ESTIMATING TECHNICAL AND ALLOCATIVE EFFICIENCY BY MEANS OF A BAYESIAN APPROACH: AN APPLICATION TO THE POSTAL SECTOR

José Baños-Pino and Ana Rodríguez-Álvarez
University of Oviedo, Oviedo Efficiency Group

ABSTRACT

The aim of this paper is to study the technology of the Spanish State Postal and Telegraph Society sector (*Correos*, hereafter). Concretely, we analyze economic efficiency (technical and allocative) and scale economies of the *Correos*' units of production (cost centers). To do this, we employ a methodology based of an input distance function which is the dual of the cost function. Applying duality theory, we also develop an economic model to assess the effect of postal infrastructures on the operators' costs. In order to carry out the empirical model, bayesian econometrics is applied to estimate the parameters in the input distance function and the technical efficiency terms.

KEYWORDS: Bayesian econometrics, scale economies, postal infrastructure shadow price, Spanish postal sector technical and allocative efficiency.

1. INTRODUCTION

The postal sector has been undergoing a profound transformation over the last decades, largely as a result of social changes produced by the rapid development of technology and communication. The liberalization of this sector (which was traditionally provided by a monopolistic public or regulated operator) has been the main bet in Europe in order to improve efficiency and quality levels. Consequently, the EU policy in the postal sector seeks to complete the internal market for postal services and to ensure, through an appropriate regulatory framework, an efficient, reliable and good-quality postal service to all its citizens at affordable prices.

In Spain, as in other European countries, postal sector was regulated during decades. It was not until the end of 1985 when Spain decided to join the European Community as a full member. In this way, European laws and regulations started to have a permanent impact in Spain (for more details see Escribano *et al.* 2003, 2004). Nowadays, *Correos* is the administrator of the largest nationwide postal network and the principal operator in the market. It is charged with providing the universal postal service until 2025 and it is obliged to provide competitors with wholesale access to its network, in accordance with Act 43/2010 of 30 December 2010 on the *Universal Postal Service Act, rights of users and the postal market*. Despite the liberalisation initiated by the EU Directives of 1997/67/EC; 2002/39/EC or 2008/6/EC, *Correos* has a turnover 10 times as large as its biggest competitor, Unipost.[1]

Some figures may be useful to analyze the productivity of the *Correos*. Following DBK report (2013), the evolution of the number of shipments and the sectorial turnover has recorded an average annual rate of reduction of 9.2% and 9.4% per cent respectively in the period 2012-2011. The market value stood at 1,635 million euros in 2012, recording a decline of 9% compared to 2011, the year in which it had posted a decrease of 1%. On the other hand, the number of workers has decreased considerably in the last 10 years (from 63,000 workers in 2002 to 55,000 workers in 2012).

By analyzing these figures the question that arises is how it is possible to improve the productivity of the company. The aim of this paper is to analyze the technology of the postal sector in Spain. By doing so, we will be able to know several characteristics of this technology that could be useful for the regulator agent in order to find optimal ways to improve the provision of the postal service. This is especially relevant in a context where demand of postal services is falling due to the growing use of digital media and where postal markets are open to competition. Moreover, and as Pateiro *et al.* (2012) pointed out, the welfare gain from the increasing competition could be offset by the loss of efficiency if there are new inefficient operators and if prices are not related with the costs. In this sense, an inadequate ruling of access to the postal network during the

[1] In this sense, in 2014, the *Comisión Nacional de los Mercados y la Competencia* has imposed a fine on the postal service provider *Correos* for abusing its dominant position.
For details see: ec.europa.eu/competition: European Competition Network: ECN, Brief 01/2014.

liberalization process can affect the network efficiency. Because of this, in this paper we calculate the (shadow) price for granting access to the postal network to a new operator.

Deprins *et al*. (1984) were the pioneers in analyzing technical efficiency of the postal sector. They use Belgian postal data to compare several methods of measuring technical efficiency and calculate an average labor-efficiency of about 90%. Palm (1987) uses a Cobb-Douglas production function and as a result he obtains an efficiency index with a large dispersion. Register (1988), who analyzes the technical efficiency for the postal administration in the USA after the reorganization in 1970, uses a frontier function in order to construct an efficiency index between the years 1955-1985. His results show that the changes in the reorganization led to a significant improvement in efficiency. For their part, Perelman and Pestieau (1994) analyze technical efficiency by comparing 16 European countries using a panel data and obtaining levels of efficiency ranged between 39 and 90 %. Borenstein *et al*. (2004) study post offices in Brazil with non-parametric techniques (DEA) and found about 44% of the offices located on the frontier. Felisberto (2013) assesses the effect of liberalization on innovation in the postal sector using as a proxy for innovation (among others) labor productivity. To do this, data from seventeen European countries over eleven years is collected. He finds evidence that liberalization has a positive effect on innovation.

At the national level, the existing literature analyzing the productive activity and efficiency of the postal sector is scarce. Morales Piñero (2009) compares the efficiency and effectiveness of the Spanish public operator relative to other European operators. With this aim, he uses a panel data, modeling a translog average cost function with fixed effects. From the results he stresses that the different delivery times (quality) are important for the explanation of efficiency. Moreover, Iturralde and Quiros (2008) analyze technical and productive change in the Postal European Union and compare the Spanish case with other European countries. According to their results, important technical inefficiencies and high dispersion across operators are observed.

On the other hand, several studies have analyzed economic efficiency by means of a cost frontier. Filippini and Zola (2005) for post offices in Switzerland; Moriarty *et al.*

(2006) and Horncastle *et al.* (2006) for Royal Mail's delivery offices; Filippini and Koller (2012a) for Swiss Post's postal delivery units or Cazals *et al.* (2008, 2011) for postal services in the UK are some examples.

Moreover, scale economies are widely analyzed in this sector. The vast majority of empirical results reveal the existence of scale economies. In this sense, Hunt and Lyink (1991); Rogerson and Takis (1993); Cohen and Chu (1997); Cazals *et al*. (2005); Filippini and Zola (2005); Bradley *et al*. (2006); d'Alcantara and Amerlynck (2006) as well as Farsi *et al*. (2006) found scale economies in this sector. The exception to these results is Mizutani and Uranishi (2003) where authors did not find evidence of scale economies in the postal industry.

More recent works are Filippini and Koller (2012a, 2012b). In the first one, they analyze economies of scale and scope in Swiss Post's post offices and franchised postal agencies under consideration of different underlying production technologies and unobserved factors using a latent class model. The results confirm the existence of unobserved heterogeneity and of increasing economies of scale and scope. In the second one, they analyze the cost structure of Swiss Post's postal delivery units by analyzing several models to deal with the problem of the unobserved heterogeneity in a panel data.

All examples above analyze productive (technical or cost) efficiency by using production or cost functions. The cost function allows multi-output technologies and therefore its use is obviously more suitable than the former in order to analyze *Correos*' technology. However, cost function assumes cost minimization and exogeneity of input prices and these assumptions could be questionable in the postal sector. To solve these problems, we propose the use of an input distance function which does not assume exogeneity in the price of the factors. This property could be significantly relevant for our aims, as the provision of postal infrastructures is conditioned by the performance of the public sector. Moreover, the input distance function does not assume cost minimization. This feature is especially attractive when analyzing the public sector, regulated sector or other subjects related to optimal provision of inputs, where generally the assumption of costs-minimizing behaviors is questioned.

In order to carry out the estimation, bayesian econometric techniques are applied. The Bayesian approach to stochastic frontiers presents advantages in terms of formally deriving posterior densities for individual efficiencies, while it allows easy incorporation of economic restrictions (see van den Broeck *et al*., 1994; Koop *et al*., 1997; or Griffin and Steel, 2008). This method will be superior to the frequently applied classical maximum likelihood statistics, since it considers unknown parameters as random variables, specified as prior distributions.

In short, the aim of this paper is to estimate an input distance function by using Bayesian econometrics to capture the technology of postal sector. To our knowledge, this is the first paper to address both issues. In the empirical investigation of these issues, a broad data set of Spanish postal sector is analyzed at the level of production units (cost centers) which constitutes the second contribution of this paper.

2. CAPTURING POSTAL SECTOR TECHNOLOGY

The objective of this section is to explain the several concepts that can help us to understand technology in the Spanish postal sector: technical efficiency; scale economies; allocative efficiency and the postal infrastructure shadow price.

