106***	(0.0074)	0.107***	(0.0071)	0.389***	(0.0851)
σ_v	0.119***	(0.0042)	0.0246***	(0.0050)	0.0288***	(0.0097)	0.125***	(0.0061)
$\lambda = \sigma_u^2 / \sigma_v^2$	3.698***	(0.0704)	4.316***	(0.0112)	3.707***	(0.0084)	3.112***	(0.0351)
Log likelihood	248.3		455.1		373.7			
Observations	437		437		437		437	

Significance levels: * 10 per cent; ** 5 per cent; *** 1 per cent

The main variables present the expected sign and are statistically significant. Output is significant and positive, in line with microeconomic theory. A 1% increase in vehicle-kilometers means total costs increase by between 0.15 and 0.22%, depending on the specification. This range is in the low band, but is quite logical given the cost structure of this sector (costs for an extra car tend to be marginal). The labor and maintenance input price is between 0.45 and 0.58, while the labor and maintenance costs account for between 45 and 58% of total costs.

Motorway length is a significant and positive network parameter that impacts on the concessionaires' total costs – a one percent increase in total motorway length increases total costs by between 0.46 and 0.52%. This is also an expected outcome in the network industry, as total costs are more important if the network length is increased than if the total distance travelled by motorway users rises. The marginal effect on total costs of an extra vehicle per distance travelled is between two and five times less than extending the motorway by the same proportion. The number of accidents with victims is non-significant in all models, indicating that the number of total accidents does not affect total motorway costs. However, the remaining network characteristic, the number of claims, has a positive sign and is significant in some specifications. If the number of claims increases by one percent, total costs increase by around 0.01 and 0.05%, probably as a result of the additional expenditure that has to be borne by the concessionaire in responding to these claims.

The time trend is negative in all models except in that of Pitt and Lee (1981), where it is non-significant. In the TFE and TRE models, there is a 0.6% decrease in total costs every year, while the Kumbhakar et al. (2014) model estimates a 0.4% decrease in total costs each year. This result is in line with that reported by Benfratello et al. (2009). In common with these authors, this can reasonably be accounted for in terms of the introduction of automatic toll systems, which reduce labor costs, and by the increase in management experience obtained over time. However, given the relatively small values of the coefficients, they do not represent structural industry changes.

Table 4. Scale and density economies

Variables	Pitt and Lee (1981)	True Fixed Effects	True Random Effects	Kumbhakar, Lien and Hartaker (2014)
Economies of density	6.887	4.844	4.642	5.120
Economies of scale	1.585	1.493	1.367	1.435

Table 4 shows that both economies of density and scale are found, which points to unexploited economies. The values, however, are higher for economies of density, indicating that an increase in the number of vehicles has greater effects than extending the motorway network. In other words, a more intensive use of a given motorway would lower the average cost considerably more than by extending it. However, recall that increasing the number of vehicle-kilometers is usually beyond the capabilities of the concessionaires. The variation across the parameters of economies of density can be attributed to the unobserved network effects, which are partially correlated with output and motorway length.

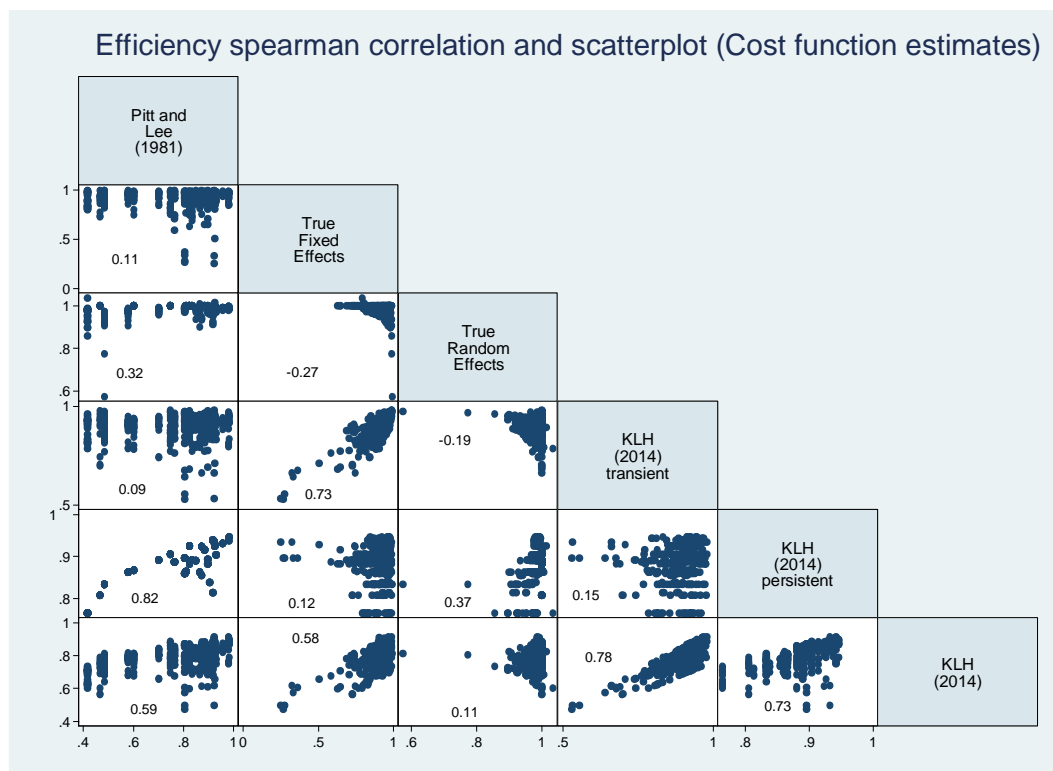
One of the reasons for estimating a stochastic cost frontier is to obtain the inefficiency parameters. The parameter λ indicates the ratio of the inefficiency terms to the random noise term. The value of u_{it} has to be positive in order to calculate the inefficiency term. Likewise, if λ is statistically significant, there is evidence of “cost” inefficiency in the data. For all models, this parameter is highly significant and positive. Table 5 presents the descriptive statistics of the inefficiency estimates obtained from the different models. This inefficiency is calculated as the excess operational costs of a given concessionaire in relation to those of the optimal concessionaire. In general, most of the higher inefficiency values are obtained with the Pitt and Lee (1981) model, while the lowest values are obtained with the TRE model, which is in line with results published elsewhere (Farsi et al., 2006). In the Pitt and Lee model, the unobserved firm-specific differences are interpreted as inefficiency, which suggests higher overestimated inefficiency values. The TRE model separates the stochastic inefficiency term from the firm-specific

heterogeneity, adding a firm-specific term that captures this inefficiency. The TFE model provides the same interpretation as that of the TRE model, while the inefficiency value obtained lies between that of the Pitt and Lee and the TRE models. The residual or transient inefficiency is captured by the TRE and TFE models, transient inefficiency by the Kumbhakar et al. (2014) model, allocative efficiency by the Pitt and Lee model and the persistent part by the Kumbhakar et al. (2014) model. The inefficiency within the transient and persistent specifications are correlated, while between both groups there is no correlation. The only discordant point is provided by the TRE model, which shows no relation with the other transient efficiency estimations.

