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The cost effects of investment coordination under alternative vertical structures in railway systems

Abstract

The main purpose of this study is to investigate how structural separation policies (especially vertical separation and the holding company) affect the costs of the rail industry, and to explore the mechanisms through which these cost impacts occur. We contribute to the past literature by focusing on investment coordination/misalignment costs and how these might vary across different railway structures. We also provide a substantially more up-to-date view of the impact of rail reforms than in previous cost function studies. A total cost function is used with a dataset involving 33 European and East Asia railway companies (1994-2017). We find that there is no "one size fits all" vertical structure from the point of view of cost minimisation and that the optimal structure from a cost perspective depends on both train density and the intensity of infrastructure investment.

Keywords: Rail reform, Vertical separation, Horizontal separation, Infrastructure investment, Total cost function

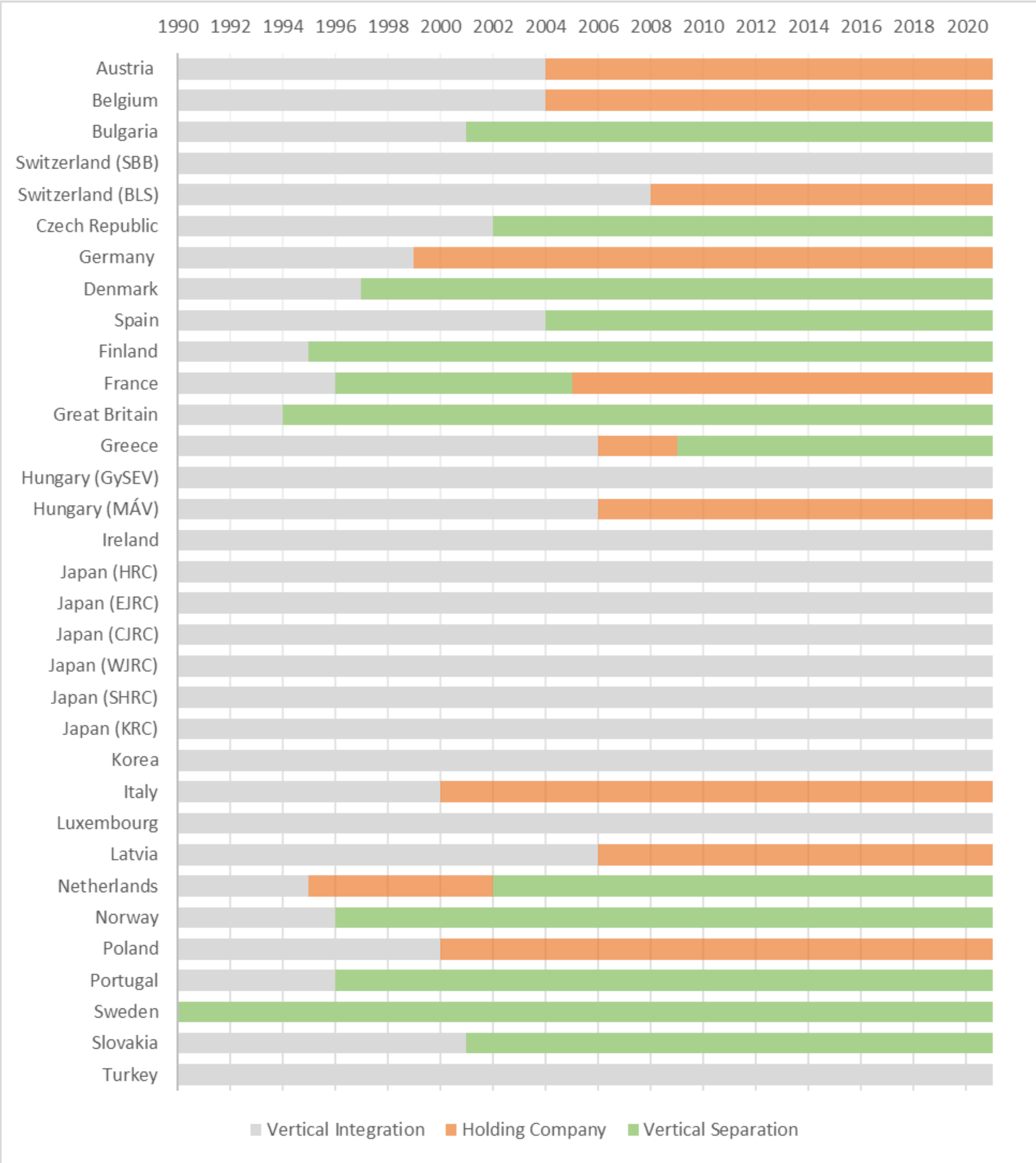
1. Introduction

Between 1970 and 1990, European railways were run by public monopolies, generally organised as vertically-integrated companies responsible for infrastructure management and train operations. However, EU railways faced a series of issues, with modal shares decreasing from 10.2% and 20.1% in 1970 to 6.6% and 11.0% in 1990 for passenger and freight railway services, respectively (Wheat and Nash, 2006). The railways became increasingly dependent on state funding, leading to significant financial difficulties. As a result, the European Commission embarked on a major programme of legislation aimed at reforming EU railways.

Since 1991, the railway reform process has been taken forward through EU (EC) legislation, aiming to split up the railway industry. The introduction of competition between different operators and the tension at the 'wheel rail interface' aimed to reduce subsidies and address inefficiencies in many European countries. The rail reforms in Europe have followed three steps: 1) separating the infrastructure from operations (at minimum into separate divisions with their own accounts), 2) establishing an independent regulator and 3) opening up the rail market (i.e. introducing competition). The rationale for the separation was that it would provide discrimination-free access to the infrastructure for transport operators and enhance competition within the railway industry. More competition, in turn, would ideally increase the efficiency and demand for railway services and raise economic welfare (Commission of the European Communities, 1996).