2.a. Concept and measurement of the technical efficiency

According to Farrel (1957), a company is technically efficient with regard to others when producing a given amount of output with the minimum amount of inputs (input-oriented). Mathematically, the index of technical efficiency is defined as:

$$TE_I(y, x) = \min\{\lambda : \lambda x \in L(y)\} \qquad [1]$$

Where L(y) is the set of possibilities of production and λ is a scalar which takes values between 0 and 1 ($0 < \lambda \leq 1$) representing the reduction of the radial consumption of inputs to obtain the maximum possible output. An alternative form of defining the technical efficiency is through the Shephard's distance function (1953, 1970). The input distance function is the reciprocal of the Farrel index of technical efficiency. We can define it formally as:

$$D_I (y, x) = \max\{1/\lambda : \lambda x \in L(y)\} \qquad [2]$$

where λ is the above defined scalar. As a result, D_I measures the maximum potential equiproportional reduction of the inputs. It takes the value one when the company is located on the frontier and will reach a higher value to the unit when they did not use the resources efficiently.

That is to say, if D_I equals one it indicates that the company is technically efficient and a value higher than the unit shows us the degree of the efficiency achieved by the company. The input distance function fulfills the following properties: is no decreasing in inputs, is decreasing in outputs, homogeneous of degree one, concave in inputs and valid for multiproduct technology (see Färe and Primont, 1995 for details). Moreover, given that the distance function allows us to choose the orientation, in our study we will estimate an input distance function, where we assume that the inputs are endogenous and the outputs exogenous, what seems to be more consistent with the Spanish postal sector.

Because of this, in this study we will use stochastic input distance frontier which, in accordance with the expression [2] and assuming short-run with a quasi-fixed factor (K), can be defined as:

$$1 = D_I (\lambda x, y, K) \qquad [3]$$

2.b. Concept and measurement of Returns to Scale

Since the estimation of the distance function allows capturing the technology, it will also be possible to determine the *returns to scale*. The returns to scale measure the changes in the production resulting from a proportional change in all the inputs. As shown by Färe and Primont (1995), the elasticity of scale can be defined as follows:

$$\varepsilon_\lambda = \frac{-1}{\sum \frac{\partial D_I(\mathrm{x, y, K})}{\partial y} y} \qquad [4]$$

where $\partial D_I\ (y, x, K)/\partial y$ is the coefficient of the first order of the distance function regarding the vector of the outputs.

The equation [4] can take different values; this way a value higher than one indicates the existence of increasing returns to scale; a value equal to one indicates that there are constant returns to scale; and finally a value lower than one indicates the presence of decreasing return to scale.

2.c. Concept and measurement of the allocative efficiency

Given the technology and the prices of the production factors, an entrepreneur is *allocatively efficient* when is capable of producing using a *proportion* of these so company's costs are minimized. To analyze allocative efficiency, Färe and Grosskopf (1990) use the dual theory cost function/input distance function as follow:

$$D(\boldsymbol{y},\boldsymbol{x},K) = min_{W^s}\ \{W^s\boldsymbol{x} : C(\boldsymbol{y},W^s,K) = 1\} \qquad [5]$$

$$C(\boldsymbol{y},w^s,K) = min_x\ \{w^s\ \boldsymbol{x} : D(\boldsymbol{y}, \boldsymbol{x}, K) = 1\} \qquad [6]$$

Where w^s is the price vector of the factors that minimize **y**'s production cost given **x** and **K**. Shadow price vector (w^s) only will coincide with market price vector (w) if the chosen amount of factors (**x**) is optimal for a given **K** value.

On the other hand, C (y, w^s, K) is the shadow cost function which indicates the minimum cost to produce **y** with a given input vector (x) and **K**, and $W^S = \frac{w^s}{C(y,w^s,K)}$ is the shadow price vector normalized by the cost.

From this duality, Shephard (1970) establishes a relationship between variable inputs and their prices through the following equations:

Shephard's lemma: $x_i^s(y,w^s,K) = \frac{\partial C(y,w^s,\ K)}{\partial w_i}$ [7]

Dual of Shephard's lemma: $W_i^s(y,x,\ K) = \frac{\partial D(y,x,\ K)}{\partial x_i}$ [8]

Thus, the duality between the input distance function and the cost function enables the identification of the shadow price vector (normalized) that minimizes the variable costs, given **y**, **x**, and K. Therefore, regarding these shadow prices, the cost minimization condition is always met.

However, such shadow price vector (w^S) may or may not coincide with the market price vector (w). Only when shadow prices and market prices coincide, companies minimize costs with respect to such market prices. Therefore, by using the methodology of the distance function, there is no need to assume that companies minimize costs with respect to the market prices which is especially attractive when analyzing postal sector.

Given any two inputs i , j = 1 , 2, ..., n, applying [8] we obtain the shadow price as shown:

$$\frac{\dfrac{\partial D_I(y,\ x)}{\partial x_i}}{\dfrac{\partial D_I(y,\ x)}{\partial x_j}} = \frac{w_i^s}{w_j^s} \qquad [9]$$

If the assumptions of cost minimization were met, this ratio should be equal to the ratio of market prices of the inputs. However, if the inputs are not chosen in the right proportion, which is to say, if we incur in *allocative inefficiency*, these price ratios will differ. In order to study the amount and the direction of such deviation, Färe and Grosskopf (1990) introduce parametric correction (k_i) between the input's market price and its shadow price:

$w_i^S = k_i\ w_i$ [10]

Dividing expression [10] by the corresponding to the input j , we obtain:

$$\frac{w_i^s}{w_j^s} = k_{ij}\frac{w_i}{w_j} \qquad [11]$$

where $k_{ij} = k_i/k_j$

Equation [11] determines whether both ratios differ, so we can obtain the sense of the *allocative inefficiency* as follows:

- If $k_{ij} = 1$, factor i and factor j are used in their optimum proportions to minimize costs, ie, the enterprise is *allocatively efficient*.
- If $k_{ij} > 1$, factor i is underused with respect to factor j.
- If $k_{ij} < 1$, factor i is overused with respect to factor j.

2.d. Effect of postal infrastructures on variable costs

The postal infrastructure network (K), which is a quasi-fixed variable in our short-run model, becomes especially relevant in this section. To analyze the effect on the infrastructural postal network in the technology, we will explore again the duality between the input distance function and the cost function. We start with the Lagrangian (L) associated with the equation [6]:

$$L = w^s\boldsymbol{x} + \mu\ [1-D(\boldsymbol{y}, \boldsymbol{x}, K)] \qquad [12]$$

where μ is the Lagrange multiplier. Applying the envelope theorem, we obtain:

$$\frac{\partial C(y,w^s,K)}{\partial K} = -\mu\frac{\partial D(y,x,K)}{\partial K} \qquad [13]$$

To explain μ' s value, we take into account the minimum first order conditions associated to [12] , which can be expressed as follows:

$$\frac{\partial L}{\partial x} = w^s - \mu\frac{\partial D(y,x,K)}{\partial x} = 0 \qquad [14]$$

$$\frac{\partial L}{\partial \lambda} = 1 - D(y,x,K) = 0 \qquad [15]$$

Multiplying equation [14] by **x** we obtain:

$$w^s x - \mu \frac{\partial D(y,x,K)}{\partial x} x = 0 \qquad [16]$$

Since D is a first degree homogeneous function in **x**, by applying Euler's theorem and [16], the following expression should be true:

$$\frac{\partial D(y,x,K)}{\partial x} x = D(y,x,K) = 1 \qquad [17]$$

Furthermore, considering that w^s as the shadow price vector which minimizes the cost for a given **x** and K, by clearing μ in [16] we obtain:

$$\mu = w^s x = C(y,w^s,K) \qquad [18]$$

Finally, according to the value obtained for μ, equation [13] can be expressed as follows:

$$\frac{\frac{\partial C(y,w^s,K)}{\partial K}}{C(y,w^s,K)} = -\frac{\partial D(y,x,K)}{\partial K} \qquad [19]$$

Namely, the value $\partial D(\boldsymbol{y}, \boldsymbol{x}, K)/\partial K$ is equal (in absolute terms) to the marginal contribution of the infrastructure to the change in variable costs (normalized). So, since C (y, w^s, K) is always positive, if the derivative of the distance function with respect to K were also positive, equation [19] would indicate that *savings in cost* may be possible thanks to the increase of infrastructure provisions, and vice versa if the derivative of the distance function with respect to K were negative . Thus, we can calculate the stress on the variable production costs due to the different postal infrastructure stocks (postal networks) available in the economy.

However, since the value of C (y, w^s, K) is not directly observable (it depends on shadow prices, w^s), equation [19] makes it impossible to calculate the savings (or the increase) on the cost of the infrastructure. To overcome this drawback, the model is redefined in logarithmic terms, so equation [17] becomes:

$$ln1 = ln\ D(\mathbf{y}, \mathbf{x}, K) \qquad [20]$$

In addition, we also know that:

$$\frac{\partial D(y,x,K)}{\partial K} = \frac{\partial \ln D(y,x,K)}{\partial \ln K}\frac{D}{K} \qquad [21]$$

The definition of normalized shadow cost function is: a function that optimizes the observed cost in a frontier point given the amount of factors used. Therefore, the following must be true:

$$C(y,w^s,K) = \frac{C}{D} \qquad [22]$$

where $\frac{C}{D}$ is the observed cost at a point on the isoquant (on the production function) .

