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The Impact of Economic Regulation on the Efficiency of European Railway Systems

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Abstract: In recent years, European railway regulation has been subject to major reform, with the powers, independence and responsibilities of rail regulators across Europe strengthened considerably. This paper studies the impact of these reforms on the efficiency levels of a panel of 17 European railways (2002-2010). The novelty lies in the incorporation of a multi-dimensional rail regulation index – capturing the complexity of regulatory powers and activities – into an econometric framework alongside other reform variables. Our results suggest that the cost-reducing benefits of regulatory reform depend on the degree of (actual or desired) market openness, vertical structure, and the intensity of network usage.

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1.0 Introduction

Starting in the 1990s, the European Commission embarked on an ambitious programme of reforms aimed at revitalising Europe's railways. The context for the reforms was the deteriorating performance of rail in terms of modal share, perceived inefficiencies in the operations of the incumbent, state-owned national monopolists, and the resulting financial need for increased subsidies from the government. Increased competition was and is seen as crucial to achieving a turn-around in performance, underpinned by strengthened economic regulation and structural unbundling of key railway functions.

The reforms have been implemented through three Railway Packages in 2001, 2004, and 2007, with the final stage of opening up passenger markets to competition contained in the 4th Railway Package approved in 2016. Importantly, in respect of economic regulation, a recast of the First Railway Package was approved in 2012 (European Commission, Directive 2012/34/EC, "Recast" hereafter). These legislative changes have led to the creation of new regulatory bodies with increased powers to act in the European railway sector, thus heralding a transformation in rail economic regulatory practice across Europe. The study of the impact of the resulting changes in economic regulation on the productive efficiency of rail systems in Europe is the focus of this paper.

There are two mechanisms through which economic regulation could impact on productive efficiency. First, direct actions of regulatory bodies influence the operations of regulated rail infrastructure managers, ensuring their efficiency in terms of the level of costs, quality of service and investment plans. Indirect actions seek to prevent discrimination, in part through ensuring that the charges paid by train operators to access the rail infrastructure are fair, transparent and efficient, with the aim of promoting competition. Greater competition, in turn, is expected to have an indirect impact on the productive efficiency of the rail system.

The literature (for instance, on US railroads) also emphasises the potentially harmful effects of excessive or misguided regulation (Burton and Sims, 2016; Mayo and Sappington, 2016). However, as suggested by the general regulation literature, context is key. Whereas in the US, rail infrastructure is mostly privately owned, and there remains some competition between different infrastructure providers, in Europe, rail infrastructure is generally a publicly owned monopoly. Also, in European railways there has been major concern around the weaknesses of rail regulation, leading to EU legislation ensuring independence of regulators previously contained within Transport Ministries. Our focus is therefore on studying the impact of giving regulators increased independence and powers to drive increased focus on cost efficiency and the promotion of competition.

Whilst there is an extensive literature studying the impact of rail reforms in Europe (see Mizutani et. al., 2015; Smith and Nash, 2014 for reviews), to date the literature has focused on studying the cost impact of introducing competition and industry restructuring, most notably in the form of horizontal separation (separation of passenger and freight operations) and vertical separation (separation of infrastructure and train operations). Where regulation has been included in previous studies, it has been incidental to a wider study of rail reforms, and has been treated in a simple way (via simple dummy variables, capturing whether the regulator is independent or not, based on whether the country has adopted one of three types of regulatory model – the Ministry model, special regulatory model or railway authority model; see Wetzel, 2008; Friebel et. al., 2010). Thus, previous studies have not been able to study the impact of the multiple activities and complex remits of rail regulatory bodies in Europe. Further, past studies are limited by characterising regulatory systems according to labels (e.g. the type of regulatory model adopted) rather than what regulators do and what powers they have.

Our paper is novel in several respects. Firstly, the empirical analysis includes a multi-faceted regulation index that better captures the complexity and subtleties of regulatory powers and activities in different regimes. This index has been developed by extracting the rail regulation data from the well-established IBM and Kirchner Rail Liberalisation Index reports (2002; 2004; 2007; 2011). This development takes the analysis beyond previous studies that have characterised economic regulation via "yes / no" dummy variables. Secondly, based on this index, we are then able to undertake rigorous, econometric testing of the impact of the strength of economic regulation on rail system costs for the first time in the literature. Thirdly, in relation to the impact of wider reforms, our paper considers a rich cost function specification that reflects the complex interrelationships between the effects of industry structure, competition, and economic regulation on railway efficiency. The paper thus builds on past research on the impact of railway reforms, generating new results with important policy implications, particularly concerning the circumstances - linked to other reforms, such as vertical separation - in which stronger regulation may be beneficial from a cost perspective.

The paper is structured as follows. Section 2 focuses on the legislative background to the European railway reforms of recent decades. Section 3 reviews the literature on the effects of railway reforms. It also includes a review of the literature on what constitutes an "ideal economic regulatory body" as a benchmark against which to evaluate our regulatory index variable. Section 4 illustrates the data and methodology, with emphasis on the construction of the regulation index. The econometric results are discussed in Section 5. Section 6 concludes.

2.0 Background on legislation on railway reforms

Multiple European Directives and two Regulations, four railway packages and one recast (regarding the First Railway Package) have shaped the policies defining the modern era for European railways. It is useful to distinguish between the early and more recent legislation. In the 1990s a start was made on structural unbundling – that is, vertical and horizontal separation (see below) - and on setting the rules for participation in the rail industry. However, it is only post-2000 that three legislative Railway Packages have built on this earlier progress, to liberalise entry into the freight and international passenger sectors and to set clear rules regarding structural unbundling, safety and regulation. On regulation, the main changes only came about with the Recast; though prior to the Recast there was considerable variation in the extent of powers and independence of rail regulators across Europe with substantial changes over time prior to 2012 (see Figure 1).

The Recast was aimed at addressing deficiencies in the regulatory and competitive environment. Firstly, new entrants faced barriers to gaining access to the market and the protection given to incumbents led to a low level of competition. Secondly, the monitoring activities exerted by national regulatory authorities were argued to be inadequate as, in most cases, deficiencies in their autonomy, competences and powers became clear. In particular, in many cases, regulatory functions were housed within ministerial bodies, limiting the independence of the regulator from government, and reducing the ability of the regulator to pursue non-discriminatory actions and monitoring of the quality of infrastructure and efficiency of infrastructure managers. The latter point is important since governments may wish to restrict funding to railways because of fiscal constraints, and therefore an independent regulator can potentially ensure funds available are consistent with the demand placed upon infrastructure managers by government. The declining quality of railway infrastructure due to limited funds has affected several EU countries.

The Recast significantly strengthened the powers and independence of regulatory authorities. Their remits were extended, encompassing the access to and charging for railway services, thus stimulating market entry and preserving fair competition (Article 56). The independence of these bodies was increased, requiring autonomy from public entities which may pressurise their decisions (Article 55), these typically being government bodies and railway undertakings. Also the activities of sanctioning, audit, investigation and appeals procedures were strengthened, and greater cross-border collaboration encouraged (Article 57).

Furthermore, Article 30 opened the possibility for the stipulation and management of "contracts" between regulators and infrastructure managers, setting out the role of regulators in evaluating the adequacy of funding needed to guarantee the condition and performance of the infrastructure for the period of the contract (the legislation also allows this approach to be implemented through a contract with government, rather than the regulatory body).

These legislative interventions reflect the fact that economic regulation of European railways is complex and multi-dimensional. The necessity of investigating this complexity is addressed by employing a regulation index, able to capture the multi-dimensional nature of economic regulation in railways. As explained in Section 4.1, our regulation index is based on the Rail Liberalisation Index reports published by IBM and Kirchner (2002; 2004; 2007; 2011), which cover the period 2002-2010. Whilst the data in our study does not extend as far as 2012 when the Recast was finally implemented, as noted above, substantial progress in strengthening the powers and independence of regulators nevertheless occurred ahead of 2012 and within the period of our sample (see Figure 1).

3.0 Literature review

Here the relevant literature is first summarised (3.1). EU rail regulator objectives are then briefly discussed (3.2) in order to provide the link between the theoretical literature on the impact of institutional arrangements on rail efficiency and the empirical model.