Rail reforms have been implemented outside of Europe as well. The privatisation of the Japan National Railway (JNR) started in 1987, leading to the creation of seven regional railway companies, with the organisational structure following the rules of horizontal (geographical) separation, functional distinction and vertical integration. China started their rail reforms in 2013 with the dissolution of China's Ministry of Railways (MOR) where both passenger and freight railways were originally operated by the publicly owned company CRC. The latest reform included transforming the rail investment organisations into companies, and transforming the 18 local rail authorities into limited companies (e.g. Beijing-Shanghai High-Speed Railway Co, Ltd). Nevertheless, Chinese railways retain an essentially vertically integrated organisational structure. Figure 1 below illustrates the structural reform status (up to 2021) for the countries involved in this study.

Figure 1: Rail Structural Reform Progress



Academics, policymakers and the industry itself have tried to evaluate the rail reforms undertaken in different countries to determine if there is an optimal reform regime. Typical post-reform rail structures include Vertical Integration (VI), Vertical Separation (VS), Holding Company (HC) and Horizontal Separation. The first three of these refer to the relationship between Rail Undertaking (RU) and Infrastructure Management (IM), i.e., whether they are integrated into one company (VI), separated into two (or more) legally distinct companies (VS) or only partially separated (HC). In the HC regime, the Rail Undertaking (RU) and Infrastructure Manager (IM) are separated organisationally but remain within the same parent (or holding) company. Horizontal separation means that the freight and passenger operations are fully separated and operated by two or more companies, i.e., geographically or line-by-line.

There has been extensive quantitative literature studying the effect of different structural reforms on rail costs and efficiency; for a summary of this literature, see Fitzova (2017). A key entry point for our study is the work of Mizutani and Uranishi (2013) and Mizutani et al. (2015), which emphasised that the cost impact of VS as compared to VI depends on train density (intensity of usage of the network). This work took a transactional cost perspective, where the cost impact of train density could be explained by the higher cost of coordination between RU and IM in the case of higher train density, given that the entailing costs for tasks such as maintenance scheduling and maintaining safety under a busy train operation schedule are expensive. Their work also highlighted the differential cost impacts of the VS regime as compared to the partial separation approach of the HC regime.