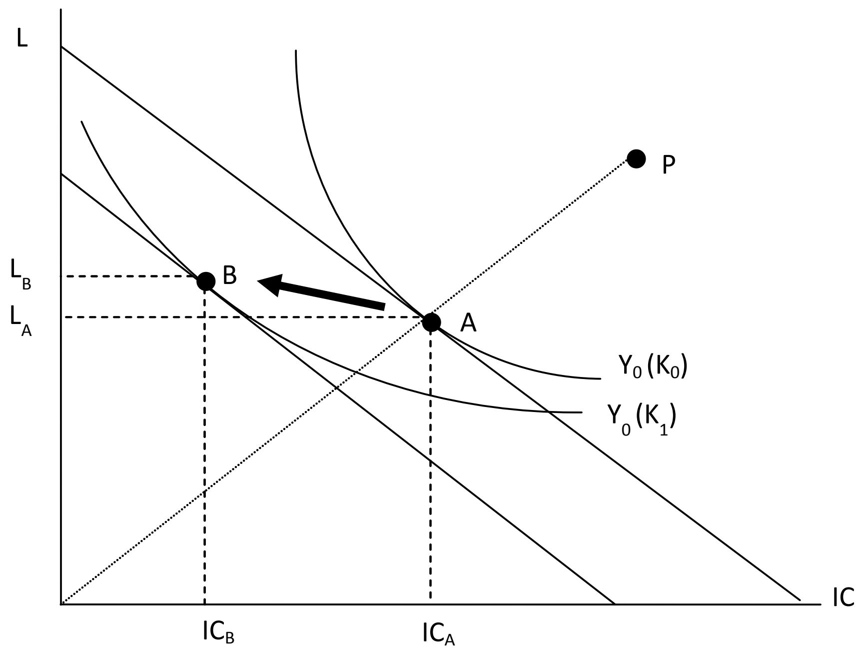
Then, using [19], [21] and [22], we finally obtain the expression:

$$\frac{\partial C(y,x,K)}{\partial K} = -\frac{\partial \ln D(y,x,K)}{\partial \ln K}\frac{C}{K} = P_K \qquad [23]$$

which is the definition of the shadow price of the quasi-fixed input of the infrastructure, a postal network in this particular case, P_K.

Since both C (variable cost) and K (stock of postal network infrastructure) are observed variables, equation [23] shows us how to obtain the shadow price of the postal infrastructures (P_K) in monetary terms once an input distance function is estimated.

Figure 1. The shadow price of quasi-fixed capital



An interpretation of the meaning of this shadow price is offered in Figure 1. To illustrate it, let's consider two variables inputs -intermediate consumption (IC) and employment (L). In the case of a change in the infrastructure provision, which implies an increase from K_0 to K_1, the equilibrium point will change, for example, from situation A to B, implying a reduction in the use of intermediate consumption and an increase in employment. Overall, this new rearrangement of variable factors would lead to a reduction in the company's variable production costs, which in turn would imply a shift of the isocost towards the origin. The change in the isocost value would, in turn, reduce the cost or the shadow price associated with the infrastructure.

Moreover, the elasticity of the variable cost with regards to the quasi-fixed input K is given by:

$$\varepsilon_{C,K} = \frac{\partial C(y,x,K)}{\partial K}\frac{K}{C} = -\frac{\partial \ln D(y,x,K)}{\partial \ln K} \qquad [24]$$

Logically, if $\varepsilon_{C,K}$ were zero, it would indicate that public capital on postal infrastructure would have no impact on the variable costs of private companies wishing to access them.

In short, with an input distance function it is possible to obtain useful information about *Correos*'s technology (technical and allocative efficiency levels and scale economies of the different production units operating in the postal sector) facilitates the correct assessment of the value that operators give to accessing the postal network infrastructure.

3. DATA

In order to carry out the objectives of this research we used the information facilitated by the National Commission of the Postal Sector (*Comisión Nacional del Sector Postal*) about the following cost units: in 2009 there are data about 49 rural offices, 544 urban offices and 962 delivery units, while in 2010 data on from 50 rural offices, 544 urban offices and 986 delivery units are available. As a result, we have a total of 3.135 observations from the years 2009 and 2010, distributed to 99 rural offices, 1.088 urban offices and 1.948 delivery units.

Regarding the outputs, we classified them into five categories: ordinary inter-city letters, certified inter-city letters, ordinary local letters, certified local letters, and money orders and parcels. On the other hand, we consider three input variables: labor, transport units and intermediate consumptions. Labor represents the number of full-time equivalent employees in each office[2]. Transport units are the vehicles used in the different cost units, obtained by dividing the transport cost of each office (fuel, repairs, maintenance, insurance, etc.) between the average cost of mail delivery vehicles (motorcycles, cars, vans and trucks). Intermediate consumptions refer to the expenditure on repairs, preservation, maintenance and supply. In addition, we use a quasi -fixed input given by the monetary value in the balance sheets of tangible and intangible fixed assets for each office, as a proxy of the postal infrastructures. These inputs were

[2] The information available has not allowed us its division into different categories.

elaborated on bases of the analytical accounting of *Grupo Correos* and its annual report. In Table 1, we summarize the descriptive statistics of the inputs and outputs used in the estimation of the distance function.

Table 1.- Descriptive Statistics
Years 2009-2010

	Mean	Median	Maximum	Minimum	Standard Dev.
Variable inputs:					
Labor	20,43	10,91	474,09	0,46	39,59
Transport units	3,14	1,48	45,91	0,02	4,21
Intermediate consumptions (thousands of euros)	43,63	6,74	843,48	0,16	101,19
Quasi -fixed input					
Postal infrastructures (thousands of euros)	676,09	350,09	8.771,12	0,13	842,9
Outputs:					
Ordinary inter-city letter (thousands of units)	1.640,49	768,12	27.328,19	0,00	2.390,75
Certified inter-city letter (thousands of units)	59,23	30,13	883,57	0,96	84,31
Ordinary local letter (thousands of units)	290,32	182,20	6.723,71	0,00	792,10
Certified local letter (thousands of units)	20,83	2,30	603,14	0,00	52,88
Money orders and parcels (thousands of units)	3,27	1,61	47,73	0,05	5,12

4. METHODOLOGY AND ECONOMETRICS SPECIFICATION

According to equation [3] and assuming a Cobb-Douglas technology with multiple outputs and inputs,[3] and once we imposed the homogeneity of degree one in inputs (see for example Coelli and Perelman, 2000), the econometric specification of the stochastic distance frontier would be defined as:

[3] In an attempt to capture the complex postal sector technology as precisely as possible, we have considered a large number of variables (five outputs and two inputs). By doing so, and given we use a Bayesian approach to estimate the model, is not feasible to test the validity of the Cobb-Douglas over the Translog functional form.

$$-LnX_{n1t} = \beta_0 + \sum_2^3 \beta_i Ln\left(\frac{X_{nit}}{X_{nlt}}\right) + \sum_1^5 \alpha_i LnY_{nit} + \sum_2^{19} \phi_i CCAA_i + \sum_2^3 \eta_i Population_i + \gamma_i \ln K_{nt} + v_{nt} - u_{nt} \quad [25]$$

Where n =1,…,N is cost center unit; t =2009, 2010 is time; X is the vector of inputs (X=1, … 3); Y the vector of outputs (Y=1, … 5) and K is the postal infrastructure (quasi-fixed input). In addition to the inputs and outputs, we included two additional variables into the last equation: *CCAA* is a dummy that gathers specific characteristics of each autonomous community while *Population* is an artificial variable that refers the population served by a postal office. In this way, $Population_1$ indicates a population served greater than 50,000 inhabitants; $Population_2$ indicates a population between 5,000 and 50,000 inhabitants and $Population_3$ a population less than 5,000 inhabitants.

Finally, u_{nt} represents the degree of the technical efficiency, $u_{nt} \sim N^+ (0, \sigma_u^2)$; and v_{nt} is the term of random perturbation that follows the distribution $v_{nt} \sim N(0, \sigma_v^2)$. The expression [25] is the function to be estimated. In addition, in this study we propose the application of the model developed by Hadri (1999), where the error component v_{nt} is normally distributed with the mean equal to zero and variance $\sigma^2_{v_{nt}}$, the latter depending on a vector of explicative variables z. That is to say:

$$\sigma^2_{v_{nt}} = g(z, \boldsymbol{\delta}) \quad [26]$$

where $\boldsymbol{\delta}$ is a vector of parameters to estimate. This specification permits to model an error of non-constant variance (with heteroskedasticity) as a function of a set of variables, which is considered the most appropriate in response to the large difference in the sample observation, which includes postal cost centers of diverse size and production specialization. According to equation [26] we assume that $\sigma^2_{v_{nt}}$ depends on several variables. Concretely, we are interested in analysing the relationship between heteroskedasticity, time and type of office as follows:

$$\text{Ln } \sigma^2_{v_{nt}} = \delta_0 + \delta_1 D_{year} + \delta_2 D_{type\ of\ office} \quad [27]$$

where D_{year} (2009 or 2010) and $D_{type\ of\ office}$ (rural, urban or delivery) are dummies.