3.1 Summary of relevant literature

The literature on railway economics has produced many studies attempting to assess the impact of railway reforms, reaching diverse conclusions. However, these studies have concentrated on changes in railway organisation, designed to increase competition and thus reduce costs and increase rail market share (see Mizutani et. al., 2015; Cantos et. al., 2010; Growitsch and Wetzel, 2009).

Since the focus has been on other aspects of the reforms, regulation impacts have often been ignored, and when included, regulation has been measured in a simple way (through dummy variables capturing the presence, or not, of an independent regulator), failing to detect the multiple activities and complex remit of regulatory bodies. Looking at the findings, Wetzel (2008) associates independent regulation with lower costs. Friebel et al. (2010) find similar benefits, especially when this reform is accompanied by sequential reforms on structural separation and open access to the market.

The literature leaves an important gap, namely the in-depth study of the impact of economic regulation on rail system costs, going beyond the utilisation of dummy variables to characterise the regulatory system. In seeking to specify appropriate regulatory variables it is useful to consider what an ideal regulator might look like and how the strength (or not) of economic regulation in a particular regime may therefore be measured as compared to this ideal.

Within the transport area and, indirectly, railways, Table 1 summarises the set of multiple ideal characteristics resulting from an OECD Round Table event in 2011 (OECD/ITF 2011). A key cornerstone of strong economic regulation is the independence of the regulator from political influence. Appropriate human and financial resources move towards this direction and help the implementation of autonomous actions by the regulator (as opposed only to being reactive), in particular directed at intervening against discriminatory practices. Moreover, the regulator's functions should be conducted with stability and predictability, transparency, accountability and cost-effectiveness. Table 1 also highlights system efficiency as a key goal of economic regulation; for further details see Benedetto et al. (2017). <Table 1 here>

The characteristics of an ideal regulator should be weighed against evidence on the adverse impacts of excessive or unintended regulation, as mentioned in the introduction; though, as noted, our focus here is on the potentially positive impacts of stronger regulatory powers to promote competition and in turn the quality and efficiency of European railways. The Recast has sought to empower regulators, addressing those ideal characteristics previously described. However, ensuring that regulators have clear powers to challenge infrastructure managers on their efficiency performance has so far proved difficult in railways; unlike comparable sectors, where regulators have stronger powers of efficiency determination (for instance, in the energy sector; Haney and Pollitt, 2011 and 2013).

The construction of the regulation index used in our study, based on the Rail Liberalisation Index reports (IBM and Kirchner; 2002, 2004, 2007 and 2011), is therefore directed at the detection of those drivers which reflect the ideal characteristics discussed above. By comparing the aspects of regulatory powers and functions covered by our index (Table 2) with the ideal (Table 1) we see that these are closely matched. In future research, these drivers may be integrated with measures better able to capture particular activities such as the ability to demand data on efficiency and financial performance from infrastructure managers, as well as the methodological expertise in analysing this type of data.

We note that the wider literature on the impact of regulation in other sectors also highlights the importance of the multi-faceted nature of economic regulation in a particular sector (see Zhang et.al., 2008; Grajek and Roller, 2012). In our study, being able to construct a regulatory index, taking account of this complexity, plays a decisive role in the analysis of the impact of the railway reforms on efficiency.

3.2 EU Rail regulatory objectives

Viewed in the context of the wider aims of EU rail policy, namely to introduce within-mode competition, the primary role of rail regulators in Europe is to prevent discrimination against new entrants on issues such as track access charges and allocation of capacity. A secondary, but important role for rail regulators is to ensure the efficiency of the monopoly infrastructure manager (Nash et. al., 2018), though as noted earlier this role is more developed in some countries than others.

Given these primary objectives of rail regulators, it is pertinent to ask what impact stronger regulation has had in improving railway efficiency, both through direct pressure on the infrastructure managers, and indirectly through the promotion of competition.

4.0 Data and methodology

This section covers the construction of the regulation index (4.1), pivotal in this paper. The economic rationale behind the model choice will follow (4.2), together with the description of the data sources and the remaining variables (4.3).

4.1 Construction of the regulation index

The IBM and Kirchner studies (2002; 2004; 2007; 2011) provide an overview on the state of the liberalisation processes in the European Union countries, formulating rankings in order to evaluate which countries are denoted by "advanced", "scheduled" and "delayed" progress. The evidence is summarised by assigning the scores (on a 1 to 10 scale) for progress in different areas of reform, broadly clustered into: the legislative transposition of the European directives and regulations; the effective implementation of these policies; and the competitive characteristics of the markets. <Table 2 here>

To develop our analysis, we extract those drivers which are specifically related to regulation, which are then used to construct a new regulation index for each country and time period in our sample (see Table 2). The index includes regulatory drivers and sub-drivers, and relative scores, for 17 European countries. The versions of the reports were published at staggered intervals; hence, the quantitative information for the intervening years between reports is estimated through an averaging approach, calculating the mean between the values connected to two consecutive studies. Where changes to the scores for certain drivers are greater than a certain threshold (chosen to equal ± 3 points; noting that the scores for individual drivers range from 1 to 10, so a 3 point change might be considered important), legislative or operational details have been sought in order to determine the reasons underlying these changeovers. When a driver is not present for a specific year, the constant scores assumption is instead employed, inserting the value connected to the temporally closest report, where that factor is examined.

In relation to the weights, these are held constant for the entire temporal interval to the ones chosen by IBM and Kirchner studies in the most recent report. This choice reflects the presumption that, with time, the authors accumulated the necessary experience to design an increasingly accurate weighting system. Scores and weights could be seen to be subjective, being determined by the reports' authors, but a degree of subjectivity is inevitable in this type of study. It is not clear that using different weights would be superior as they would likewise involve (a different) set of judgements; and such an approach would distract from our main purpose which is to study the impact of regulation on costs, with regulation being measured by the well-established, widely-used IBM index[1]. An alternative approach would have been to include dummy variables for different aspects covered by the index. However, from a practical perspective, it would also include the addition of many more dummy variables and interactions, which would be cumbersome particularly given the other reform variables included in the model and our aim to link regulatory power with vertical structure. Further, such an approach risks ignoring the complexity and subtlety of rail regulation, including the importance of combinations of different regulatory powers. The range of activities performed to construct the regulation index is summarised in Table 3. Figure 1 shows the trends in the regulation index for the railway systems in our sample. <Table 3 here> <Figure 1 here>

4.2 Economic rationale behind the model choice

We consider the a priori expectations regarding the effects of regulation on costs firstly in respect to the effects of regulation when considered on its own; and second, when interacted

[1] Laabsch and Sanner (2012) model modal split in a multivariable design which includes rail industry structure and market opening, as measured by the IBM index in the 2007 and 2011 reports. Growitsch and Wetzel (2009) use the 2004 IBM index to study the correlation between economies of scope and level of market opening. For other examples where the IBM index was used as a data source, see Wetzel (2008) and Cantos et al. (2010).

with other reforms. In terms of direct interventions, regulatory control of rail infrastructure managers may result in improved cost efficiency, better planning and prioritisation of new investment and, more widely, improved quality. At the same time, there is a risk that heavy regulation becomes burdensome and could increase costs.

Indirect actions seek to prevent discrimination, in part through ensuring that the charges that train operators pay to access the rail infrastructure are fair, transparent and efficient, with the aim of promoting competition. Greater competition, in turn, would be expected to have an indirect impact on the productive efficiency of the rail system. That said, on-rail competition could in some cases lead to higher costs (for a given traffic level) through loss of economies of density. In addition, with regard to the interaction between regulation and competition, when actual competition is absent (though permitted by law), regulatory resources targeting the non-discriminatory practices may appear unjustified from a cost-benefit perspective.

The level of interdependence between the infrastructure manager and train operating companies in a railway system can be particularly high, especially when decisions on investments, access and timetabling, and real time operations are involved. Here a regulatory body may have an important role to play as an impartial third party overseeing the transaction process, ensuring non-discriminatory access to the network, particularly where the rail infrastructure manager is part of an integrated or holding company structure, and helping to reduce transaction costs created by unbundled configurations. However, even a strong regulator may not be able to overcome the potential discriminatory behaviour of an integrated incumbent. It may also be argued that, on the contrary, when the mechanisms dealing with transactions between different parties, and within the same holding company structure, are transparent, the presence of a regulatory third party may be superfluous.