The purpose of this paper is to develop the literature in two important directions. First, there have been only a limited number of studies focused on investigating the factors leading to differences in cost efficiency between the two dominant forms of vertical structure in the EU – that is, VS and the HC regimes. Our study aims to extend the econometric framework used in previous studies to incorporate investment coordination as a key source of potential cost and misalignment (building on the work of, for example, van de Velde et al. (2012) and Mizutani et. al., 2015). To do this, we seek to understand the quality and impact of investment coordination under different organisational structures by introducing the intensity of the infrastructure investment into the cost function relationship. Second, we substantially expand the dataset to 2017 as compared to previous cost studies that only extended as far as 2010[1]. This is important not simply in terms of expanding the sample size – crucially, the updated dataset gives us more years of data to observe the lasting impact of the most recent reforms, especially for countries that reformed their railways in the late 2000s. We have not considered other policy factors apart from vertical structures (e.g. public/private ownership) for the following reasons. First, our hypothesis in the study is that the vertical structure affects cost through misalignments generated from coordination between RUs and the IM. Private/public ownership is supposed to have a limited impact on coordination between RUs and the IM, given that they are heavily regulated to avoid discrimination. Ownership may be correlated to some extent with competition on the network (in the sense that new competition is often linked with increased private sector participation), and thus, we introduce a competition variable in our study. Second, it should be noted that the ownership in our sample is a complex mix for some countries (e.g., Japan's passenger rail is privatised but freight rail is still state-owned), thus making it hard to incorporate into the model. Finally, the wider literature also shows a stronger cost impact of structural and regulatory reform; see van de Velde et al. (2012) and Smith et al. (2018).

Following van de Velde et al. (2012), we use the term 'investment coordination' to refer to the way different vertical structures absorb and translate infrastructure investment into system-wide performance and cost outcomes – see Figure 2. Our empirical approach does not measure

[1] Latest data of 2010 relates to previous cost function studies. Fitzová (2020) utilises more up to date data (up to 2017) but this was a DEA study using data on physical measures rather than costs.

IM–RU investment decision-making directly; instead, the interaction between investment intensity and the vertical structure dummies captures how investment activity manifests in total system costs under each regime. This aligns with the EVES framework, where misalignment effects are expected to be observable in costs rather than through direct behavioural data.

The remainder of the paper is structured as follows. Section 2 briefly discusses the relevant literature. Section 3 sets out the data and methodology. The results are presented and discussed in Section 4. Section 5 concludes.

2. Literature Review

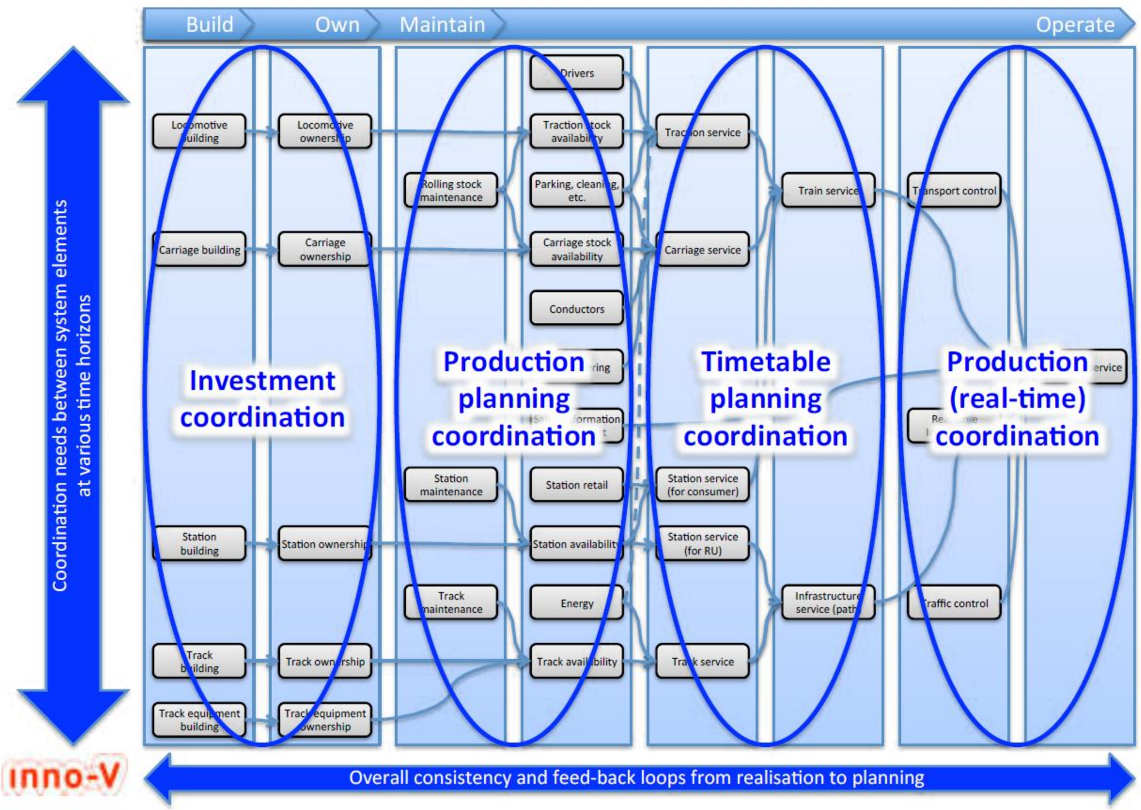
Many studies have aimed to quantitatively assess the effects of different rail reforms on rail efficiency, most notably: market liberalisation (competition level), regulation (by an independent regulator), the coordination between RU and IM (vertical separation or integration) and the relationship between passenger and freight rail (horizontal separation). There is extensive literature, utilising both cost function and other methods such as data envelopment analysis DEA). For a detailed recent review, see Fitzova (2017).