In summary, this work proposes the estimation of the system of equations [25] and [27] which will be resolved jointly with the objective of calculation of the technical efficiency in the Spanish postal sector. The estimation of the system [25-27] will allow us to calculate the indices of the technical efficiency (TE) for each cost center (production unit) in each period through the following expression:

$TE_{nt} = \exp(-u_{nt})$ [28]

In this way, we ensure that $0 < TE_{nt} \leq 1$. So, if TE_{nt} takes the value one the cost center works on the production frontier and is technically efficient, whereas if it reaches a value lower than one it implies that it incurs inefficiency. The more distant the TE_{nt} index is from unity, the more technically inefficient the analyzed production unit will be.

5. EMPIRICAL RESULTS

Equations [25-27] have been simultaneously estimated by using a Bayesian approach.

This methodology combines prior information about the parameters of interest with the observed information contained in the data and then, using the Bayes theorem, it leads to the posterior distributions of the parameters. Therefore, firstly we should assign prior distributions for the parameters introduced in the input distance model (25). The distribution assumed for the β, α, ϕ, η and γ parameters are multivariate normal, i.e. $\beta \sim N(0, \Sigma_\beta)$, where 0 is a vector of zero means and Σ_β^{-1}, the inverse of the variance, is a precision diagonal matrix with priors set to 0.0001 for all coefficients. Besides, these distributions should be truncated to take into account the regularity conditions. Regarding the inefficiency term u_i, we suppose it follows a half-normal distribution (Aigner *et. al*. 1977), $u_N \sim N^+(0, \lambda)$, with a gamma distribution for $\lambda^{-1} \sim G(1,1/37.5)$, as van den Broeck *et al.* or Griffin and Steel (2007) detail. Finally, given the specification for our idiosyncratic error term $\sigma^2_{v_N}$ and according to (27), we impose a normal distribution for the δ parameters, $\delta \sim N(0, \Sigma_\delta)$.

To proceed with the Bayesian inference, the model was run using the WinBUGS package, which implements Markov Chain Monte Carlo (MCMC) techniques. For our application, the MCMC algorithm involved 200,000 iterations where the first 20,000 were discarded in a burn-in phase, and the chain was thinned every 8 draws in order to remove autocorrelations. The means of the parameters of the input distance function and their 95% confidence intervals are presented in Table 2. Given that the variables have been previously divided by their geometric mean, first order parameters in Table 2 show the elasticity of the distance function at the sample mean. All input and output coefficients are significant and have the expected sign, thus the estimated distance function satisfies the theory's requirements (decreasing outputs and non-decreasing inputs).

Once the model is estimated, it is possible to discover useful features of technology such as the *elasticity of scale*. Applying equation [4] and using the coefficients shown on Table 2, elasticity of scale features a value of 1.048. This would indicate that the production technology of *Correos*' postal services in Spain presents increasing returns to scale.

On the other hand, and in an attempt to capture the influence of the environmental factors on the technology we have included the artificial variable "Autonomous Communities", defining a dummy variable which would reflect unobservable and time invariant aspects specific for each region, such as its specific orography and geographical situation. Also, regarding the Autonomous Communities dummies included in equation (30), it must be stated that the region of Andalusia was eliminated. Therefore, the estimated coefficients shown in Table 2 indicate each region's position with regards to the reference point.

Moreover, and regarding the population dummies, Table 2 presents the coefficients of the population served less than 50,000 inhabitants (Population_2; Population_3) versus population greater than 50,000 inhabitants (Population_1), used as a reference variable. Both coefficients are positive and significant, indicating that the centers with lower population to serve appear to be the most efficient. This can be explained if we take into account that the centers with more population served use more resources to do so.

Therefore, it would not be accurate to claim higher inefficiency but a different and more costly activity in terms of required resources.

As we have explained above, this paper follows the model proposed by Hadri (1999) which assumes that the random error term (v_{nt}) may be heteroskedastic due to both, time and the different activity of every office due to several factors (for example, population densities among others). Results shown in Table 2 lead us to deduce that the random perturbation term suffers indeed from heteroskedasticity, which is explained by the type of office (rural office, urban office or delivery center) and time. From the results we can deduce the presence of heteroskedasticity, concretely the variance of the v error term is a function of the type of office and time. As expected, units and urban offices have less variance than rural offices. In consequence, we may infer the existence of a density effect. That is to say, units and urban centers (with not very extensive but highly populated distribution network) can perform their service better than rural offices (with wider networks but less clientele). This introduces heteroskedasticity as a function of the density. Moreover, according to the results, the variance of the random error term is a negative function of time.

With regard technical efficiency (TE), the TE indexes for each cost unit is calculated using the estimate of the distance function and applying the equation [28]. Figures 2, 3 and 4 show the TE values achieved by rural offices, urban units and delivery centers by Autonomous Community, respectively. In all cases, the TE values are very close than one (around 95%) which indicates high efficiency. Moreover, from Figure 5 which analyses TE by region without distinguishing by type of center, we can also deduce that there are not significant differences between the TE indexes by Autonomous Communities.

On the other hand, Table 3 shows the joint comparative of the TE values (at the sample mean) for the 1,580 *Correos*' cost centers, including rural offices, urban offices and delivery units in 2009 and 2010. The TE index values of all offices have a mean value close to 0.95. In other words, this value indicates that, using the set of existing cost centers as a reference point, it could be possible to reach their production levels cutting resources by 5% (radial reduction of all inputs on 1/0.95).

Table 2. Input Distance Function Estimated

Variable	Mean	2.50%	97.50%
Constant	-0.1663	-0.1989	-0.1354
Variable Intputs			
Ln (X_2/X1) (Transport units/Labor)	0.1848	0.1627	0.2069
Ln (X_3/X1) (Intermediate consumption /Labor)	0.0899	0.0655	0.1145
Outputs			
Ln Y1 (ordinary inter-city letter)	-0.6280	-0.7026	-0.5363
Ln Y2 (certified inter-city letter)	-0.1508	-0.1823	-0.1175
Ln Y3 (ordinary local letter)	-0.0718	-0.0894	-0.0518
Ln Y4 (certified local letter)	-0.0055	-0.0129	-0.0021
Ln Y5 (money orders and parcels)	-0.0975	-0.1132	-0.0821
Quasi-fixed input			
Ln K (tangible fixed and intangible assets)	0.1346	0.09081	0.1794
Autonomous Community			
ARAGON	-0.0160	-0.0597	0.0277
ASTURIAS	-0.0493	-0.0942	-0.0051
BALEARIC ISLANDS	-0.1170	-0.1594	-0.0743
BASQUE COUNTRY	0.0092	-0.0278	0.0468
CANARY ISLANDS	-0.2534	-0.2888	-0.2181
CANTABRIA	-0.0287	-0.0865	0.0280
CASTILE AND LEÓN	-0.0179	-0.0521	0.0165
CASTILE-LA MANCHA	0.0966	0.0638	0.1288
CATALONIA	-0.0498	-0.0736	-0.0265
CEUTA	-0.2127	-0.4611	0.0334
EXTREMADURA	0.0642	0.0241	0.1034
GALICIA	-0.0528	-0.0840	-0.0216
LA RIOJA	-0.0020	-0.0706	0.0673
MADRID	-0.1953	-0.2257	-0.1657
MELILLA	-0.2697	-0.5160	-0.0224
MURCIA	-0.0135	-0.0558	0.0295
NAVARRA	0.0186	-0.0383	0.0767
VALENCIA	0.0069	-0.0200	0.0341
Population			
5,000 inh. < $Population_2$ < 50,000 inh.	0.2119	0.1861	0.2380
$Population_3$ < 5,000 inhabitants	0.1179	0.0781	0.1576
Estimation of the heteroskedastic model for the Ln (σ_v^2)component			
Constant	0.5563	0.3836	0.6861
Type of office	-0.0188	-0.0246	-0.0130
Year	-0.0002	-0.0003	-0.0001