In summary, there is no clear cut expectation on the impact of stronger and more independent regulation on rail system costs, though overall we would expect it to bring about a reduction in costs. However, regulation and its impacts will surely be closely interrelated with the structural setting and the degree of competition. The results presented below investigate these points empirically.

4.3 Data sources and model

We utilise part of the dataset developed in Mizutani et. al. (2015) and earlier in van de Velde et. al. (2012) and Mizutani and Uranishi (2013), which in turn mostly derives from the International Union of Railways (UIC), supplemented by data provided by Community of European Railway and Infrastructure Companies (CER) members. A summary data description is set out below; for further details see Mizutani et. al. (2015) and van de Velde et. al. (2012).

For our analysis we are limited by the period and countries covered by the IBM index. Thus, our sample covers 18 European railways (2002-2010; the sample size is 130; see Table 4). Since our focus is on the impact of European legislation, this is appropriate. <Table 4 here>

Turning to the model formulation, we estimate a translog cost function and the associated system of cost share equations. For ease of comparison with the rail reform literature, we adopt as our starting point two model specifications (in terms of the explanatory variables) utilised in Mizutani et. al. (2015). Model 1 is a single-output (total train km Q), hedonic model with the following hedonic characteristics: passenger revenue share (H_{PR}); passenger load factor (H_{LF}); passenger trip length (H_{PTL}); and average freight train length (H_{FRC}). Model 2 is a multiple-output model, with separate variables for both types of operations (revenue passenger km (Q_P) and revenue tonne km (Q_F)).

We also develop a second version of the multiple-output model that we consider better reflects the underlying factors describing costs. Model 3 has two separate outputs, but these are defined as passenger and freight train km (Q_{PTKM}; Q_{FTKM}), rather than passenger km and freight tonne km. This third model is justified by the consideration that costs produced by the formation of the railway outputs are only partially accounted for by measurements centred on passenger km and freight tonne km. Train kilometres run are heavily influenced by public service obligations in the case of passenger services and the mix of types of traffic in the case of both passenger and freight traffic. Model 3 also retains some of the hedonic characteristics of Model 1, though with some changes to reflect the different specification of the outputs between Models 1 and 3. In particular, in Model 3 we exclude passenger revenue share (H_{PR}) and replace load factor for passenger transport (H_{LF}) with number of cars per passenger train (H_{PXC}). The removal of H_{PR} is justified by the fact that the shares of passenger and freight traffic are allowed for directly in the disaggregated train km variables. Replacing load factor of passenger service by train length is justified by the belief that it is the formation of the train rather than the number of passengers carried that is the primary influence on costs. We consider that this approach enriches the specification to reflect the fact that costs will be driven by output characteristics (such as trip length) as well as outputs (disaggregate passenger and freight measures).

The total cost measure is equal to the sum of the total infrastructure costs of the main network manager (except in Switzerland where there are two infrastructure companies) and the costs incurred by the totality of passenger and freight companies operating on that system. While the computation of this cost measure is straightforward for integrated organisations, in the case of separated entities, infrastructure charges are subtracted from operator costs (to avoid double-counting). In most cases subsidies are included as revenue (therefore not impacting on costs), but in previous work (van de Velde et. al., 2012 and Mizutani et al., 2015) it was noted that in some cases some subsidies are netted off against depreciation costs and it was not possible to fully address this issue in those studies; the issue is however mitigated to some extent as the effect will be captured through reduced capital prices. Other issues include the question of how to include new entrants to the market which is particularly important in countries where new entry is high (for details of the approach taken, see van de Velde et. al., 2012). The model includes input prices for labour, energy, material and capital (for their computation, see Mizutani et al., 2015). Alongside total route length (N), a technology (T) variable is included, defined by the percentage of electrified lines[2].

Turning to policy variables, our starting point is the inclusion of those variables previously tested in the literature, namely: proportion of freight in total revenues (R), measured as the ratio of revenues from freight transport to total rail transport revenues; vertical separation (D_{Vs}), as compared to vertical integration (D_{VI}) or the holding company (D_{HC}) model[3], and also linking this relationship to the degree of traffic intensity on the network – measured by train density (V), defined as the number of train km per route-km (per day); horizontal separation of passenger and freight services (D_{Hs}); the existence (or not) and intensity of passenger competition (CMP) and the existence (or not) of freight competition (D_{CF}); and finally, as the main contribution of this paper, a multi-faceted regulation index (REG). The REG variable is also interacted with the vertical separation dummy variable to test the link between these two important reforms; interactions between regulation and other variables were tested and rejected.

As in van de Velde et.al. (2012) and Mizutani et. al. (2015), our passenger competition measure, CMP, consists of four dummies (0-1), depicting: no competition; competition is legally permitted; up to 10 per cent of the market subject to tendering or open-access; up to 25 per cent of the market subject to tendering or open-access; through to competition across the whole network. By summing the individual dummies, an overall measure is then obtained for each railway system. This measure represents an advance compared to the previous literature which had not distinguished between differing degrees of competitive entry. The same depth of information was not available for the freight markets (see van de Velde et al., 2012), hence a

[2] A time trend variable was also tested to represent technology (not retained as the preferred model; see also Mizutani and Uranishi, 2013).
[3] D_{HC} is the omitted dummy variable. To retain model invariance to the choice of excluded dummy requires an interaction term for the excluded dummy (which was dropped on statistical grounds).

simple dummy variable is used in this case (D_{CF}). Descriptive statistics for the key policy variables used in this study are set out in Table 5. <Table 5 here>

We do not consider endogeneity to be a problem in this case. Changes in the structure and regulation of railways have been driven in part by cross-European directives led by the European Commission rather than individual countries. Of course, some countries in Europe appear to have a greater appetite for market opening than others, but such effects are common across network industries in general, and there is no evidence that these tendencies relate to economic factors facing railways within individual countries. As with the past literature we thus consider regulatory reforms to be driven by factors exogenous to the railways[4].

We also considered the use of fixed effects in the estimation of the models to control for unobserved heterogeneity and (related to the above point) to guard against omitted variable bias where country-specific factors might be correlated with the regressors (in particular the policy variables). However, as also pointed out by Mizutani et al. (2015), in studies of rail reforms there is little within variation for some of the key policy variables (particularly with regard to vertical structure) which limits the approach. Following the previous literature, the heterogeneity between railway systems is instead captured by including variables capturing rail characteristics. In our case the use of fixed effects does not in any case greatly impact on the conclusions regarding the regulation variables in our preferred model[5].

The econometric model specification (for Model 1 – total train km) is shown below (the multiple-output models, Models 2 and 3, derive from this specification):

$$\ln TC = \alpha_0 + \alpha_Y \ln Q + \sum_f \eta_f \ln H_f + \sum_j \beta_j \ln w_j + \gamma_N \ln N + \tau_T T +$$

$$\left(\frac{1}{2}\right) \alpha_{YY} (\ln Q)^2 + \sum_j \alpha_{Yj} (\ln Q)(\ln w_j) + \alpha_{YN} (\ln Q)(\ln N) + \alpha_{YT} (\ln Q)(T) +$$

$$\left(\frac{1}{2}\right) \sum_k \sum_j \beta_{jk} (\ln w_j)\,(\ln w_k) + \sum_j \beta_{jN} (\ln w_j)(\ln N) + \sum_j \beta_{jT} (\ln w_j)\,(T) +$$

4 See Mizutani et al. (2015), Mizutani and Uranishi (2013), van de Velde et al. (2012) and Friebel et al. (2010).
5 Though it did produce counter-intuitive coefficients on other variables.

$$\left(\frac{1}{2}\right)\gamma_{NN}(\ln N)^2 + \gamma_{NT}(\ln N)(T) + \left(\frac{1}{2}\right)\tau_{TT}(T)^2 + (\delta_{VS1} + \delta_{VS2}\ln V + \delta_{VS3}\ln R + \delta_{VS4}\ln REG)\, D_{VS} + \delta_{VI}D_{VI} + \delta_{HS}D_{HS} + \delta_{REG}REG + \delta_{CMP}CMP + \delta_{CF}D_{CF} \quad (1)$$

As noted, the differences between Models 1-3 relate to the output Q and hedonic specification H_f. Otherwise, the functional form remains the same.