Table 5: Cost efficiency measures

Model	Mean	Standard Deviation	Minimum	Maximum
Pitt and Lee (1981)	.7815	.15937	.41623	.9797
True Fixed Effects	.9079	.10156	.2499	.9940
True Random Effects	.9821	.03235	.5736	1.036
KLH (2014) transient	.8944	.06365	.5291	.9797
KLH (2014) persistent	.8836	.04200	.7646	.9460
KLH (2014)	.7905	.07284	.4739	.9118

Figure 1. Cost efficiency indicators: correlation and scatterplot



5.2. Production function results

The stochastic production function estimators are shown in Table 6.

Table 6: Stochastic estimates of production function parameter

	Pitt and Lee (1981)		True Fixed Effects		True Random Effects		Kumbhakar, Lien and Hartaker (2014)	
	Coefficients	Standard error	Coefficients	Standard error	Coefficients	Standard error	Coefficients	Standard error
β_{LAB}	0.359***	(0.0389)	0.416***	(0.0011)	0.437***	(0.0308)	0.401***	(0.0378)
β_K	-0.035**	(0.0153)	-0.053***	(0.0001)	-0.058**	(0.0185)	-0.032**	(0.0220)
β_{LEN}	0.395***	(0.045)	0.442***	(0.0008)	0.434***	(0.0515)	0.339***	(0.0558)
β_{ACC}	0.087***	(0.022)	0.031**	(0.0004)	0.064***	(0.0185)	0.103***	(0.0220)
β_{CLA}	-0.259***	(0.0185)	-0.093***	(0.0002)	-0.172***	(0.0259)	-0.257***	(0.0180)
β_T	0.016***	(0.0013)	0.013***	(0.0001)	0.015***	(0.0015)	0.016***	(0.0013)
Constant	0.236***	(0.0460)			-0.136***	(0.0374)	-0.258***	(0.0507)
σ_u	0.590***	(0.0795)	0.162***	(0.0094)	0.111***	(0.0095)	0.512***	(0.0001)
σ_v	0.129***	(0.0045)	$3 \cdot 10^{-8}$	(0.0064)	0.069***	(0.0067)	0.108***	(0.0131)
$\lambda = \sigma_u^2 / \sigma_v^2$	4.557***	(0.0805)	4784435***	(0.0776)	1.622***	(0.0164)	3.038***	(...)
Log likelihood	205.3		357.1		235.3			
Observations	436		436		436		436	

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The two main inputs in our production function are labor and capital. The number of workers is positive and significant; that is, an increase in labor affects vehicle-kilometers. A 1% increase in labor implies a 0.36 to 0.44% increase in vehicle-kilometers. In contrast, the amount of capital invested is negative and significant for all specifications. This result,

at first sight counterintuitive, implies that an increase in the stock of capital is related to less motorway use. This result is examined below in the policy section to explain the current financial problems faced by many toll motorway concessionaires today.

Motorway length has a positive and significant effect on output. Logically, an increase in total length means that more vehicles travel on the network and/or they drive longer distances. Here, there are notable variations across specifications (ranging from 0.34 to 0.44).

Two motorway concession quality variables are included in the analysis. The number of accidents with victims is positively related to output; that is, a higher volume of traffic on a motorway is related to an increase in the accident rate. However, the number of customer complaints negatively affects concessionaire output. Drivers' perception is that of poorer motorway quality and so use it less, while a higher number of accidents is unrelated to a reduction in traffic volume. Motorway users seem to have little awareness of accidents, but if the toll system underperforms or motorway maintenance is poor, they opt to use the infrastructure less. The magnitude of the coefficients differs for both quality variables, indicating that a 1% increase in the number of complaints results in a larger output reduction than the corresponding increase due to a 1% rise in the number of accidents with victims. The time trend is positive and significant across all specifications, there having been an advance in technology of around 1.3-1.6% per year between 1988 and 2015. Note that the rate of motorization (number of vehicles/1000 pop.) doubled between 1990 and 2014 with an average annual growth rate of 2.9%.

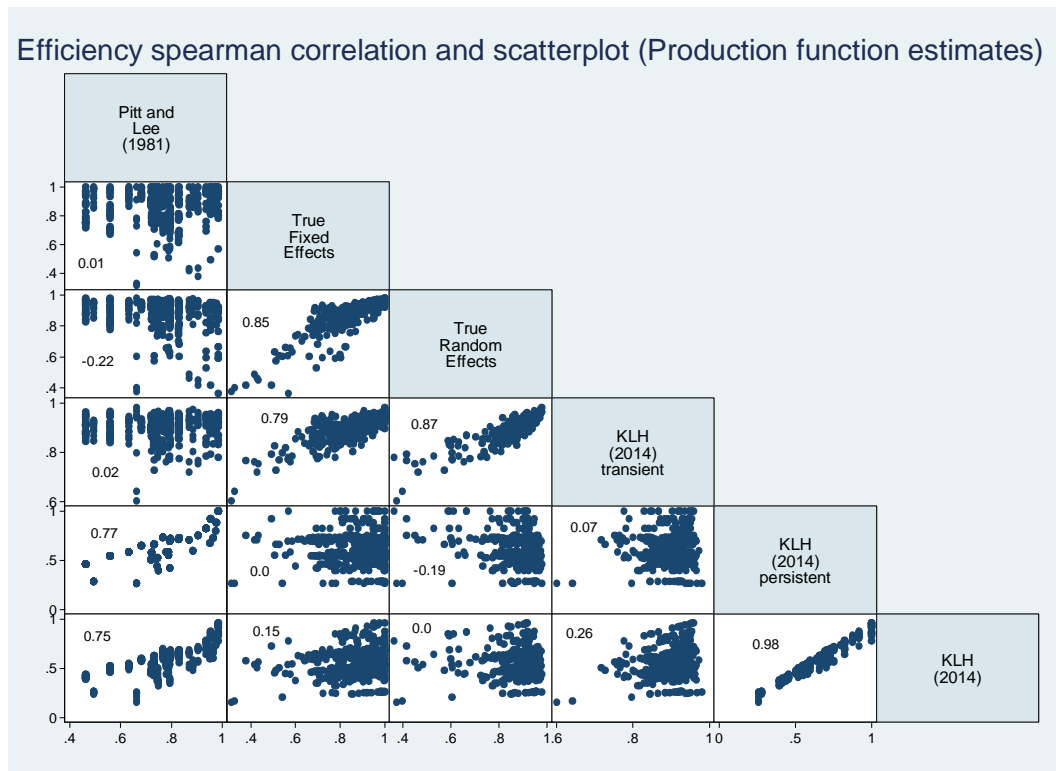
Table 7. Production efficiency measures

Model	Mean	Standard Deviation	Minimum	Maximum
Pitt and Lee (1981)	.7660	.13536	.4623	.9836
True Fixed Effects	.8606	.12113	.3159	.9999
True Random Effects	.8801	.10105	.3642	.9770
KLH (2014) transient	.9008	.04854	.6011	.9805
KLH (2014) persistent	.6259	.16035	.2617	1
KLH (2014)	.5644	.1490	.1573	.9598

In the case of the efficiency estimators, the TFE, TRE and the Kumbhakar et al. (2014) transient efficiency estimates show higher values than those reported for the cost function (Table 7). As expected, there is a low correlation between the persistent and transient efficiency specifications (Figure 2). However, the Pitt and Lee (1981) and the Kumbhakar

et al. (2014) persistent estimates show a clear correlation, as do the models that estimate transient efficiency, with Spearman correlations ranging between 0.79 and 0.87. Thus, within groups there is a strong correlation, and the TRE model performs well in comparison with the cost specification reported above. This result indicates that part of the inefficiency is due to input allocations that are not easily change, such as the capital stock.