Nº observations = 3.135

Figure 2.- Technical Efficiency Indexes (Rural Offices) by Autonomous Community

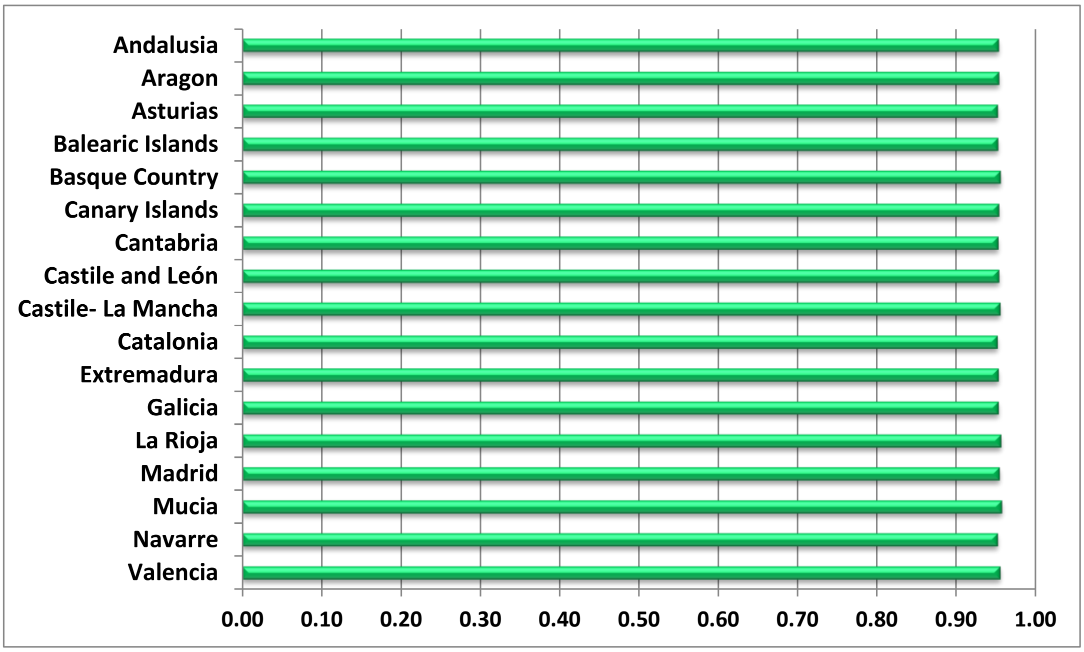


Figure 3.- Technical Efficiency Indexes (Urban Offices) by Autonomous Community

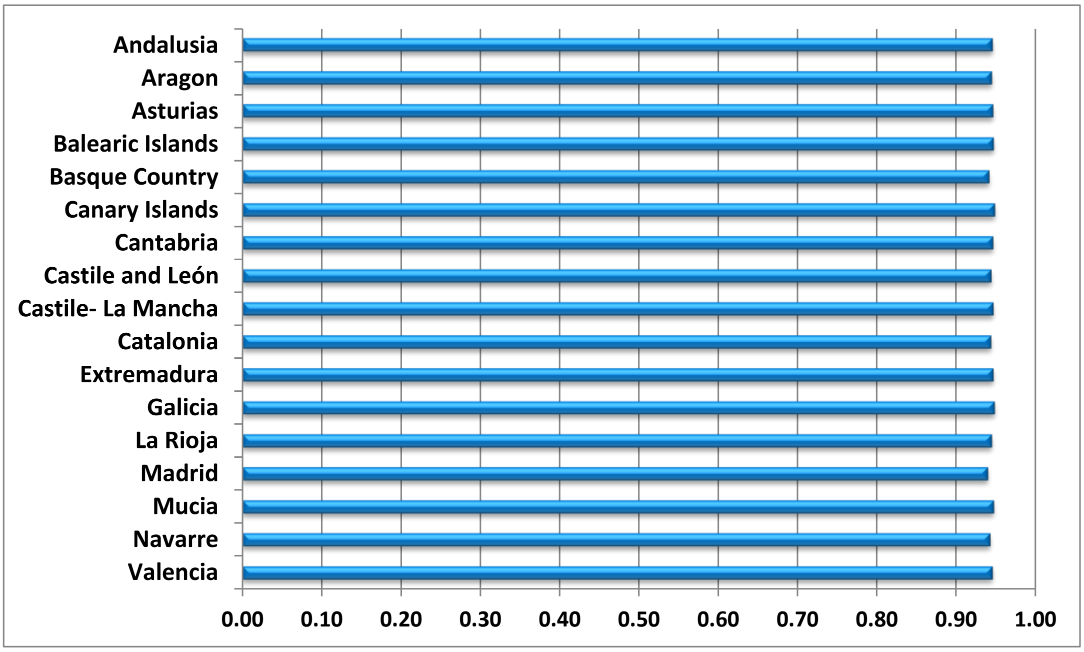


Figure 4.- Technical Efficiency Indexes (Delivery Centers) by Autonomous Community

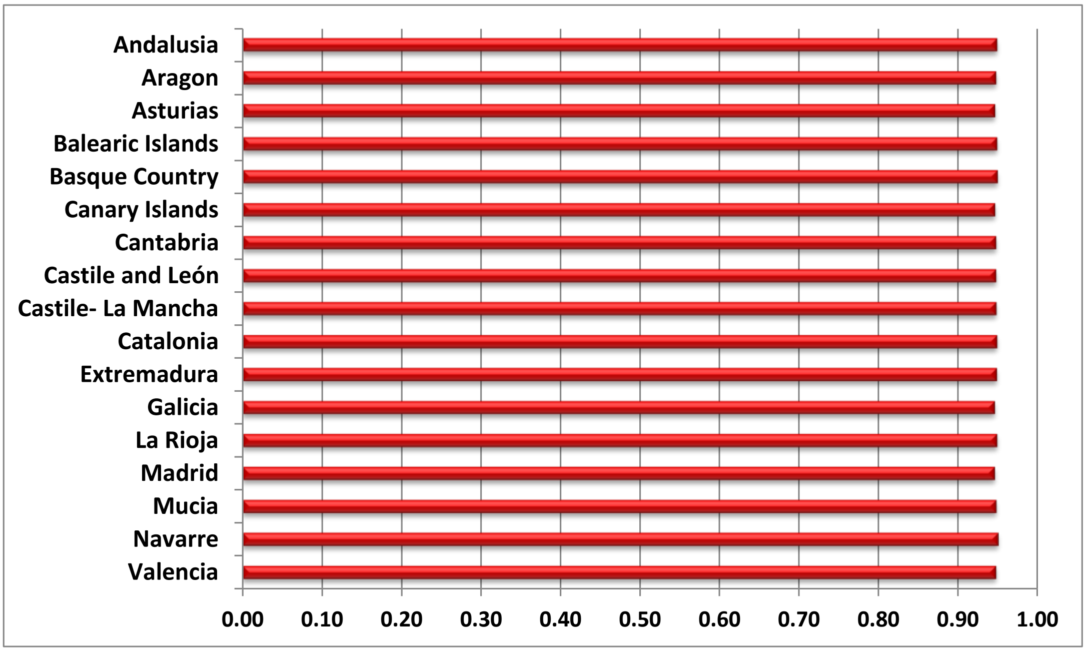


Figure 5. Technical Efficiency Indexes (all cost centers) by Autonomous Community

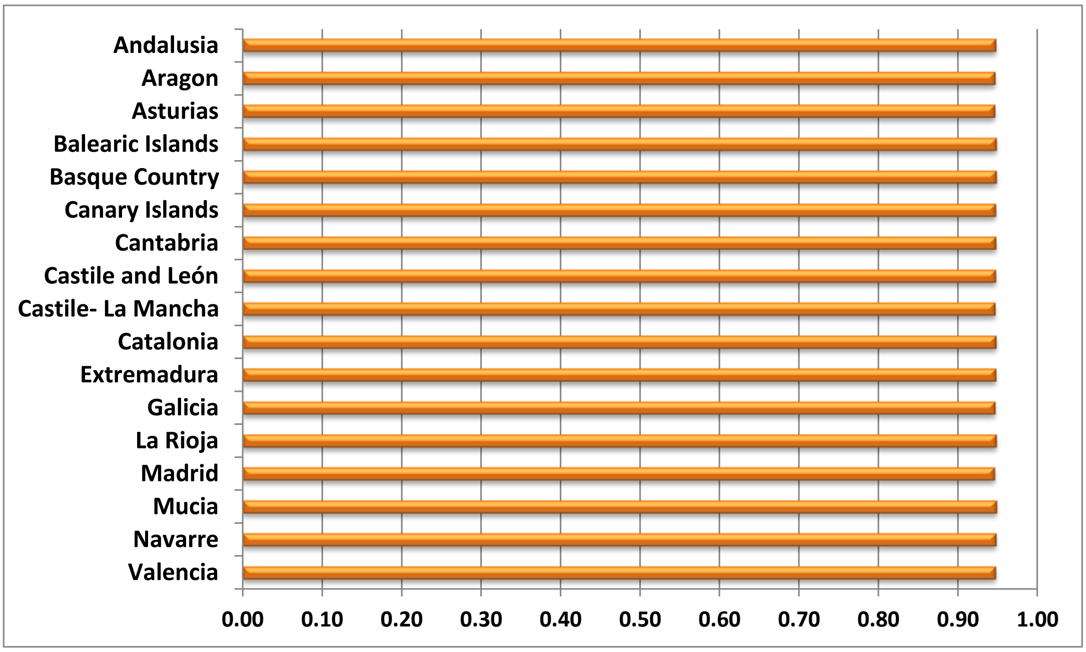


Table 3.- Technical Efficiency Indexes. Descriptive Statistics for all cost centers (years 2009 and 2010).