Linear homogeneity of degree one in input prices is imposed in the usual way via the following restrictions: $\sum_j \beta_j = 1$, $\sum_k \beta_{jk} = 0, \sum_j \beta_{jN} = 0, \sum_j \beta_{jT} = 0, \sum_j \alpha_{Yj} = 0, \sum_j \alpha_{mj} = 0$, $\beta_{jk} = \beta_{kj}, \beta_{jN} = \beta_{Nj}, \beta_{jT} = \beta_{Tj}, \alpha_{Yj} = \alpha_{jY}, \alpha_{YN} = \alpha_{NY}, \alpha_{YT} = \alpha_{TY}, \alpha_{mn} = \alpha_{nm}, \alpha_{mj} = \alpha_{jm}, \alpha_{mN} = \alpha_{Nm}, \alpha_{mT} = \alpha_{Tm}, \gamma_{NT} = \gamma_{TN}$. Shephard's Lemma is applied to the total cost function, from which the input share equations are obtained as follows:

(Model 1): $s_j = \beta_j + \alpha_{Yj}(\ln Y) + \sum_k \beta_{jk}(ln\, w_k) + \beta_{jN}(lnN) + \beta_{jT}(T),$ (2)

where s_j: input j's share of total cost. The related equations for Models 2 and 3 have the same functional form, but include disaggregated measurements of the outputs.

The system is estimated using the seemingly unrelated regressions (SUR) method. In order to facilitate interpretation, each variable is divided by the sample mean.

5.0 Econometric results

Here we discuss the general statistical properties of the results, focusing on the parameter estimates on the policy variables. Policy implications are explored in the last sub-section.

5.1 General statistics properties and production-related variables

The SUR econometric results are presented in Table 6. We have three basic model specifications, which differ based on the outputs and hedonic variables selected. For each of these three models we have two variants, first excluding and then including variables capturing the presence of competition. Hence, six models are estimated: (i) Case 1 (total train km as the single output, with output hedonic characteristics as in Mizutani and Uranishi, 2013); (ii) Case 2 (two outputs: revenue passenger km and revenue tonne km as in Mizutani and Uranishi 2013);

(iii) Case 3 (two outputs: passenger train km and freight train km, together with output hedonic characteristic variables); (iv-vi) Cases 4-6 (Cases 1-3 + competition dummies). <Table 6 here>

We prefer the models with disaggregated train km (Cases 3 and 6) based on AIC and BIC criteria[6]. In addition to the imposition of constraints to ensure homogeneity and symmetry conditions, monotonicity was tested and verified for all the 6 cases[7]. Global concavity in input prices for all cases was tested; the condition holds for around three quarters of the sample (this compares favourably to previous studies, such as Mizutani and Uranishi, 2013)[8]. There is no convenient way of imposing global concavity, and doing so may affect the flexibility properties of the translog (see for example Coelli et. al., 2005). Further, concavity violations do not necessarily imply the lack of an underlying optimisation process (Wales, 1977).

The coefficients on the outputs, input prices, and control variables are in line with past studies. Regarding the hedonic characteristics, passenger travel length (H_{PTL}) and average freight train length (H_{FRC}) are expected to increase costs as the results show. Passenger revenue share (H_{PR}), included in Cases 1 and 4, is not found to have a significant impact.

Passenger load factor (H_{LF}) takes an unexpected (and statistically significant) negative sign when included (Cases 1 and 4). This measure is computed as passengers per train divided by seat capacity. As noted above, in Case 3 (and 6) we replace the load factor variable with a measure of train length (H_{PXC}) on the basis that it is formation of the train rather than the number of passengers carried that is the primary influence on costs. This variable, also unexpectedly, takes a negative sign, given the other variables included in the cost function. High load factors and longer trains should increase costs, since output is measured in train km. Given the signs and sizes of the coefficients on these two variables in the different models, it seems that they

[6] AIC and BIC criteria are standard model selection criteria where lower (more negative) values of AIC and BIC signal that the model fits the data more closely.
[7] The partial derivatives of the total cost function with respect to output and input factor prices turn out not to be negative, therefore satisfying the monotonicity requirements at the sample mean.
[8] Hessian matrices were constructed in order to determine whether their eigenvalues were non-positive, as the matrices needed to be negative semi-definite for the whole sample.

are picking up a similar effect – perhaps capturing the unit cost reducing impact of economies of traffic density (though the latter should be captured through the output specification). The inclusion or not of these variables does not affect the policy conclusions for our preferred models so we leave these variables in the model.

In conclusion, multiple-output cases seem to be characterised by higher stability when different specifications are considered. In line with the preference to these models accorded by Mizutani et al. (2015), and also considering the AIC / BIC criteria, we favour the multiple-output models (Cases 2, 3, 5 and 6) over single-output models (Cases 1 and 4). Of the disaggregated models we prefer Cases 3 and 6, partly because we consider the train length variable (H_{PXC}) to be a more important cost driver than passenger load factor (H_{LF}), and partly based on model fit. The discussion below will further clarify this selection.

5.2 Policy variables

At a high level, our results show that strong economic regulation reduces costs (statistically significant). However, the precise mechanism by which this is achieved, and how it relates to other reforms, depends on the output / hedonic specification. Considering firstly the models without competition variables (Cases 1 to 3), in Case 1 the coefficient on regulation index variable is negative and statistically significant at the 5 per cent level. The interpretation is that stronger regulation – as measured by the index used in this study – reduces total rail system costs[9]. In the multiple output models (Cases 2 and 3) the effect of regulation occurs only when combined with vertical separation (the coefficient of $REG * D_{VS}$ is negative and statistically significant). We also note that the overall impact of regulation on cost in Cases 2 and 3 - based on the coefficients on REG and $REG * D_{VS}$ - is negative (significant at the 5 per cent level).

[9] We avoid giving an elasticity interpretation on the regulation index parameter estimates to avoid indicating an unwarranted degree of accuracy with respect to the regulation index measure (given the subjectivity involved in its measurement).

Thus, for Case 1, the regulation effect occurs irrespective of vertical structure, whereas in Cases 2 and 3 it occurs only when combined with vertical separation.

The findings on the impact of vertical separation and vertical integration (relative to the holding company model) confirm the results found in Mizutani et al. (2015). That is, around the sample mean, vertical structure does not seem to have much impact. However, as the network becomes more intensely used, vertical separation starts to increase costs relative to the holding company model (whereas for more lightly used systems, vertical separation reduces costs relative to the holding model). This confirmation is important from a European policy perspective, since the sample used here is quite different from the one used in the former studies (only including European railways), providing further confirmation of the finding of a link between the impact of vertical separation and traffic density. Horizontal separation is also found to have a strong cost-reducing impact, as in the previous literature.

With the inclusion of competition variables (Cases 4 to 6) the results are similar, though the effects of regulation are reduced (in absolute size and, to a degree, statistical significance). The results of Case 4 are very similar to Case 1, where the size, sign and statistical significance of the coefficient on the REG variable is largely unaffected. However, for Case 6, as compared to Case 3, the coefficient on the interaction variable ($REG * D_{VS}$) reduces in magnitude and statistical significance (from the 1 per cent to the 5 per cent level). The two variables, REG and $REG * D_{VS}$, are jointly significant at the 10 per cent level, but the p-value for the combined impact of regulation deriving from the two parameter estimates is 0.1544.

Thus, the substantial, differential effect of regulation in vertically separated systems, as compared to the holding company model, remains a statistically significant finding (based on the negative and significant coefficient on the $REG * D_{VS}$ variable) – that is, regulation is still relatively more effective in separated systems. However, the overall cost effect of regulation in separated systems, though still negative (sum of the coefficients of REG and $REG * D_{VS}$ =

-0.1402), is no longer statistically significant even at the 10 per cent level. This reduction in the statistical significance of the regulation effect in Case 6, compared to Case 3, is expected given the potential overlap between the indirect effects of regulation (captured by the REG variable and its interactions) and market opening (captured by CMP and D_{CF}).

In particular, passenger competition (CMP) has its largest (cost reducing) and most statistically significant impact on costs in Case 6 (-0.0684; significant at the 1 per cent level). This (expected) role for passenger competition is interesting because previous studies have tended not to find statistically significant impact of this variable. On the other hand, our findings on freight competition are similar to those in the previous literature, where its statistical significance borders 5 per cent level only in one occasion (Case 4) and its sign indicates a small increasing effect on costs. For completeness, we note that Case 6 also produces similar results to Case 3 in respect of the impact of vertical separation, and its link with intensity of usage of the network, as well as the cost reducing effect of horizontal separation.