Figure 2. Production efficiency indicators correlation and scatterplot



The different results obtained with regard to transient and persistent efficiency, both in the case of the production and cost frontiers, need to be tested to determine the respective impacts of regulation and ownership in the motorway sector.

6. EMPIRICAL APPLICATIONS

The inefficiency estimation allows us to test whether or not there are differences in the inefficiency values related to the characteristics of the various motorway concessionaires. To do so we adopt as our statistical tool the Kruskal-Wallis test. This is a rank-based nonparametric that can be used to determine if there are statistically significant differences between two or more groups of a variable. The efficiency measure is an ordinal variable; therefore, we can test whether the probability of a random observation

from each group is equally likely to be above or below a random observation from another group. Unlike the ANOVA test of equality of means, the Kruskal-Wallis can be seen as a comparison of the mean ranks. However, the Kruskal-Wallis test does not provide the mean differences, which means a second test, such as the ANOVA test, is needed to confirm the mean value differences. As post hoc tests are run to confirm where the differences occurred between groups, they should only be run when there is an overall significant difference in group means.

6.1. Regulatory reforms

Although initial toll prices depend on each specific concession contract and the winning bid,¹¹ any price update is determined by a common regulatory framework for all concessions. Before 2001, national legislation introduced a general rule providing for automatic, yearly price adjustments based on inflation, a widely employed regulation in this industry (Iossa, 2015). As Bel and Fageda (2005) report, prices increased at a rate of 95% of the retail price index (RPI). However, this regulation was reformed in 2001 with a shift from the inflation link to a more sophisticated price cap regulation (RPI-X). This more complex, detailed price regulation was introduced when the presence of private toll motorways increased due to new concession awards and the plan to privatize the National Motorway Company (Albalade, Bel and Fageda, 2009). Even though a price cap formula was introduced, the typical X factor, which is commonly attributed to the target of efficiency gains (Bernstein and Sappington, 1999; Sappington, 2002), was simply the deviation between the expected and real traffic received by each concession. The predicted traffic volume was included in the economic and financial plan for the concession, as approved by the government (Albalade, Bel and Fageda, 2009). However, different bounding rules within the industry remained, leaving old concessions less constrained (Bel and Fageda, 2005). Thus, the new regulatory framework combined inflation and traffic deviations to update tolls.

To analyze the impact of the regulation, we create a dummy variable that takes a value of one for years after 2001, and 0 otherwise. In order to capture the regulatory impact more

¹¹ Note that the typical bidding process is based on a minimum price auction, in which for given technical standards and a fixed length of concession, the firm making the lowest toll bid obtains the concession.

accurately, we restrict the sample to the period 1998 through 2003. Although a price cap regulation affecting public utilities is usually expected to provide efficiency gains with respect to other forms of price regulation, the specific design of the X factor in the Spanish motorway industry might not necessarily provide incentives to improve productivity. According to the categories of tariff adjustment regulation of Iossa (2015), this regulation lies somewhere between the price cap regulation and the banded rate regulation, because tariffs are updated to take into account earning and risk sharing objectives due to traffic fluctuations, which are partly exogenous and beyond the control of the concessionaire.

Table 8 summarizes mean concessionaire efficiency for both groups and the mean difference results from the Kruskal-Wallis test. In the case of the transient efficiency models, introducing the price cap scheme results in a better concessionaire performance, with the exception of two production specifications. The mean difference test shows that for four of the specifications there is a statistically better performance as a result of the introduction of the price cap introduction, whereas in two specifications there are no differences between the groups.¹² The price cap scheme seems to have a much more marked effect on technical efficiency on the production side than it does on the cost side (all technical efficiencies on the production frontiers are statistically different while only one out of three are on the cost frontiers).

Thus, even if the X factor of the price cap regulation does not identify a productivity target, its composition provides better incentives than inflation adjustments. Under an adjustment system based on inflation, concessionaires are fully protected from input price increases, while under price cap regulation their protection diminishes by the correction produced by the deviations between actual and predicted demand. Thus, concessionaires have more incentives to contain input costs. The evidence provided in Table 8 seems to support this hypothesis. On the production side, note that the price cap regulation produces lower toll increases in concessions that have received higher actual traffic with respect to forecasts, in order to limit monopoly profits and transfer risk to road users. However, as prices increase less than they do in other concessions that may set higher

¹² The analysis was also conducted for the whole sample (1988-2014) and the difference between the price-cap years and those prior to them are statistically significant at the 1% level on all four specifications, while the other two non-significant efficiency difference groups are maintained

prices because their actual traffic is similar or closer to forecasts, traffic – the outcome variable – may still increase more in the former concessionaires that apply stricter toll increases due to the negative price elasticity of demand.¹³

Table 8. Mean efficiency and Kruskal-Wallis test on price cap scheme

	Prod TFE	Eff TFE	Cost TFE	Eff TRE	Prod TRE	Eff TRE	Cost TRE	Eff residual	Prod residual	Eff residual	KLH residual	Cost residual	Eff residual	KLH residual
Mean efficiency D _{pricecap=0} (n=23)	0.8363	0.8625	0.8625	0.8689	0.9867	0.9867	0.9867	0.8986	0.8986	0.8986	0.8778	0.8778	0.8778	0.8778
Mean efficiency D _{pricecap=1} (n=70)	0.8970	0.9003	0.9003	0.9067	0.9841	0.9841	0.9841	0.9153	0.9153	0.9153	0.9003	0.9003	0.9003	0.9003
χ^2_1 -value	6.229	5.797	5.797	3.824	0.102	0.102	0.102	3.968	3.968	3.968	2.635	2.635	2.635	2.635
p-value	0.0126	0.0161	0.0161	0.0505	0.7491	0.7491	0.7491	0.0464	0.0464	0.0464	0.1046	0.1046	0.1046	0.1046

6.2. Central vs. regional granting authorities.

A further characteristic of the Spanish motorway industry is that it reflects the political decentralization of the State, so that we find that both central and regional authorities have awarded toll motorway concessions. Although toll motorway regulation falls under national legislation enacted by the Spanish Parliament (*Congreso de los Diputados*) – and as a result there are no major differences in this respect, regional authorities can allocate resources, decide which projects are to be awarded, design the motorway technical project and specify the features of the concession contracts. Thus, efficiency differences may arise from the scope granted to the regional authorities by national legislation. Because we can differentiate as to whether the motorway is promoted (or the concession contract is awarded) by the central government or not, we decided to test the efficiency implications of this.

¹³ Matas and Raymond (2003) evaluate the price elasticity of toll motorway concessionaires in Spain finding a short-run elasticity of -0.3 and a long-run elasticity of -0.5.