	Rural Offices	Urban Offices	Delivery Centers	All Offices
Mean	**0.9539**	**0.9457**	**0.9478**	**0.9473**
Median	**0.9540**	**0.9464**	**0.9484**	**0.9478**
Maximum	**0.9616**	**0.9697**	**0.9835**	**0.9835**
Minimum	**0.9465**	**0.8895**	**0.9041**	**0.8895**
Standard Deviation	**0.0028**	**0.0072**	**0.0086**	**0.0082**
Number of observations	**99**	**1.088**	**1.948**	**3.135**

Regarding allocative efficiency (AE), Figures 6, 7, 8 and 9 show the results for the allocative inefficiency indexes k_{ij} (see equation 11) of the rural offices, urban offices, delivery centers and for all cost centers by Autonomous Communities, respectively. More specifically, two types of indicators are shown. The first one ($k_{L, Tr}$) refers to how cost centers assign the labor factor (L) in relation to the transport elements (Tr). The second one, $k_{L\ ,\ CI}$, reflects the production units allocation of labor (L) in terms of intermediate consumption (IC).

Regarding the use that all cost centers (rural, urban and delivery centers) make of transport elements and intermediate consumption, we see that all $K_{L, TR}$ and $K_{L, CI}$ values are less than one, which denotes that the labor factor is used beyond its optimal proportion. However, there is an exception to this result. According to Figure 8 Madrid could be overusing intermediate consumption input with regard to labor ($k_{L,CI}$ greater than one). However, it is necessary to consider that this $k_{L,CI}$ value for Madrid is very close to one (the allocative efficiency value), as Figure 9 also shows. Similarly, Catalonia, Valencia, Navarra and Basque Country have $k_{L,CI}$ values close to the efficient level. Another finding from Figure 8 is that delivery centers have better allocative efficiency levels (closer than one) than the other types of cost centers.

Figure 6.- Allocative Efficiency Indexes (rural offices) by Autonomous Community

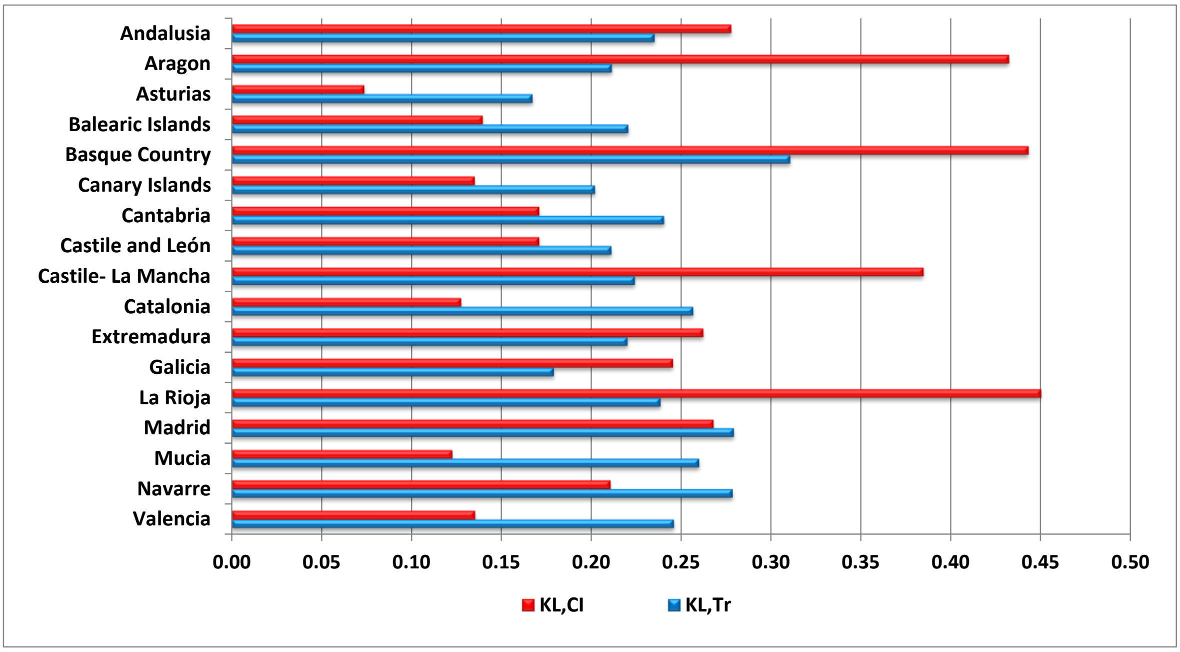


Figure 7.- Allocative Efficiency Indexes (urban offices) by Autonomous Community

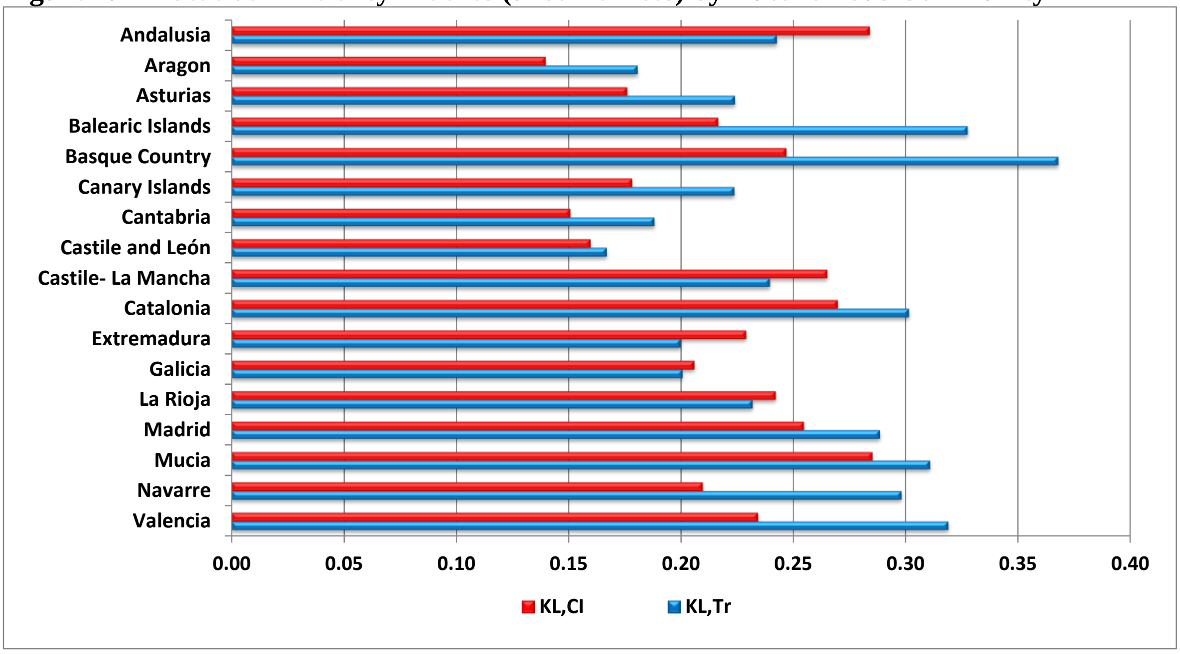


Figure 8.- Allocative Efficiency Indexes (Delivery Centers) by Autonomous Community