Overall, we prefer the multi-output models which we think offer a more realistic characterisation of the impact of traffic on costs and also produce plausible policy findings: the interaction between regulation and vertical separation is still strongly beneficial in terms of efficiency, and its slightly reduced influence allows competition to play a decisive role, at least for the passenger sector. As reported previously, this is particularly true for Case 6 which best demonstrates the benefits from passenger competition (thus our preferred model).

5.3 Policy implications

The implications of the results in Case 6 are that vertical separation and strong regulation are both needed in order to bring about cost reductions. Consider a situation where the two reforms are not implemented together (that is where there is a holding company or fully integrated structure). In these contexts, even a strong economic regulator may not always be able to decipher the potentially discriminatory web of connections within the holding or integrated structure. Indeed, for that reason, in other industries, regulatory bodies have enforced full, legal separation (for example, the gas industry in the UK).

On the other hand, even if vertical separation has been implemented, the absence of a strong economic regulator may lead to increased costs due to transaction / misalignment costs, and because the separated companies in the system are not pressurised on efficiency to the same extent they would be with the holding company model or vertical integration (where competitive pressure impacts on the firm as a whole, thus also pressuring the infrastructure division of the integrated structure). Thus in vertically separated contexts, strong regulation may well be needed to guarantee that necessary pressure on the efficiency of infrastructure managers that railway operators are not able to exert. Therefore, both vertical separation and regulation seem to function better when associated, as the results show. Since only a few regulators directly act or have the powers to request data on the efficiency levels of infrastructure managers in our sample, the beneficial role of regulators in vertically separated contexts may be associated primarily with the increase in operational transparency, and potentially through enabling increased competition (to the extent that this effect is not captured by the competition variables).

Given our finding of an important interaction between regulation and vertical separation, we now consider how our study contributes to the wider debate on the relative cost of separated and integrated structures which, according to Mizutani and Uranishi (2013) and Mizutani et al. (2015), depends on traffic density. In previous studies, specific train density cut-off points - beyond which vertical separation stops producing beneficial effects on efficiency - have been computed. In this study we expand on previous analyses to take account of the strength of regulation, categorised into low, mean and high regulation[10].

[10] Based on the minimum, mean and maximum values of the REG variable in our sample.

Figure 2 shows the results. In situations where regulation is weak, vertical separation reduces costs when density is less than around 0.38 times the average density level in the sample (corresponding to just 26 data-points). Put the other way round, our model predicts that vertical separation therefore increases costs for most of the sample when regulation is weak. Increasing the strength of regulation to its mean value brings this critical value up to 1.06 times the sample average density level (which is the case for 68 observations). This finding suggests that for an average railway in terms of train density, and with "average regulation", the choice of vertical structure has little effect on costs. Further intensification of regulation (up to its maximum value) augments the critical value for density to around 1.29 times its average level, meaning that vertical separation reduces costs for 98 observations in the sample, out of 130. Thus, the presence of a strong regulator increases the number of railway systems which would benefit from vertical separation (from a cost perspective) by moving the density cut-off point over to the right (see Figure 2).

At mean levels of regulation, the density cut-off point in our study is 1.06 times the sample mean, which is similar to that in Mizutani et. al. (2015). Although the sample in our study differs from those in previous studies, the average train density levels in the studies are similar. However, the presence of a more powerful regulator, together with vertical separation, may greatly contribute to reducing costs for a wider range of density levels and in turn railways than previously found. <Figure 2 here>

In sum, regulation seems to have beneficial effects on railway efficiency, particularly when associated with vertical separation (and when train density levels are not too high), and when instrumental in creating competition (in passenger in particular). Therefore, the decision whether or when to introduce or strengthen regulatory powers seems to be dependent on the degree of (actual or desired) market openness, the extent of structural unbundling, and the intensity of usage of the rail network. These inter-relationships should therefore be taken into account when designing regulatory policy.

6.0 Conclusions

In recent years European railway regulation has been subject to major reform, with the powers, independence and responsibilities of rail regulators strengthened considerably. The primary purpose of this paper is to study the impact of economic regulation on rail system costs, which is important because of the different approaches adopted across Europe, and the changes induced by EU reforms. Further, reforms have continued beyond the period of our sample and our study therefore sheds light on the expected impact that these changes could have.

The unique contribution, as compared to the previous literature, lies in the incorporation of a multi-faceted rail regulation index – that captures the complexity and subtleties of regulatory powers and activities – into an econometric framework. Since previous studies have focused on dummy variables to capture the presence (or not) of an independent economic regulator, this approach enables a richer study of the impact of European regulatory reforms than has been attempted previously. As a secondary objective, the research also asks how different reforms interact to produce more efficient railways in Europe; in particular focusing on the relationship between regulation, vertical separation and competition. We use a panel of 17 European railways (2002-2010), using a dataset based on published UIC data, supplemented by data supplied by the European rail industry.

We find that the presence of strong economic regulation leads to lower rail system costs; importantly, in our preferred model, this cost reducing effect occurs only when combined with vertical separation. The implication is that vertical separation and strong regulation are both needed in order to bring beneficial impacts in the form of cost reductions. With integrated structures, even a strong economic regulator may not always be able to ensure a level playing field for new entrants. On the other hand, even in vertically separated cases, the absence of a strong economic regulator may lead to higher costs resulting from transaction / misalignment costs; and strong regulation may be needed to guarantee pressure on the efficiency of infrastructure managers that railway operators are not able to exert. Therefore, both vertical separation and regulation seem to function better when associated. Our results confirm previous results on the beneficial effects of horizontal separation; and that passenger competition reduces costs; previous studies have typically not been able to pick up this latter effect.

The policy implication of our paper is that strengthening the powers, activities and independence of regulatory bodies is likely to be beneficial in terms of cost reduction either directly or indirectly via competition; but that the benefits may only be felt when implemented alongside vertical separation. Likewise, vertical separation, without strong regulation, may be ineffective, though the final impact will also depend on the intensity of usage of the network, as found in Mizutani et. al. (2015). In this respect, our study shows that the presence of strong economic regulation implies that vertical separation may be beneficial (in reducing costs) for railways even with higher train density levels than previously envisaged, although it remains the case that for very densely trafficked railways a holding company model is to be preferred. The inter-relationships between different reform types, and the intensity of network usage, should therefore be taken into account when designing regulatory policy and wider reforms.

There are some limitations that suggest avenues for future research. The dataset does not extend post the finalisation of the 2012 Recast, so an updated study would shed light on the final impact of these reforms. However, new survey work would be needed to support the extension of the regulation index beyond our sample. Consideration of the relative impacts of different aspects of the regulatory index could be a useful avenue for future research. Further research is also needed to enable a bottom-up identification of the areas where (and the conditions through which) regulation, structure and competition may interact and produce efficiency benefits. Such research would complement the econometric results in this study.

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Table 1 Summary of Ideal Rail Regulator Characteristics

Ideal characteristics	Purposes
Independence	Legislative and operational independence from government and railway companies
Stability and predictability	Minimising political influence and promoting the conditions for long-term planning
Non-discrimination	Maintaining a level playing field for operators when accessing the infrastructure
Distinct responsibilities	Avoiding overlapping of roles and accountability between regulator and government (or other agencies)
Human and financial resources	Appropriate resources and skills to meet regulatory objectives
Transparency	Ensuring the accountability of the regulator
Pro-activity and effectiveness	Growing autonomous powers for investigations and interventions
System efficiency	Accessing and analysing data on infrastructure managers' quality and efficiency
Cost-effectiveness	The extent to which the regulator delivers its functions effectively, given its resources (value for money)

Source: own analysis based on the literature.