We create a dummy variable that takes a value of 1 if the motorway is promoted/granted by the central government authority and 0 otherwise. In our case, motorways not granted by the central government can only have been promoted by regional governments.¹⁴

Table 9 shows the mean efficiency by group and the Kruskal-Wallis values for the persistent efficiency estimation. We found empirical evidence that motorways promoted by regional authorities are more efficient than those promoted by the central authority in three specifications, whereas we find no statistical differences for persistent efficiency in the production function in the Kumbhakar et al. (2014) specification. However, when performing the same analysis for models in which inefficiency does not absorb unobserved heterogeneity (TRE, TFE and KLH residual), we obtain non-statistical differences between groups for the six specifications. This result seems to support the argument that lower tiers of government allocate resources for motorways better, probably due to a better selection of projects and the avoidance of white elephants. Indeed, the current financial crisis in the industry in Spain only affects motorways awarded by the central government and, according to Albalade et al. (2015), their main problems are linked to project selection issues: route choices, overcapacity and above all, low actual demand. All these elements have resulted in large gaps between capacity and demand, generating financial stress. This trend is easily identifiable in the descriptive statistics for our sample. Although regional motorways are more expensive per km, their revenues per km double those awarded by central government. Motorway concessionaires appointed by regional authorities have invested an average of 8.36 million euros per km, while those appointed by the central government have invested just 6.82 million euros per km. This difference (22.6%) can be attributed to the worse land conditions and geological difficulties that regional motorways faced in their construction phase. Moreover, regional motorways receive higher volumes of road users recording an average of 0.898 million per km, whereas the central government motorway concessionaires receive an average of just 0.416.

In contrast, there is no empirical evidence of different management performance on these motorways as regards residual efficiency. Thus, regional authorities do not seem to select

¹⁴ We include as regional governments the *Diputaciones*, the public administration operating at the province level. This tier of administration lies between local and regional governments.

better managers (private concessionaires or themselves) nor do they appear to provide better management incentives than those provided by the central authority.

Table 9. Mean efficiency and Kruskal-Wallis test on motorway granting authority

	<i>Prod Eff Pitt and Lee</i>	<i>Cost Eff Pitt and Lee</i>	<i>Prod Eff KLH persistent</i>	<i>Cost Eff KLH persistent</i>
<i>Mean efficiency D_{central}=0 (n=206)</i>	0.7999	0.8504	0.6132	0.8930
<i>Mean efficiency D_{central}=1 (n=328)</i>	0.7466	0.7421	0.6308	0.8798
<i>χ₁²-value</i>	17.031	26.190	0.009	2.852
<i>p-value</i>	0.0001	0.0001	0.9243	0.0913

6.3. Ownership models

Although the motorway industry in Spain is based primarily on private participation, there is some public participation in some of the concessionaires. The impact that public entities have as shareholders on efficiency can be tested in the same way as above. Thus, we create a dummy variable that takes a value of 1 if there is public participation in a concessionaire in a specific year, and 0 otherwise. In the case of the transient efficiency estimations, five of the six tests show no statistical differences. The one exception is in the case of the cost efficiency estimations using the TRE model, where private concessionaires are estimated to be more efficient.¹⁵ Given that the residual efficiency results are not clear, we decided to examine the ownership issue in greater depth by creating different variables.

Table 10 summarizes all the Kruskal-Wallis results from the transient specifications for the different ownership dummy groups. In the first group, public participation is divided between central and regional governments. Restricting the sample concessions to those

¹⁵ Persistent inefficiency models are time invariant, which means that changes in the public/private composition of shareholders cannot be absorbed in the efficiency variations.

with public participation, we then create a dummy variable that takes a value of 1 if participation is regional and 0 otherwise (central government). The results for the six specifications indicate that regional governments are more efficient than the central government when they are concessionaire shareholders. In the next group, we compare private ownership vs. central government ownership, omitting regional government participation. For all specifications, except that of cost efficiency in the TRE model, the performance of central government is less efficient than that of private-owned firms. In short, firms owned by central government underperform in comparison with all other concessionaire types.

We also compared regional and private companies, omitting concessionaires with a central government participation. In four of the specifications, there are no statistically significant differences between regional and private firms. However, in the case of production efficiency with the TFE model and in that of cost efficiency with the TRE model, there is statistical evidence indicating that regional government participation is more efficient than that of fully private concessionaires. Given these overall results, we need to be cautious in drawing any conclusions and would suggest that there is no difference in their respective performances. This result is confirmed when we create two groups from the whole sample: regional government shareholders, on the one hand, and private and central government shareholders, on the other. We create a dummy variable that takes a value of 1 if a regional government participates as a shareholder in the concessionaire, and 0 otherwise. The results for transient efficiency show non-statistical differences between regional shareholders in management vs central government/private concessionaires. The only discordant result is that of cost efficiency in the TRE model, where regional level participation implies a better managerial performance.¹⁶ These results indicate that the management of concessions by regional governments is on a par with that of private concessionaires.

To sum up, public ownership participation does not result in better management efficiency than that provided by private concessionaires. However, regional governments perform better than central government, but at the same level as that of private

¹⁶ Recall the TRE model tends to give discordant efficiency estimations.

concessionaires. In short, central government capital participation seems to be associated with the relatively inefficient ownership model.

6.4 Privatization

Having tested the role played by public ownership, we turn our attention to the privatization process. Some concessionaires were nationalized in 1984 by the central government (i.e., Audasa, Aucalsa, Audenasa and Austroestradas) only to be fully or partially privatized again by public auction in 2003. This means we are able to test whether the ownership models present any differences in terms of their efficiency. In order to analyze the impact of privatization on management efficiency, we performed a Kruskal-Wallis test on the concessions that had been privatized. We create a dummy that takes a value of 1 if at least 50% of shares are under public ownership and 0 otherwise. For all model specifications, the mean level of motorway efficiency under full or partial public ownership is lower than that under private ownership (Table 11). A Kruskal-Wallis test suggests a rejection of the null hypothesis of both sub-samples having an equal mean efficiency level, except that of the Kumbhakar et al. (2014) specification for residual efficiency. As for the specific impact of privatization on efficiency, Figure 3 shows the evolution of residual efficiency of the privatized concessionaires. After 2003, there is some evidence that efficiency increased in Audasa and Aucalsa. Nonetheless, the evolution is not clear in the case of Audenasa, whereas in Autoestradas inefficiency increased after privatization. Generally, private ownership and management seem to improve management efficiency in Spain, whereas if we perform the same analysis for persistent efficiency specifications, there are no statistical differences between groups.¹⁷ In the case of the short-term impacts of privatization, we find mixed results. This seems to indicate that the specific features of each concession may be relevant in terms of whether we might expect (or otherwise) short-term efficiency gains from privatization.

¹⁷We also performed the Kruskal-Wallis for all observations (not just the privatized concessions) and the results are mostly maintained for both inefficiency measures.