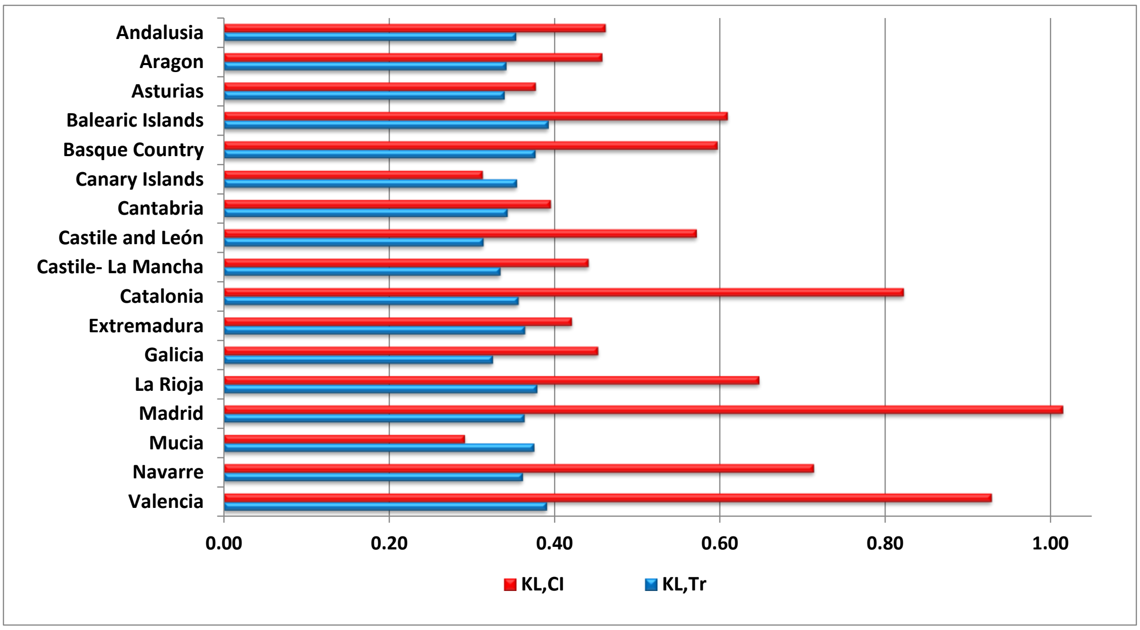
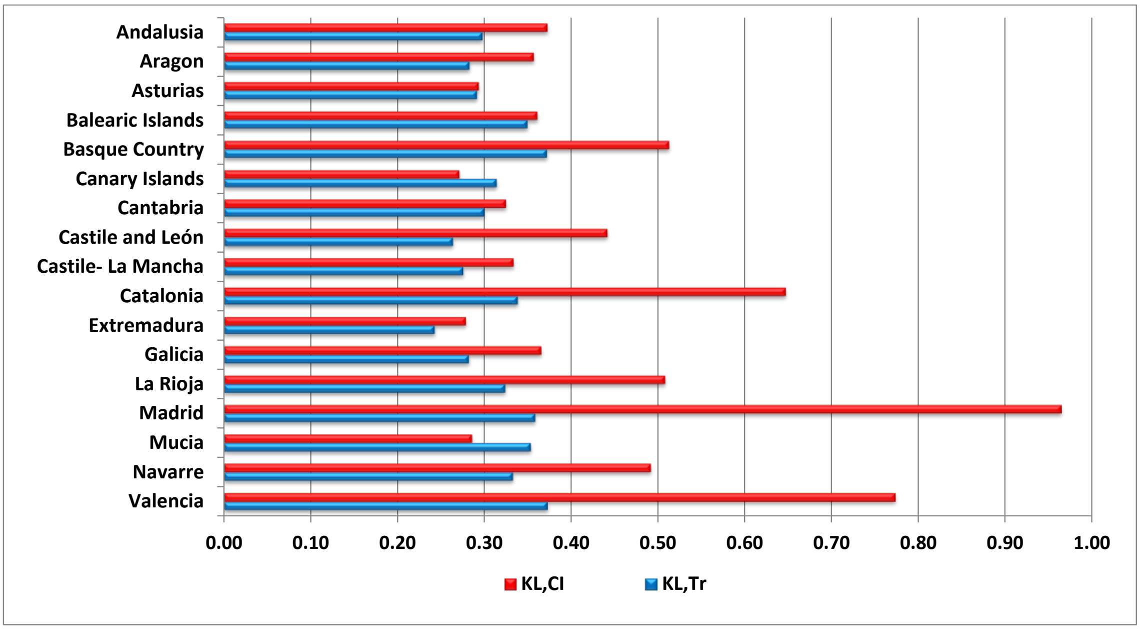


Figure 9.- Allocative Efficiency Indexes (all cost centers) by Autonomous Community



Finally, Tables 4 and 5 summarize the main descriptive statistics of the allocative efficiency indexes ($K_{L,Tr}$, $K_{L,CI}$) by cost center. On average, the degree of detected allocative inefficiency is similar between rural and urban offices, and it improves when we consider delivery units. However, we must conclude that the magnitude of the calculated allocative efficiency indexes should alert us because estimated allocative efficiency indexes show that *Correos*' cost centers units in Spain are far from using the input combinations in order to minimize production costs, especially considering the volume of their staff.

Table 4.- Allocative Efficiency ($K_{L,Tr}$) Indexes.
Descriptive Statistics for all cost centers (years 2009 and 2010).

	Rural Offices	Urban Offices	Delivery centers
Mean	**0.2296**	**0.2528**	**0.3558**
Median	**0.2261**	**0.2769**	**0.3564**
Maximum	**0.3745**	**0.6260**	**1.1781**
Minimum	**0.1271**	**0.0380**	**0.0420**
Standard Deviation	**0.0426**	**0.1099**	**0.0916**
Number of observations	**99**	**1.088**	**1.948**

Table 5.- Allocative Efficiency ($K_{L,Cl}$) Indexes.
Descriptive Statistics for all cost centers (years 2009 and 2010).

	Rural Offices	Urban Offices	Delivery centers
Mean	**0.2785**	**0.2427**	**0.6417**
Median	**0.1846**	**0.2223**	**0.2704**
Maximum	**1.6303**	**1.3638**	**2.9660**
Minimum	**0.0368**	**0.0324**	**0.0394**
Standard Deviation	**0.2636**	**0.1326**	**0.6641**
Number of observation	**99**	**1.088**	**1.948**

Additionally, this research presents an economic model to assess the effect of postal infrastructures on the operators' costs. The positive sign of the quasi-fixed coefficient indicates that *Correos*' current postal network infrastructure leads to savings on the variable costs of its production units. If we accept that different operators share *Correos*' productive technology, their gaining access to its postal network would be beneficial. As we have explained above, once the input distance function has been estimated, it is possible to calculate the shadow price of quasi-fixed input capital. To do so, just multiply the coefficient previously obtained from the input distance function given by expression $\frac{\partial \ln D(y, x, K)}{\partial \ln K}$ by the ratio variable cost/infrastructure stock following equation [23].

In the event that a market dealer would like access *Correos*' postal network, and since it would be easier for the regulator to know the company's variable costs than its fixed value, in order to approximate the "toll" of network usage we should multiply the estimated γ coefficient of equation [25] by the variable costs of the operator. That is, if C denotes the operator's annual variable cost, the amount to be demanded each year for granting access to the postal network would be, in monetary terms:

$$\frac{\partial \ln D(y, x, K)}{\partial \ln K} C = \hat{\gamma}\, C \qquad [29]$$

Equation [29] might be applied to any *Correos*' cost center or to any other postal operator wishing to use *Correos*' current postal network infrastructure. Moreover, it should be interpreted as the true valuation (shadow price) done by companies (operators) of those infrastructures.

In this way, from estimated coefficients the shadow evaluation of the cost to access the postal network has been quantified annually at an average of 13.46 % of the variable costs of each operator willing to use *Correos*' postal network.

6. CONCLUSIONS

In this paper technology of the *Sociedad Estatal Correos y Telégrafos* sector has been analysed. Concretely, we have analyzed economic efficiency (technical and allocative) and scale economies of the *Correos*' units of production. To do this, we have employed a methodology based of an input distance. Moreover, applying duality theory, we have also developed an economic model to assess the effect of postal infrastructures on the operators' costs. To this aim, we have taken into account 1,580 cost centers, analyzed between 2009 and 2010. In order to estimate econometrically the distance function, we have considered five types of outputs: ordinary or certified inter-city letters, ordinary or certified local letters, money orders and parcels. We have also used for the estimation three variables factors of production: labor, transport elements, intermediate consumption and the postal infrastructure as a quasi-fixed input. In order to carry out the estimation, bayesian econometrics techniques have been applied. This method has been revealed superior to the frequently applied classical maximum likelihood statistics, since this method considers unknown parameters as random variables, specified as prior distributions.

In the estimation of the distance function we have also considered the importance of the population served and of the environmental factors in the provision of services. The obtained results state that the centers with lower population -population to serve less than 50,000 inhabitants -appear as technically more efficient. This can be explained by the fact that precisely the centers that have to face with more population are those that would need more resources in order to serve it. As a result, it would not be rigorous to speak about greater inefficiency in this case but about a more costly activity in terms of the employed factors, a circumstance that should be taken into account by the market regulator.

Moreover, from the results we have contrasted the presence of increasing returns to scale in the production technology in the *Correos*' cost centers. More specifically, we estimated an average elasticity of scale equal to 1.048. On the other hand, the comparison of the different cost centers under study manifests that, on average, the different offices share similar indicators of technical efficiency (around 95%).