As noted in the introduction, a key entry point for our study is the work of Mizutani and Uranishi (2013) and Mizutani et al. (2015). These studies highlighted that there may not be a "one-size-fits-all" approach to the vertical structure, with cost impacts of different structures depending on the intensity of usage of the network. Further, this body of work highlighted the different nuances in rail structure, in particular the Holding Company (HC) regime which is a form of separation permitted under EU legislation, but falling short of full VS (with the IM and the main RU being organisationally distinct, but owned by the same parent or holding company).

The above papers highlighted a transaction cost perspective to explain the cost impact of different structures. These concepts were further developed by van de Velde et al. (2012) who provided a comprehensive qualitative analysis of the potential misalignment issues between different rail organisations (i.e. RU and IM). Using a transaction-based approach, Van de Velde et al. developed a generic model to describe the main production processes in the rail industry. The generic model includes the main sectors and functions in the rail industry, which are grouped under four coordination headings: investment, production planning (traincrew levels), timetable planning and real-time coordination (see Figure 2). Table 1 shows the potential misalignments within each coordination, as discussed in the works of van de Velde et al. (2012) and Nash et al. (2014). Importantly, misalignments exist not only in the VS regime but also in the other regimes as well (the HC and VI regimes).

The work of Mizutani and Uranishi (2013) and Mizutani et al. (2015) shows that VS increases costs relative to the HC or VI regimes at high train density levels. The authors argue that this is intuitive because any misalignment in short-term coordination, including disruption handling, timetable planning coordination, and production (real-time) coordination in the VS regime, would be expected to increase as networks approach capacity.

Figure 2: Generic model of four coordinations in a railway



Source: EVES report - Economic effects of Vertical Separation in the railway sector (van de Velde et al. 2012)

Table 1: Examples of misalignment issues across the coordination circles

Investment Coordination	Production Planning Coordination	Timetable Planning Coordination	Production (Real-time) Coordination
• Extension / decommissioning • Upgrading / downgrading	• Quality of resources and reliability • Small/medium scale investments	• Maintenance/renewal versus operations • Timetable robustness	• Disruption handling • Feedback loops

Source: EVES report - Economic effects of Vertical Separation in the railway sector (van de Velde et al. 2012)

There remain some important gaps in the literature. First, only a few studies focus on investigating the factors leading to the differences in cost efficiency between the two dominant forms of vertical structure in the EU, different regimes – that is, VS or the HC regime. In particular, the investment coordination aspects have not been studied in an econometric framework. Second, 2010-11 is the most recent year of data involved in the cost studies carried out within this literature, which cannot reflect the effect of the latest reforms in many countries across Europe.