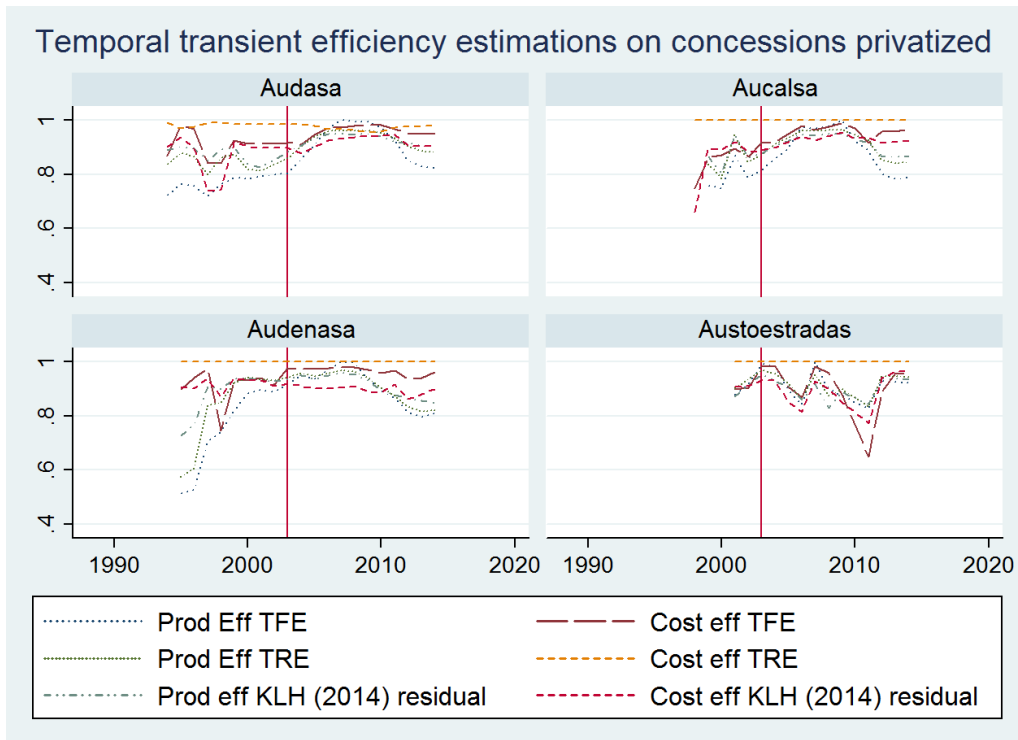
Table 10. Mean efficiency and Kruskal-Wallis test on different ownership

Dummy Ownership comparison	Descriptive statistics	Prod Eff TFE	Cost Eff TFE	Prod Eff TRE	Cost Eff TRE	Prod Eff KLH residual	Cost Eff KLH residual
Regional vs. Central	<i>Mean efficiency</i> $D_{regcentral=0}$ (n=28)	0.7733	0.8845	0.8210	0.9818	0.8736	0.8639
	<i>Mean efficiency</i> $D_{regionalcentral=1}$ (n=55)	0.8844	0.9156	0.8793	0.9915	0.9023	0.9018
	χ^2 -value	11.024	3.175	3.533	2.783	4.355	2.906
	<i>p-value</i>	0.0009	0.0748	0.0602	0.0953	0.0369	0.0882
Private vs. Central	<i>Mean efficiency</i> $D_{privcentral=0}$ (n=28)	0.7733	0.8845	0.8848	0.9803	0.9026	0.8953
	<i>Mean efficiency</i> $D_{privcentral=1}$ (n=354)	0.8636	0.9086	0.8210	0.9818	0.8736	0.8684
	χ^2 -value	8.220	4.782	4.701	2.542	5.503	4.079
	<i>p-value</i>	0.0041	0.0288	0.0301	0.1094	0.0190	0.0434
Regional vs. Private	<i>Mean efficiency</i> $D_{regpriv=0}$ (n=354)	0.8636	0.9086	0.8847	0.9803	0.9026	0.8953
	<i>Mean efficiency</i> $D_{regpriv=1}$ (n=47)	0.9079	0.9166	0.8885	0.9900	0.9062	0.8993
	χ^2 -value	4.732	1.195	0.051	16.570	0.251	0.737
	<i>p-value</i>	0.0296	0.2744	0.8220	0.0001	0.6164	0.3906
Regional vs. Central and Private	<i>Mean efficiency</i> $D_{regcentralpriv=0}$ (n=381)	0.8572	0.9068	0.8802	0.9805	0.9006	0.8933
	<i>Mean efficiency</i> $D_{regcentralpriv=1}$ (n=55)	0.8844	0.9156	0.8793	0.9915	0.9023	0.9018
	χ^2 -value	2.162	0.822	0.0	24.306	0.333	0.073
	<i>p-value</i>	0.1415	0.3646	0.9937	0.0001	0.5636	0.7866

Table 11. Mean efficiency and Kruskal-Wallis test on privatized concessions

	Prod TFE	Eff TFE	Cost TFE	Eff TRE	Prod TRE	Eff TRE	Cost TRE	Eff residual	Prod KLH residual	Eff KLH residual	Cost KLH residual
Mean efficiency $D_{\text{privatized}=0}$ (n=23)	0.7734	0.8942	0.8454	0.9928	0.8766	0.8842					
Mean efficiency $D_{\text{privatized}=1}$ (n=70)	0.9056	0.9476	0.9170	0.9945	0.9131	0.9093					
χ^2_1 -value	15.755	5.543	7.243	11.920	5.750	0.674					
p-value	0.0001	0.0186	0.0071	0.0005	0.0165	0.4117					

Figure 3. Transient efficiency estimations of privatized concessions



7. CONCLUDING REMARKS

This paper builds an empirical model, applying the framework provided by stochastic frontier analysis, in an effort to study the technical and cost efficiencies of Spanish toll motorway concessionaires. The models proposed are production and cost stochastic frontiers, which complement each other in terms of their parameter estimations and efficiency analyses. The presence of structural problems in the production process of this sector in Spain points to the need to undertake separate efficiency estimations. To this end, we estimate persistent and transient efficiency using the Pitt and Lee (1981), the true fixed effects, the true random effects and the Kumbhakar, Lien and Hardaker (2014) models. The estimates are conducted on panel data for the years 1988 to 2014, controlling for different network characteristics. The main findings of the paper can be summarized as:

- Cost function estimates for the motorway industry show significant technical progress has been made in the order of 0.3-0.6% per year.
- The presence of unexploited economies of scale and density, with the latter being much larger. Increasing the number of vehicles has a more marked effect than extending the Spanish motorway network. The fragmentation of the Spanish network, operated as it is by many concessionaires, has hindered the potential of network effects and, hence, the exploitation of economies of scale and density. The current financial crisis suffered by the industry in Spain could lead to the merger of various concessionaires, which could favor the further exploitation of economies of scale and density.
- On the production function side, a slightly negative relation is found between capital stock and vehicles. This may account for the overinvestment in the sector that has placed the industry under considerable financial stress.
- The efficiency estimations show no relation between transient and persistent efficiency. This highlights the importance of estimating both for policy purposes and for recommendations. Transient efficiency is greater than persistent efficiency because of the non-competitive environment of motorways and the allocation of inputs.