Table 2 Regulation Index: Drivers and Weights

Macro-area	Driver	Sub-driver	Weight
Competence of the regulation authority	General aspects of the regulatory authority	Existence of the regulatory authority pursuant to Art. 30 Directive 2001/14/EC (responsible for non-discriminatory access)	0.017
		Transparency of competence of regulatory authority	0.017
		Transparency in case of proceedings/sanctions	0.017
		Independence of political influence	0.017
		Existence of an annual report	0.017
	Object of the regulation	Inspection of network statement (10 aspects)	0.022
		Investigations concerning allocation procedure	0.022
		Investigations concerning charging scheme	0.022
		Investigations concerning level or structure of user fees	0.022
		Monitoring competition	0.022
		Can/must start investigations upon request	0.015

Macro-area	Driver	Sub-driver	Weight
	Powers of the regulatory authority	Can/Must start investigations ex officio	0.015
		Legally binding character of regulatory authority decisions	0.029
		Determination by the regulatory body	0.015
		Possibility of imposing coercive means	0.015
		Possibility of imposing fines	0.015
		Possibility of issuing ex-post and/or ex-ante decisions	0.015
		Legal certainty of ex-ante decisions	0.015
		Monitoring processes	0.015
Administrative barriers	Licensing	Independence of decision maker from incumbent	0.034
		Transparency of licensing process	0.017
	Safety certificate	Independence of decision maker from incumbent	0.012
		Transparency of issue process	0.012
	Homologation of vehicles	Independence of decision maker from incumbent	0.059
		Transparency of issue process	0.059
Operational barriers	Train path access conditions	Existence of priority regulations for certain RUs	0.055
		Non-discriminatory access to services	0.055
		Non-discriminatory marketing for all train paths	0.041
		Transparent mechanism to resolve conflicts	0.028
		Framework contracts	0.028
		Transparent and standard train path allocation process	0.039
	Infrastructure charging system	Coverage of infrastructure charging system	0.110
		Publication of infrastructure charging system	0.055
		Uniform charging system	0.055
Total			1.000

Source: own analysis based on the original source documents (see Section 4 above).

Table 3 Activities Performed to Construct the Regulation Index (in chronological order)

Collection of the Rail Liberalisation Index reports published in 2002, 2004, 2007 and 2011, in part available online, and in part obtained through direct request to Deutsche-Bahn (DB) staff.
Selection of the relevant sub-drivers presented in the studies, for the purpose of identifying a range of typical regulatory issues.
Conglomeration of the regulatory data of 17 European countries in a single panel.
Calculation of the regulatory index for each report and each country (4 indices for 17 countries), making use of the weights chosen by the authors for the 2011 study, then re-calculated according to the chosen set of sub-drivers. Example: The sum of the weights of the selected sub-drivers accounts for 53.8 per cent of the whole Rail Liberalisation Index 2011. Within that index, the sub-driver "Existence of the regulatory authority pursuant to Art. 30 Directive 2001/14/EC (responsible for non-discriminatory access)" had a weight of 0.09 per cent, which corresponds to a 0.17 per cent in our study (see Table 2).

Inclusion of additional data for the gap years; see section 4.1 for further detail.
Identification of the reasons behind the main changes impacting on the scores of specific sub-drivers over time.

Table 4 Country Networks and Transport (or Rail) Regulatory Bodies

Country network	Interval	Observations	Regulatory body
Austria (OBB)	2002-2010	9	Schienen-Control Gmbh (monitoring) Schienen-Control Kommission (complaints)
Belgium (SNCB/NMBS)	2002-2007	6	Service de Régulation du Transport Ferroviaire et de l'Exploitation de l'Aéroport de Bruxelles
Germany (DBAG)	2002-2010	9	Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway
Denmark (DSB)	2002-2007	6	Danish Railway Regulatory Body
Finland (VR)	2002-2010	9	Finnish Transport Safety Agency (Trafi)
France (SNCF)	2002-2007	6	Autorité de Régulation des Activités Ferroviaires et Routières (ARAFER)
Great Britain (TOC)	2002-2009	8	Office of Rail and Road (ORR)
Greece (OSE)	2002-2007	6	Regulatory Authority for Railways (RAS)
Ireland (CIE)	2002-2007	6	No regulatory body
Italy (FS)	2002-2007	6	Transport Regulation Authority
Luxembourg (CFL)	2002-2007	6	Institut Luxembourgeois de Régulation
Netherlands (NS)	2002-2010	9	Authority for Consumers & Markets (ACM)
Norway (NSB)	2002-2009	8	Norwegian Railway Authority
Portugal (CP)	2002-2007	6	Instituto da Mobilidade e dos Transportes terrestres URF – Unidade de Regulação Ferroviária
Spain (RENFE)	2002-2007	6	Comisión Nacional del Mercado y la Competencia (CNMC) Direccion de Transportes y del Sector Postal Subdirección del Sector Ferroviario
Sweden (SJ)	2002-2007	6	Swedish Transport Authority
Switzerland (BLS)	2002-2010	9	Railways Arbitration Commission RACO
Switzerland (SBB CFF FFS)	2002-2010	9	Railways Arbitration Commission RACO
All observations	2002-2010	130	

Table 5 Descriptive Statistics for Key Policy Variables

Parameters	Definition	Mean	Standard deviation	Range
D_{VS} (vertical separation)	Vertical separation dummy (vertical separation = 1)	0.4692	0.5010	0.000 to 1.000
D_{VI} (vertical integration)	Vertical integration dummy (vertical integration = 1)	0.3231	0.4695	0.000 to 1.000
D_{HC} (holding company)	Holding company dummy (omitted)	-	-	-
D_{HS} (horizontal separation)	Horizontal separation dummy (horizontal separation = 1)	0.3462	0.4776	0.000 to 1.000
REG (regulation index)	Manipulated scores from Rail Liberalisation Index reports	7.30	2.29	1.51 to 9.85
CMP (passenger competition)	Passenger competition (0 = no competition, 1～4)	1.2846	1.2466	0.000 to 4.000
D_{CF}(freight competition)	Freight competition dummy (freight competition = 1)	0.5846	0.4947	0.000 to 1.000

Table 6 Full Econometric Estimation Results

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Q	0.5735***	-	-	0.6236***	-	-
	(0.0829)			(0.0936)		
Q_P	-	0.1695***	-	-	0.1840***	-
		(0.0575)			(0.0577)	
Q_F	-	0.3657***	-	-	0.3693***	-
		(0.0466)			(0.0463)	
Q_{PTKM}	-	-	0.3102***	-	-	0.3516***
			(0.0753)			(0.0741)
Q_{FTKM}	-	-	0.2374***	-	-	0.2567***
			(0.0549)			(0.0549)
H_{PR}	-0.1941	-	-	-0.1909	-	-
	(0.1489)			(0.1557)		
H_{LF}	-0.3608***	-	-	-0.3073***	-	-
	(0.0599)			(0.0664)		
H_{PTL}	0.1817***	-	0.0991**	0.1726***	-	0.0950**
	(0.0299)		(0.0507)	(0.0298)		(0.0492)
H_{PXC}	-	-	-0.3899***	-	-	-0.4348***
			(0.0886)			(0.0873)
H_{FRC}	0.0855**	-	0.3384***	0.0713	-	0.2907***
	(0.0445)		(0.0510)	(0.0456)		(0.0526)