In addition to the calculation of the index of technical inefficiency, we were able to estimate if the different offices use optimally their factors of production from the perspective of the costs. In this regard, from the measurement of the allocative efficiency we deduce that, on average, the factor labor is systematically over employed in relation to other production inputs, transport elements and intermediate consumption. Madrid delivery unit is the sole exception because, unlike other centers, it overuses the intermediate consumptions variable with regard labor. Also, we have contrasted that, on average, the detected degree of the allocative inefficiency is similar between the rural and urban offices, being the situation improved in the case of delivery units. In short, the magnitude of the computed indices of allocative inefficiency allow us to conclude that the units of *Correos* are still quite far away from operating with the possible minimum costs of production.

Finally, the exploitation of the duality between the cost function and the distance function has allowed us to measure the relevance of the access to the postal infrastructures network regarding certain economic variables, especially in terms of production costs. The results have confirmed that stock of postal infrastructures (postal network) positively affects the production levels of the operators. Furthermore, we have presented a theoretical model that provides an easily applicable rule to approximate the monetary value that should be charged annually to each operator willing to use *Correos*' postal network.

7. REFERENCES

Aigner, D., Lovell, K. and Schmidt, P. (1977): "Formulation and estimation of stochastic frontier production function models", *Journal of Econometrics,* 6, pp. 21-37.

Borenstein, D., Becker, J. L. and Prado V. J. (2004): "Measuring the efficiency of Brazilian post office stores using data envelopment analysis", *International Journal of Operations and Production Management*, 24 (10), pp. 1055-1078.

Bradley, M., Colvin, J. and Perkins, M. (2006): "Measuring scale and scope economies with a structural model of postal delivery", *Working Paper Series in Economics* nº 195, University of Lüneburg.

Cazals, C., Florens J. P. and Soteri, S. (2005): "Delivery costs for postal services in the UK: some results on scale economies with panel data", in M.A. Crew y P.R. Kleindorfer (eds): *Regulatory and Economic Challenges in the postal and delivery sector*, Kluwer Academic Publishers, Boston, MA, pp. 203-212.

Cazals, C., Dudley, P., Florens, J. P. and Rodriguez, F. (2008): "Delivery offices cost frontier: a robust non parametric approach with exogenous variables", *The Review of Network Economics,* 7(2), pp.294-308.

Cazals, C., Dudley, P., Florens, J. P. and Jones, M. (2011): "The effect of unobserved heterogeneity in stochastic frontier estimation: comparison of cross section and panel with simulated data for the Postal", *The Review of Network Economics,* 10(3), pp. 1-22.

Coelli. T. and Perelman, S. (2000): "Technical efficiency of European railways: A distance function approach", *Applied Economics,* 32(15), pp. 1967-1976.

Cohen, R. H. and Chu, E. H. (1997): "A measure of scale economies for postal systems", in M.A Crew and P.R. Leindorfer (eds): *Managing change in the postal and delivery industry*, Kluwer Academic Publishers, Boston, MA, pp. 115-132.

D´Alcantara, G. and Amerlynck, B. (2006): "Profitability of the universal service postal provider under entry with economies of scale in collection", in M.A. Crew and P. R. Kleindorfer (eds): *Progress toward liberalization of the postal and delivery sector*, Springer, New York, pp. 39-58.

Deprins, D., Simar, L. and Tulkens, H. (1984): "Measuring labor-efficiency in post offices", in M. Marchand, P. Pestieu and H. Tulkens (eds): *The performance of public enterprises: concepts and measurement*, North-Holland, Amsterdam. pp. 243-267.

Escribano, A., González, P. and Lasheras, J. (2003): "Regulación y análisis económico del servicio postal en España", *Información Comercial Española*, 808, pp. 161-188

Escribano, A., González, P.; Lasheras, J. (2004): "Evolution and Analysis of the Market Structure of Postal Services in Spain**",** in M.A. Crew and P. R. Kleindorfer (eds): *Competitive transformation of the postal and delivery sector*, Springer, Massachusetts, pp. 287-310.

Färe, R. and Grosskopf, S. (1990): "A distance function approach to price efficiency", *Journal of Public Economics*, 43, pp. 123-126.

Färe, R. and Primont, D. (1995): *Multi-output production and duality: theory and applications*, Kluwer Academic Publishers, Boston, MA.

Farrell, M. J. (1957): "The measurement of productive efficiency", *Journal of the Royal Statistical Society, Series A, General*, 120, pp. 253-281.

Farsi, M., Filippini, M. and Trinkner, M. (2006): "Economies of scale, density and scope in Swiss Post's Mail Delivery", *Swiss Economics Working Paper* 5.

Felisberto, C. (2013): "Liberalisation, competition and innovation in the postal sector", *Empirical Economics*, 44, pp. 1207-1434.

Filippini, M. and Koller, M. (2012 a): "Cost efficiency measurement in postal delivery networks", *Quaderno 12-06*, University of Lugano.

Filippini, M. and Koller, M. (2012 b): "Economies of scale and scope in postal outlets under consideration of unobserved heterogeneity", *Annals of Public and Cooperative Economics*, 83(4), pp. 435-443

Filippini, M. and Zola, M. (2005): "Economies of scale and cost efficiency in the postal services: empirical evidence from Switzerland", *Applied Economics Letters*, 12, pp. 437-441.

Griffin, J. and Steel, M. (2007): "Bayesian stochastic frontier analysis using WinBUGS", *Journal of Productivity Analysis*, 27, pp. 163-173.

Griffin, J. and Steel, M. (2008): “Flexible mixture modelling of stochastic frontiers”, *Journal of Productivity Analysis*, 29, pp. 33-50.

Hadri, K. (1999): “Estimation of a Doubly Heteroscedastic Stochastic Frontier Cost Function”, *Journal of Business Economics and Statistics* 17 (3), pp. 359-363

Horncastle, A., Jevons, D., Dudley, P. and Thanassoulis, E. (2006): “Efficiency analysis of delivery offices in the Postal Sector using Stochastic Frontier and Data Envelopment Analysis”, in M. A. Crew and P. R. Kleindorfer (eds): *Liberalization in the postal and delivery sector*, Edward Elgar, Cheltenham, UK and Northampton, MA, pp. 149-164.

Hunt, L. and Lynk. E. (1991): “An empirical examination of the case for post office divestiture in the UK”, *Scottish Journal of Political Economy*, 38, pp. 177-191.

Iturralde, M. J. and Quiros, C. (2008): “Liberalización y eficiencia en el sector postal de la Unión Europea”, *Economía Industrial*, 361, pp. 121-132

Koop, G., Osiewalski J. and Steel, M. (1997): “Bayesian efficiency analysis through individual effects: hospital cost frontiers”, *Journal of Econometrics* 76, pp. 77-106.

Mizutani, F. and Uranishi, S. (2003): “The Post Office vs. Parcel Delivery Companies: Competition effects on costs and productivity”, *Journal of Regulatory Economics*, 23, pp. 299-319

Morales Piñero, J. (2009): *Reforma de empresas públicas y su efecto en la eficiencia y la eficacia: el caso de los servicios postales de España*, Universitat Autònoma de Barcelona.

Moriarty, R., Yorke, S., Harman, G., Cubbin, J., Meschi, M. and Smith, P. (2006): Economic analysis of the efficiency of Royal Mail Units and the implications for Regulatory Policy, in M. A. Crew and P. R. Kleindorfer (eds): *Liberalization in the postal and delivery sector,* Edward Elgar, Cheltenham, UK and Northampton, MA, pp. 165-182.

Palm, A. (1987): “La performance technique de Dix Huit-services postaux”, *Annales de L´ Economie Publique, Sociale et Cooperativa,* 3, pp. 305-319.

Pateiro, C., García, J. M. and Barreiro, J. M. (2012): “Las dimensiones territoriales urbana e interurbana de la liberalización del sector postal y cuestiones de ineficiencia del acceso a la red”, *Revista de Economía Pública Urbana*, 17, pp. 79-105

Perelman, S. and Pestieu, P. (1994): “A comparative performance study of postal services: a productive efficiency approach”, *Annales d´Economie et de Statisque*, 33, pp. 187-202.

Register, C. A. (1988): “Technical efficiency within the US postal services and the postal reorganization act of 1970”, *Applied Economics*, 20, pp. 1185-1197.

Rogerson, C. M., Takis, W. M. and Lenard, T. M. (1993): “Economies of scale and scope and competititon in postal services”, in M. A. Crew and P. R. Kleindorfer (eds): *Regulation and the nature of postal delivery services*, Kluwer Academic Publishers, Boston, MA, pp. 109-132.

Shephard, R. W. (1953): *Cost and Production Functions*, Princeton University Press, Princeton.

Shephard, R. W. (1970): *Theory of Cost and Production Functions*, Princeton University Press, Princeton.

Van den Broeck, J., Koop, G., Osiewalski, J. and Steel, M. (1994): “Stochastic frontier models: A Bayesian perspective”, *Journal of Econometrics*, 61, pp. 273-303.