- The price cap regulation introduced in 2001 increased the transient efficiency of the production function, while on the cost side no significant difference in performance was recorded.
- Lower tiers of government (regional) in their role as granting authorities seem to allocate resources for motorways better. This probably reflects their ability to select viable projects and to avoid white elephants. Better persistent efficiency levels are found in the case of concessionaires appointed by regional authorities; however, on the management efficiency side no significant differences are found across the tiers of government. Note that all the concessionaires presenting signs of financial stress were appointed by the central government.
- No differences are found between public and private ownership models, except in the case of central government participation. This resulted in greater inefficiency than in the case of regional participation and full private ownership.
- Most motorway concessionaires that have been privatized increased their transient efficiency after privatization, lending some limited support to efficiency gains achieved through privatization in the short run. However, this finding needs to be treated with caution given the small sample considered.

All in all, therefore, this paper demonstrates the power of production and cost stochastic frontier panel data techniques as a tool not only for measuring efficiency but also for evaluating public policies in terms of their efficiency outcomes. Besides this, our main results on regulatory and ownership reforms provide highly pertinent insights for those implementing transport policy. It is our firm belief that the methodology employed here offers great potential to regulators and policy evaluation bodies working in the field of transportation. Although few studies of this kind, in which two types of efficiency are measured, have been reported to date, we expect to see considerably more in the future given their huge potential for refining the analysis and evaluation of public policy efficiency.

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Albalate, D. (PPRE-IREA); Fernández-Villadangos, L. (PPRE-IREA)

“Exploring Determinants of Urban Motorcycle Accident Severity: The Case of Barcelona”
(Març 2009)

XREAP2009-03

Borrell, J. R. (PPRE-IREA); Fernández-Villadangos, L. (PPRE-IREA)

“Assessing excess profits from different entry regulations”
(Abril 2009)

XREAP2009-04

Sanromá, E. (IEB); Ramos, R. (AQR-IREA), Simon, H.

“Los salarios de los inmigrantes en el mercado de trabajo español. ¿Importa el origen del capital humano?”
(Abril 2009)

XREAP2009-05

Jiménez, J. L.; Perdiguero, J. (PPRE-IREA)

“(No)competition in the Spanish retailing gasoline market: a variance filter approach”
(Maig 2009)

XREAP2009-06

Álvarez-Albelo, C. D. (CREB), Manresa, A. (CREB), Pigem-Vigo, M. (CREB)

“International trade as the sole engine of growth for an economy”
(Juny 2009)

XREAP2009-07

Callejón, M. (PPRE-IREA), Ortún V, M.

“The Black Box of Business Dynamics”
(Setembre 2009)

XREAP2009-08

Lucena, A. (CREB)

“The antecedents and innovation consequences of organizational search: empirical evidence for Spain”
(Octubre 2009)



XREAP2009-09

Domènech Campmajó, L. (PPRE-IREA)

“Competition between TV Platforms”

(Octubre 2009)

XREAP2009-10

Solé-Auró, A. (RFA-IREA), **Guillén, M.** (RFA-IREA), **Crimmins, E. M.**

“Health care utilization among immigrants and native-born populations in 11 European countries. Results from the Survey of Health, Ageing and Retirement in Europe”

(Octubre 2009)

XREAP2009-11

Segarra, A. (GRIT), **Teruel, M.** (GRIT)

“Small firms, growth and financial constraints”

(Octubre 2009)

XREAP2009-12

Matas, A. (GEAP), **Raymond, J.Ll.** (GEAP), **Ruiz, A.** (GEAP)

“Traffic forecasts under uncertainty and capacity constraints”

(Novembre 2009)

XREAP2009-13

Sole-Ollé, A. (IEB)

“Inter-regional redistribution through infrastructure investment: tactical or programmatic?”

(Novembre 2009)

XREAP2009-14

Del Barrio-Castro, T., **García-Quevedo, J.** (IEB)

“The determinants of university patenting: Do incentives matter?”

(Novembre 2009)

XREAP2009-15

Ramos, R. (AQR-IREA), **Suriñach, J.** (AQR-IREA), **Artís, M.** (AQR-IREA)

“Human capital spillovers, productivity and regional convergence in Spain”

(Novembre 2009)

XREAP2009-16

Álvarez-Albelo, C. D. (CREB), **Hernández-Martín, R.**

“The commons and anti-commons problems in the tourism economy”

(Desembre 2009)

2010

XREAP2010-01

García-López, M. A. (GEAP)

“The Accessibility City. When Transport Infrastructure Matters in Urban Spatial Structure”

(Febrer 2010)

XREAP2010-02

García-Quevedo, J. (IEB), **Mas-Verdú, F.** (IEB), **Polo-Otero, J.** (IEB)

“Which firms want PhDs? The effect of the university-industry relationship on the PhD labour market”

(Març 2010)

XREAP2010-03

Pitt, D., **Guillén, M.** (RFA-IREA)

“An introduction to parametric and non-parametric models for bivariate positive insurance claim severity distributions”

(Març 2010)

XREAP2010-04

Bermúdez, Ll. (RFA-IREA), **Karlis, D.**

“Modelling dependence in a ratemaking procedure with multivariate Poisson regression models”

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XREAP2010-05

Di Paolo, A. (IEB)

“Parental education and family characteristics: educational opportunities across cohorts in Italy and Spain”

(Maig 2010)



XREAP2010-06

Simón, H. (IEB), **Ramos, R.** (AQR-IREA), **Sanromá, E.** (IEB)

“Movilidad ocupacional de los inmigrantes en una economía de bajas cualificaciones. El caso de España”
(Juny 2010)

XREAP2010-07

Di Paolo, A. (GEAP & IEB), **Raymond, J. Ll.** (GEAP & IEB)

“Language knowledge and earnings in Catalonia”
(Juliol 2010)

XREAP2010-08

Bolancé, C. (RFA-IREA), **Alemany, R.** (RFA-IREA), **Guillén, M.** (RFA-IREA)

“Prediction of the economic cost of individual long-term care in the Spanish population”
(Setembre 2010)

XREAP2010-09

Di Paolo, A. (GEAP & IEB)

“Knowledge of catalan, public/private sector choice and earnings: Evidence from a double sample selection model”
(Setembre 2010)

XREAP2010-10

Coad, A., Segarra, A. (GRIT), **Teruel, M.** (GRIT)

“Like milk or wine: Does firm performance improve with age?”
(Setembre 2010)

XREAP2010-11

Di Paolo, A. (GEAP & IEB), **Raymond, J. Ll.** (GEAP & IEB), **Calero, J.** (IEB)

“Exploring educational mobility in Europe”
(Octubre 2010)

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Borrell, A. (GiM-IREA), **Fernández-Villadangos, L.** (GiM-IREA)

“Clustering or scattering: the underlying reason for regulating distance among retail outlets”
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Di Paolo, A. (GEAP & IEB)

“School composition effects in Spain”
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Fageda, X. (GiM-IREA), **Flores-Fillol, R.**

“Technology, Business Models and Network Structure in the Airline Industry”
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Albalate, D. (GiM-IREA), **Bel, G.** (GiM-IREA), **Fageda, X.** (GiM-IREA)

“Is it Redistribution or Centralization? On the Determinants of Government Investment in Infrastructure”
(Desembre 2010)

XREAP2010-16

Oppedisano, V., Turati, G.

“What are the causes of educational inequalities and of their evolution over time in Europe? Evidence from PISA”
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XREAP2010-17

Canova, L., Vaglio, A.