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
w_L	0.3261***	0.3373***	0.3297***	0.3261***	0.3367***	0.3296***
	(0.0090)	(0.0078)	(0.0082)	(0.0090)	(0.0078)	(0.0082)
w_E	0.0437***	0.0452***	0.0433***	0.0438***	0.0454***	0.0433***
	(0.0031)	(0.0028)	(0.0029)	(0.0031)	(0.0028)	(0.0028)
w_M	0.2601***	0.2578***	0.2614***	0.2597***	0.2574***	0.2618***
	(0.0079)	(0.0073)	(0.0073)	(0.0079)	(0.0073)	(0.0072)
w_K	0.3701***	0.3597***	0.3655***	0.3703***	0.3605***	0.3653***
	(0.0086)	(0.0088)	(0.0079)	(0.0086)	(0.0088)	(0.0079)
N	0.4719***	0.4849***	0.4794***	0.4364***	0.4913***	0.4663***
	(0.0899)	(0.0852)	(0.0962)	(0.0940)	(0.0845)	(0.0936)
T	0.2816***	0.0870	0.3999***	0.3057***	0.1036	0.4665***
	(0.0626)	(0.0760)	(0.0882)	(0.0633)	(0.0758)	(0.0873)
$Q \cdot Q$	0.2205	-	-	0.1700	-	-
	(0.1500)			(0.1497)		
$Q_P \cdot Q_P$	-	0.3349***	-	-	0.2765***	-
		(0.0934)			(0.0980)	
$Q_F \cdot Q_F$	-	-0.1362	-	-	-0.1139	-
		(0.1016)			(0.1059)	
$Q_{PTKM} \cdot Q_{PTKM}$	-	-	0.3126***	-	-	0.3674***
			(0.1198)			(0.1199)
$Q_{FTKM} \cdot Q_{FTKM}$	-	-	-0.0564	-	-	-0.0855
			(0.1097)			(0.1076)
$N \cdot N$	-0.2647	-0.3525	-0.8433***	-0.4221**	-0.4568**	-0.9455***
	(0.1737)	(0.2324)	(0.2349)	(0.1902)	(0.2413)	(0.2282)
$w_L \cdot w_L$	0.1476***	0.1705***	0.1272***	0.1472***	0.1708***	0.1281***
	(0.0196)	(0.0169)	(0.0196)	(0.0195)	(0.0169)	(0.0195)
$w_L \cdot w_E$	0.0063	-0.0021	0.0072	0.0063	-0.0022	0.0062
	(0.0070)	(0.0069)	(0.0065)	(0.0070)	(0.0069)	(0.0064)
$w_L \cdot w_M$	-0.0508***	-0.0559***	-0.0454***	-0.0497***	-0.0563***	-0.0447***
	(0.0105)	(0.0088)	(0.0099)	(0.0105)	(0.0088)	(0.0098)
$w_L \cdot w_K$	-0.1031***	-0.1125***	-0.0889***	-0.1037***	-0.1122***	-0.0896***
	(0.0124)	(0.0111)	(0.0128)	(0.0124)	(0.0110)	(0.0128)
$w_E \cdot w_E$	0.0329***	0.0309***	0.0341***	0.0329***	0.0309***	0.0343***
	(0.0053)	(0.0055)	(0.0049)	(0.0052)	(0.0054)	(0.0048)
$w_E \cdot w_M$	-0.0135***	-0.0082***	-0.0118***	-0.0134***	-0.0082***	-0.0117***
	(0.0038)	(0.0033)	(0.0034)	(0.0038)	(0.0033)	(0.0033)
$w_E \cdot w_K$	-0.0257***	-0.0207***	-0.0295***	-0.0257***	-0.0206***	-0.0287***
	(0.0038)	(0.0037)	(0.0041)	(0.0039)	(0.0037)	(0.0040)

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
$w_M \cdot w_M$	0.1002***	0.1013***	0.0934***	0.0988***	0.1018***	0.0934***
	(0.0092)	(0.0080)	(0.0085)	(0.0092)	(0.0080)	(0.0083)
$w_M \cdot w_K$	-0.0359***	-0.0373***	-0.0362***	-0.0357***	-0.0374***	-0.0370***
	(0.0079)	(0.0075)	(0.0075)	(0.0078)	(0.0075)	(0.0075)
$w_K \cdot w_K$	0.1647***	0.1704***	0.1546***	-0.0357***	0.1702***	0.1553***
	(0.0113)	(0.0113)	(0.0114)	(0.0078)	(0.0113)	(0.0114)
$Q \cdot w_L$	0.1545***	-	-	0.1548***	-	-
	(0.0188)			(0.0188)		
$Q \cdot w_E$	0.0171***	-	-	0.0166***	-	-
	(0.0060)			(0.0061)		
$Q \cdot w_M$	0.0177	-	-	0.0200	-	-
	(0.0140)			(0.0140)		
$Q \cdot w_K$	-0.1894***	-	-	-0.1915***	-	-
	(0.0160)			(0.0160)		
$Q \cdot N$	0.1011	-	-	0.2130	-	-
	(0.1557)			(0.1644)		
$Q \cdot T$	-0.0945	-	-	-0.0521	-	-
	(0.0926)			(0.0939)		
$Q_P \cdot Q_F$	-	0.0646	-	-	0.0549	-
		(0.0761)			(0.0836)	
$Q_P \cdot w_L$	-	0.1258***	-	-	0.1258***	-
		(0.0129)			(0.0129)	
$Q_P \cdot w_E$	-	0.0085**	-	-	0.0086**	-
		(0.0044)			(0.0043)	
$Q_P \cdot w_M$	-	-0.0034	-	-	-0.0038	-
		(0.0103)			(0.0103)	
$Q_P \cdot w_K$	-	-0.1310***	-	-	-0.1307***	-
		(0.0132)			(0.0132)	
$Q_P \cdot N$	-	-0.2448*	-	-	-0.1629	-
		(0.1481)			(0.1561)	
$Q_P \cdot T$	-	-0.1818*	-	-	-0.1335	-
		(0.1006)			(0.1033)	
$Q_F \cdot w_L$	-	0.0901***	-	-	0.0902***	-
		(0.0135)			(0.0135)	
$Q_F \cdot w_E$	-	-0.0033	-	-	-0.0035	-
		(0.0050)			(0.0049)	
$Q_F \cdot w_M$	-	0.0132	-	-	0.0136	-
		(0.0121)			(0.0121)	

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
$Q_F \cdot w_K$	-	-0.1000***	-	-	-0.1003	-
		(0.0146)			(0.0146)	
$Q_F \cdot N$	-	0.2741***	-	-	0.2763***	-
		(0.0869)			(0.865)	
$Q_F \cdot T$	-	0.1421*	-	-	0.1239	-
		(0.0870)			(0.0901)	
$Q_{PTKM} \cdot Q_{FTKM}$	-	-	-0.1833*	-	-	-0.1914*
			(0.1073)			(0.1055)
$Q_{PTKM} \cdot w_L$	-	-	0.1016***	-	-	0.1025***
			(0.0168)			(0.0167)
$Q_{PTKM} \cdot w_E$	-	-	0.0200***	-	-	0.0195***
			(0.0053)			(0.0052)
$Q_{PTKM} \cdot w_M$	-	-	0.0083	-	-	0.0085
			(0.0121)			(0.0118)
$Q_{PTKM} \cdot w_K$	-	-	-0.1299***	-	-	-0.1305***
			(0.0144)			(0.0144)
$Q_{PTKM} \cdot N$	-	-	0.15478	-	-	0.1822
			(0.1410)			(0.1365)
$Q_{PTKM} \cdot T$	-	-	-0.1450	-	-	-0.1273
			(0.0957)			(0.0927)
$Q_{FTKM} \cdot w_L$	-	-	0.0735***	-	-	0.0739***
			(0.0159)			(0.0158)
$Q_{FTKM} \cdot w_E$	-	-	-0.0107**	-	-	-0.0107**
			(0.0055)			(0.0054)
$Q_{FTKM} \cdot w_M$	-	-	0.0152	-	-	0.0158
			(0.0133)			(0.0130)
$Q_{FTKM} \cdot w_K$	-	-	-0.078***	-	-	-0.0790***
			(0.0150)			(0.0150)
$Q_{FTKM} \cdot N$	-	-	0.3768***	-	-	0.4150***
			(0.1273)			(0.1236)
$Q_{FTKM} \cdot T$	-	-	0.1848***	-	-	0.2075***
			(0.0719)			(0.0699)
$w_L \cdot N$	-0.1627***	-0.2404***	-0.1803***	-0.1626***	-0.2408***	-0.1810***
	(0.0176)	(0.0185)	(0.0158)	(0.0175)	(0.0186)	(0.0157)
$w_L \cdot T$	-0.0321	-0.0823***	-0.0574***	-0.0327***	-0.0831***	-0.0584***
	(0.0097)	(0.0125)	(0.0111)	(0.0096)	(0.0125)	(0.0111)
$w_E \cdot N$	-0.0111**	-0.0006	-0.0026	-0.0106*	-0.0005	-0.0023
	(0.0057)	(0.0065)	(0.0055)	(0.0058)	(0.0064)	(0.0053)

Parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
$w_E \cdot T$	0.0019	0.0070	0.0099***	0.0021	0.0073	0.0097***
	(0.0034)	(0.0047)	(0.0040)	(0.0034)	(0.0046)	(0.0039)
$w_M \cdot N$	-0.0186	-0.0158	-0.0251*	-0.0210	-0.0156	-0.0257**
	(0.0136)	(0.0154)	(0.0134)	(0.0136)	(0.0154)	(0.0131)
$w_M \cdot T$	0.0201***	0.0182*	0.0131	0.0194**	0.0174	0.0135
	(0.0084)	(0.0112)	(0.0096)	(0.0084)	(0.0112)	(0.0094)
$w_K \cdot N$	0.1924***	0.2568***	0.2080***	0.1942***	0.2569***	0.2089***
	(0.0153)	(0.0188)	(0.0146)	(0.0153)	(0.0188)	(0.0145)
$w_K \cdot T$	0.0101	0.0570***	0.0345***	0.0113	0.0585***	0.0353***
	(0.0091)	(0.0133)	(0.0107)	(0.0091)	(0.0133)	(0.0107)
$N \cdot T$	0.3283***	0.0213	0.0024	0.2840***	-0.0036	0.0129
	(0.0972)	(0.1341)	(0.1306)	(0.0978)	(0.1334)	(0.1266)
$T \cdot T$	-0.0766	-0.0851	0.0620	-0.0972	-0.0952	0.0199
	(0.0746)	(0.1114)	(0.0802)	(0.0748)	(0.1140)	(0.0785)
D_{VS}	0.0267	-0.1314	-0.1047	0.1041	-0.1108	-0.0169
	(0.0601)	(0.0846)	(0.0895)	(0.0674)	(0.0953)	(0.0932)
$V \cdot D_{VS}$	0.3514***	0.4758***	0.2359	0.3877***	0.4915***	0.3258**
	(0.1036)	(0.1128)	(0.1487)	(0.1028)	(0.1185)	(0.1469)
$R \cdot D_{VS}$	0.0209	-0.1322**	-0.1087	0.0898	-0.0827	-0.0342
	(0.0609)	(0.0686)	(0.0725)	(0.0664)	(0.0767)	(0.0739)
D_{VI}	-0.0098	0.0491	0.0544	0.0022	0.0528	0.0635
	(0.0415)	(0.0383)	(0.0415)	(0.0418)	(0.0381)	(0.0411)
D_{HS}	-0.3433***	-0.2698***	-0.3756***	-0.3054***	-0.1965***	-0.3041***
	(0.0432)	(0.0583)	(0.0556)	(0.0582)	(0.0723)	(0.0617)
REG	-0.1232**	0.0613	0.0499	-0.1200**	0.0823*	0.0741
	(0.0530)	(0.0444)	(0.0525)	(0.0529)	(0.0461)	(0.0527)
$REG \cdot D_{VS}$	0.0423	-0.2412***	-0.3278***	0.0840	-0.1515	-0.2143**
	(0.0937)	(0.0840)	(0.0966)	(0.1047)	(00964)	(0.1041)
CMP	-	-	-	-0.0414*	-0.0338**	-0.0684***
				(0.0250)	(0.0176)	(0.0210)
D_{CF}	-	-	-	0.0661**	-0.0048	0.0584*
				(0.0334)	(0.0351)	(0.0336)
C_0	0.2554***	0.2794***	0.2947***	0.2508***	0.3240***	0.3200***
	(0.0530)	(0.0444)	(0.0301)	(0.0442)	(0.0417)	(0.0417)
Log of likelihood	800.086	812.099	823.518	801.493	813.473	826.862
Pseudo R^2	0.991	0.991	0.989	0.991	0.991	0.990
AIC	-1522.172	-1538.197	-1555.036	-1520.986	-1536.944	-1557.725
BIC	-1410.338	-1414.893	-1423.129	-1403.417	-1407.905	-1420.083
Observations	130	130	130	130	130	130

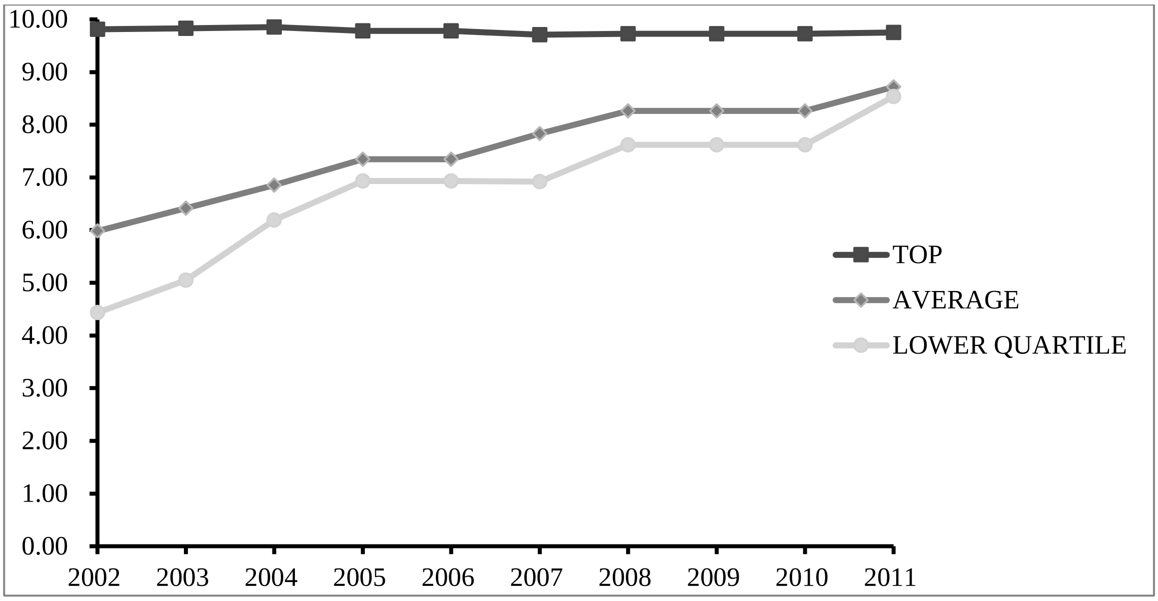

Figure 1 Regulation Index Trends for Top, Average and Lower Quartile in the Sample (2002-2011)

Source: own analysis based on the original source documents (see Section 4 above).

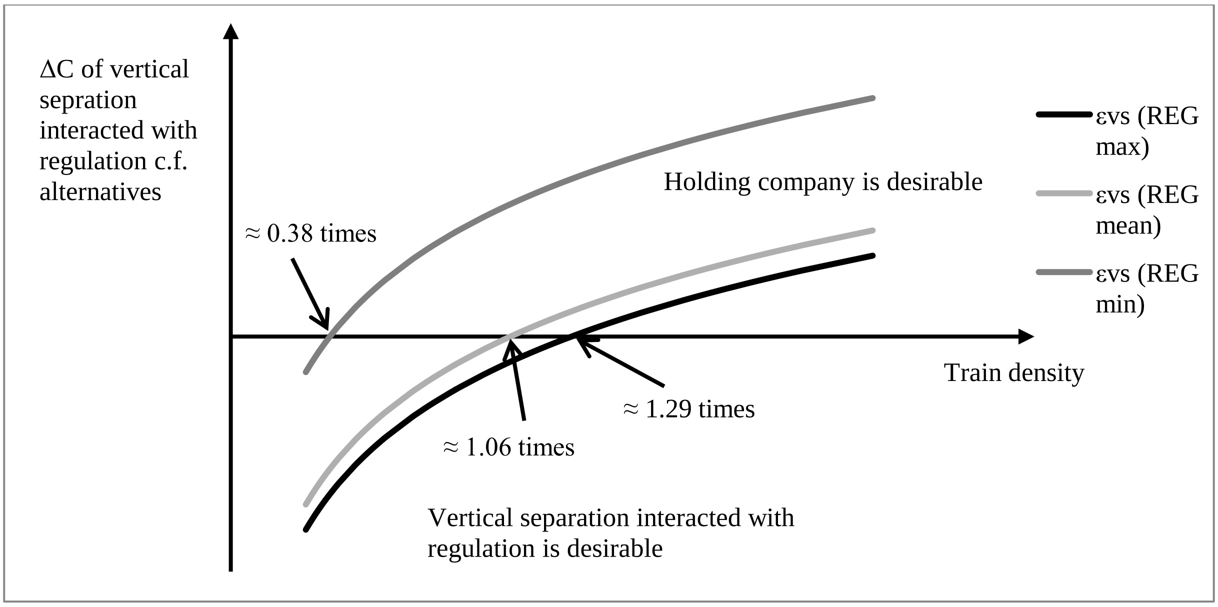

Figure 2 Cost Difference between Vertical Separation Interacted with Minimum, Mean and Maximum Levels of Regulation and Holding Company, and its Relationship with Train Density

Source: own analysis based on the econometric estimations.