“Why do educated mothers matter? A model of parental help”
(Desembre 2010)

2011

XREAP2011-01

Fageda, X. (GiM-IREA), **Perdiguero, J.** (GiM-IREA)

“An empirical analysis of a merger between a network and low-cost airlines”
(Maig 2011)



XREAP2011-02

Moreno-Torres, I. (ACCO, CRES & GiM-IREA)

“What if there was a stronger pharmaceutical price competition in Spain? When regulation has a similar effect to collusion”
(Maig 2011)

XREAP2011-03

Miguélez, E. (AQR-IREA); **Gómez-Miguélez, I.**

“Singling out individual inventors from patent data”
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Moreno-Torres, I. (ACCO, CRES & GiM-IREA)

“Generic drugs in Spain: price competition vs. moral hazard”
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Nieto, S. (AQR-IREA), **Ramos, R.** (AQR-IREA)

“¿Afecta la sobreeducación de los padres al rendimiento académico de sus hijos?”
(Maig 2011)

XREAP2011-06

Pitt, D., Guillén, M. (RFA-IREA), **Bolancé, C.** (RFA-IREA)

“Estimation of Parametric and Nonparametric Models for Univariate Claim Severity Distributions - an approach using R”
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Guillén, M. (RFA-IREA), **Comas-Herrera, A.**

“How much risk is mitigated by LTC Insurance? A case study of the public system in Spain”
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Ayuso, M. (RFA-IREA), **Guillén, M.** (RFA-IREA), **Bolancé, C.** (RFA-IREA)

“Loss risk through fraud in car insurance”
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Duch-Brown, N. (IEB), **García-Quevedo, J.** (IEB), **Montolio, D.** (IEB)

“The link between public support and private R&D effort: What is the optimal subsidy?”
(Juny 2011)

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Bermúdez, Ll. (RFA-IREA), **Karlis, D.**

“Mixture of bivariate Poisson regression models with an application to insurance”
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Varela-Irimia, X-L. (GRIT)

“Age effects, unobserved characteristics and hedonic price indexes: The Spanish car market in the 1990s”
(Agost 2011)

XREAP2011-12

Bermúdez, Ll. (RFA-IREA), **Ferri, A.** (RFA-IREA), **Guillén, M.** (RFA-IREA)

“A correlation sensitivity analysis of non-life underwriting risk in solvency capital requirement estimation”
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Guillén, M. (RFA-IREA), **Pérez-Marín, A.** (RFA-IREA), **Alcañiz, M.** (RFA-IREA)

“A logistic regression approach to estimating customer profit loss due to lapses in insurance”
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Jiménez, J. L., Perdiguero, J. (GiM-IREA), **García, C.**

“Evaluation of subsidies programs to sell green cars: Impact on prices, quantities and efficiency”
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Arespa, M. (CREB)

“A New Open Economy Macroeconomic Model with Endogenous Portfolio Diversification and Firms Entry”
(Octubre 2011)

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Matas, A. (GEAP), **Raymond, J. L.** (GEAP), **Roig, J.L.** (GEAP)

“The impact of agglomeration effects and accessibility on wages”
(Novembre 2011)

XREAP2011-17

Segarra, A. (GRIT)

“R&D cooperation between Spanish firms and scientific partners: what is the role of tertiary education?”
(Novembre 2011)

XREAP2011-18

García-Pérez, J. I.; **Hidalgo-Hidalgo, M.**; **Robles-Zurita, J. A.**

“Does grade retention affect achievement? Some evidence from PISA”
(Novembre 2011)

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Arespa, M. (CREB)

“Macroeconomics of extensive margins: a simple model”
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García-Quevedo, J. (IEB), **Pellegrino, G.** (IEB), **Vivarelli, M.**

“The determinants of YICs’ R&D activity”
(Desembre 2011)

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González-Val, R. (IEB), **Olmo, J.**

“Growth in a Cross-Section of Cities: Location, Increasing Returns or Random Growth?”
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Gombau, V. (GRIT), **Segarra, A.** (GRIT)

“The Innovation and Imitation Dichotomy in Spanish firms: do absorptive capacity and the technological frontier matter?”
(Desembre 2011)

2012

XREAP2012-01

Borrell, J. R. (GiM-IREA), **Jiménez, J. L.**, **García, C.**

“Evaluating Antitrust Leniency Programs”
(Gener 2012)

XREAP2012-02

Ferri, A. (RFA-IREA), **Guillén, M.** (RFA-IREA), **Bermúdez, Ll.** (RFA-IREA)

“Solvency capital estimation and risk measures”
(Gener 2012)

XREAP2012-03

Ferri, A. (RFA-IREA), **Bermúdez, Ll.** (RFA-IREA), **Guillén, M.** (RFA-IREA)

“How to use the standard model with own data”
(Febrer 2012)

XREAP2012-04

Perdiguero, J. (GiM-IREA), **Borrell, J.R.** (GiM-IREA)

“Driving competition in local gasoline markets”
(Març 2012)

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D’Amico, G., **Guillen, M.** (RFA-IREA), Manca, R.

“Discrete time Non-homogeneous Semi-Markov Processes applied to Models for Disability Insurance”
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XREAP2012-06

Bové-Sans, M. A. (GRIT), Laguardo-Ramírez, R.
“Quantitative analysis of image factors in a cultural heritage tourist destination”
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XREAP2012-07

Tello, C. (AQR-IREA), **Ramos, R.** (AQR-IREA), **Artís, M.** (AQR-IREA)
“Changes in wage structure in Mexico going beyond the mean: An analysis of differences in distribution, 1987-2008”
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Jofre-Monseny, J. (IEB), **Marín-López, R.** (IEB), **Viladecans-Marsal, E.** (IEB)
“What underlies localization and urbanization economies? Evidence from the location of new firms”
(Maig 2012)

XREAP2012-09

Muñiz, I. (GEAP), **Calatayud, D.**, **Dobaño, R.**
“Los límites de la compacidad urbana como instrumento a favor de la sostenibilidad. La hipótesis de la compensación en Barcelona medida a través de la huella ecológica de la movilidad y la vivienda”
(Maig 2012)

XREAP2012-10

Arqué-Castells, P. (GEAP), **Mohnen, P.**
“Sunk costs, extensive R&D subsidies and permanent inducement effects”
(Maig 2012)

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Boj, E. (CREB), **Delicado, P.**, **Fortiana, J.**, **Esteve, A.**, **Caballé, A.**
“Local Distance-Based Generalized Linear Models using the dbstats package for R”
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Royuela, V. (AQR-IREA)
“What about people in European Regional Science?”
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Osorio A. M. (RFA-IREA), **Bolancé, C.** (RFA-IREA), **Madise, N.**
“Intermediary and structural determinants of early childhood health in Colombia: exploring the role of communities”
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Miguellez, E. (AQR-IREA), **Moreno, R.** (AQR-IREA)
“Do labour mobility and networks foster geographical knowledge diffusion? The case of European regions”
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Teixidó-Figueras, J. (GRIT), **Duró, J. A.** (GRIT)
“Ecological Footprint Inequality: A methodological review and some results”
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Varela-Irimia, X-L. (GRIT)
“Profitability, uncertainty and multi-product firm product proliferation: The Spanish car industry”
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Duró, J. A. (GRIT), **Teixidó-Figueras, J.** (GRIT)
“Ecological Footprint Inequality across countries: the role of environment intensity, income and interaction effects”
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Manresa, A. (CREB), **Sancho, F.**
“Leontief versus Ghosh: two faces of the same coin”
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Alemany, R. (RFA-IREA), **Bolancé, C.** (RFA-IREA), **Guillén, M.** (RFA-IREA)

“Nonparametric estimation of Value-at-Risk”

(Octubre 2012)

XREAP2012-20

Herrera-Idárraga, P. (AQR-IREA), **López-Bazo, E.** (AQR-IREA), **Motellón, E.** (AQR-IREA)

“Informality and overeducation in the labor market of a developing country”

(Novembre 2012)

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Di Paolo, A. (AQR-IREA)

“(Endogenous) occupational choices and job satisfaction among recent PhD recipients: evidence from Catalonia”

(Desembre 2012)

2013

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Segarra, A. (GRIT), **García-Quevedo, J.** (IEB), **Teruel, M.** (GRIT)

“Financial constraints and the failure of innovation projects”

(Març 2013)

XREAP2013-02

Osorio, A. M. (RFA-IREA), **Bolancé, C.** (RFA-IREA), **Madise, N.**, **Rathmann, K.**

“Social Determinants of Child Health in Colombia: Can Community Education Moderate the Effect of Family Characteristics?”

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XREAP2013-03

Teixidó-Figueras, J. (GRIT), **Duró, J. A.** (GRIT)

“The building blocks of international ecological footprint inequality: a regression-based decomposition”

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Salcedo-Sanz, S., **Carro-Calvo, L.**, **Claramunt, M.** (CREB), **Castañer, A.** (CREB), **Marmol, M.** (CREB)

“An Analysis of Black-box Optimization Problems in Reinsurance: Evolutionary-based Approaches”

(Maig 2013)

XREAP2013-05

Alcañiz, M. (RFA), **Guillén, M.** (RFA), **Sánchez-Moscona, D.** (RFA), **Santolino, M.** (RFA), **Llatje, O.**, **Ramon, Ll.**

“Prevalence of alcohol-impaired drivers based on random breath tests in a roadside survey”

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XREAP2013-06

Matas, A. (GEAP & IEB), **Raymond, J. Ll.** (GEAP & IEB), **Roig, J. L.** (GEAP)

“How market access shapes human capital investment in a peripheral country”

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Di Paolo, A. (AQR-IREA), **Tansel, A.**

“Returns to Foreign Language Skills in a Developing Country: The Case of Turkey”

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Fernández Gual, V. (GRIT), **Segarra, A.** (GRIT)

“The Impact of Cooperation on R&D, Innovation and Productivity: an Analysis of Spanish Manufacturing and Services Firms”

(Novembre 2013)

XREAP2013-09

Bahraoui, Z. (RFA); **Bolancé, C.** (RFA); **Pérez-Marín, A. M.** (RFA)

“Testing extreme value copulas to estimate the quantile”

(Novembre 2013)

2014

XREAP2014-01

Solé-Auró, A. (RFA), **Alcañiz, M.** (RFA)

“Are we living longer but less healthy? Trends in mortality and morbidity in Catalonia (Spain), 1994-2011”

(Gener 2014)



XREAP2014-02

Teixidó-Figueres, J. (GRIT), **Duro, J. A.** (GRIT)
“Spatial Polarization of the Ecological Footprint distribution”
(Febrer 2014)

XREAP2014-03

Cristobal-Cebolla, A.; **Gil Lafuente, A. M.** (RFA), **Merigó Lindhal, J. M.** (RFA)
“La importancia del control de los costes de la no-calidad en la empresa”
(Febrer 2014)

XREAP2014-04

Castañer, A. (CREB); **Claramunt, M.M.** (CREB)
“Optimal stop-loss reinsurance: a dependence analysis”
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Di Paolo, A. (AQR-IREA); **Matas, A.** (GEAP); **Raymond, J. Ll.** (GEAP)
“Job accessibility, employment and job-education mismatch in the metropolitan area of Barcelona”
(Maig 2014)

XREAP2014-06

Di Paolo, A. (AQR-IREA); **Mañé, F.**
“Are we wasting our talent? Overqualification and overskilling among PhD graduates”
(Juny 2014)

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Segarra, A. (GRIT); **Teruel, M.** (GRIT); **Bové, M. A.** (GRIT)
“A territorial approach to R&D subsidies: Empirical evidence for Catalanian firms”
(Setembre 2014)

XREAP2014-08

Ramos, R. (AQR-IREA); **Sanromá, E.** (IEB); **Simón, H.**
“Public-private sector wage differentials by type of contract: evidence from Spain”
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XREAP2014-09

Bel, G. (GiM-IREA); **Bolancé, C.** (Riskcenter-IREA); **Guillén, M.** (Riskcenter-IREA); **Rosell, J.** (GiM-IREA)
“The environmental effects of changing speed limits: a quantile regression approach”
(Desembre 2014)

2015

XREAP2015-01

Bolance, C. (Riskcenter-IREA); **Bahraoui, Z.** (Riskcenter-IREA), **Aleman, R.** (Riskcenter-IREA)
“Estimating extreme value cumulative distribution functions using bias-corrected kernel approaches”
(Gener 2015)

XREAP2015-02

Ramos, R. (AQR-IREA); **Sanromá, E.** (IEB), **Simón, H.**
“An analysis of wage differentials between full- and part-time workers in Spain”
(Agost 2015)

XREAP2015-03

Cappellari, L.; **Di Paolo, A.** (AQR-IREA)
“Bilingual Schooling and Earnings: Evidence from a Language-in-Education Reform”
(Setembre 2015)

XREAP2015-04

Álvarez-Albelo, C. D., **Manresa, A.** (CREB), **Pigem-Vigo, M.** (CREB)
“Growing through trade: The role of foreign growth and domestic tariffs”
(Novembre 2015)

XREAP2015-05

Caminal, R., **Di Paolo, A.** (AQR-IREA)
“Your language or mine?”
(Novembre 2015)



XREAP2015-06

Choi, H. (AQR-IREA), **Choi, A.** (IEB)

When one door closes: the impact of the hagwon curfew on the consumption of private tutoring in the Republic of Korea
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2016

XREAP2016-01

Castañer, A. (CREB, XREAP); **Claramunt, M M.** (CREB, XREAP), **Tadeo, A., Varea, J.** (CREB, XREAP)

Modelización de la dependencia del número de siniestros. Aplicación a Solvencia II
(Setembre 2016)

XREAP2016-02

García-Quevedo, J. (IEB, XREAP); **Segarra-Blasco, A.** (GRIT, XREAP), **Teruel, M.** (GRIT, XREAP)

Financial constraints and the failure of innovation projects
(Setembre 2016)

XREAP2016-03

Jové-Llopis, E. (GRIT, XREAP); **Segarra-Blasco, A.** (GRIT, XREAP)

What is the role of innovation strategies? Evidence from Spanish firms
(Setembre 2016)

XREAP2016-04

Albalate, D. (GiM-IREA, XREAP); **Rosell, J.** (GiM-IREA, XREAP)

Persistent and transient efficiency on the stochastic production and cost frontiers – an application to the motorway sector
(Octubre 2016)



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