Our study aims to fill in the above gaps by extending the framework of analysis to focus on investment coordination/misalignment costs and how these might vary across different vertical structures. The past literature, e.g. Mizutani et. al. (2013), van de Velde et al. (2012) and Mizutani et. al. (2015), have focused their econometric estimation more on the timetabling and real-time coordination impacts, through exploring the relationship between the cost of different cost structures and train density specifically. We use an econometric model to investigate whether potential misalignments exist in the investment coordination within the VS regime. In addition, we substantially update the dataset to 2017, thus expanding the sample size and increasing confidence in the econometric findings, whilst also enabling the impact of recent reforms to be better understood, given that the reform process in some EU countries extended to the late noughties and beyond.

3. Data and Methodology

3.1 Data

The data analysed in this study uses, as a starting point, a dataset developed originally by Mizutani and Uranishi (2013) and then enhanced by Mizutani et al. (2015) and van de Velde et al. (2012). Importantly, we added new variables that enable us to study the cost effects of investment under different organisational structures and also update the dataset substantially in time, which, as noted, is important in studying the impact of reforms given the timing of their introduction in different countries. The rail companies and years involved in the dataset are shown in Table 2 (see also van de Velde et al. (2012) and Mizutani et al. (2015)).

Table 2: Railway operators and time periods included in this study

Country	Company	Year
AT – Austria	OBB	1994 - 2017
BE – Belgium	SNCB/NMBS	1994 - 2009
BG – Bulgaria	BDZ	2002 - 2010
CH – Switzerland	BLS	1994 - 2010
CH – Switzerland	SBB CFF FFS	1994 - 2010
CZ – Czech Republic	CD	1994 - 2017
DE – Germany	DB AG	1994 - 2017
DK – Denmark	DSB	1994 - 2009
ES – Spain	RENFE	1994 - 2012
FI – Finland	VR	1994 - 2017
FR – France	SNCF	1994 - 2014
GB – Great Britain	ATOC	1994 - 2017
GR – Greece	OSE	1994 - 2007
HU – Hungary	GySEV/ROEE	1994 - 2013
HU – Hungary	MAV	1994 - 2017
IE – Ireland	CIE	1994 - 2010
IT – Italy	FS	1994 - 2016
JP – Japan	HRC	1994 - 2016
JP – Japan	EJRC	1994 - 2016
JP – Japan	CJRC	1994 - 2016
JP – Japan	WJRC	1994 - 2016
JP – Japan	SHRC	1994 - 2016
JP – Japan	KRC	1994 - 2016
KR – South Korea	KORAIL	1994 - 2017

LU – Luxembourg	CFL	1994 - 2012
LV – Latvia	LDz	2008 - 2010
NL – Netherlands	NS	1994 - 2017
NO – Norway	NSB	1994 - 2009
PL – Poland	PKP	1994 - 2016
PT – Portugal	CP	1994 - 2011[2]
SE – Sweden	SJ	1994 - 2017
SK – Slovakia	ZSSK	1994 - 2007
TR - Turkey	TCDD	1994 - 2016
Total Number of observations		653

Table 3 below provides a summary of the definitions of all variables used in the model, consistent with the standard rail cost-function literature (e.g. Mizutani & Uranishi, 2013 and Mizutani et al., 2015). Following Mizutani et al. (2015), the cost data was collected from UIC International Railisa Stastics supplemented to some extent from other sources such as individual company accounts. We collected the energy price and consumption data from the IEA[3], Eurostat, and company accounts (i.e. JR companies and KORAIL) as they are not available in the UIC dataset after 1990. In some cases, e.g. Japan, the data comprises multiple, regional, vertically integrated companies. In other countries, where there has been some form of vertical separation, we compute one, single total cost of the rail industry, defined as the sum of the different train operating companies' costs (after subtracting infrastructure charges paid as they are just a transfer payment) and the cost of the infrastructure-providing company (i.e. infrastructure manager). This follows the approach taken in Mizutani et. al. (2015) and the literature in general and reflects the fact that for vertically separated industries, it would involve an arbitrary allocation to allocate rail infrastructure costs to the different train operating companies running on the network. That said, it should be noted that some of the vertically-integrated companies in Japan are larger than some of the smaller countries in the sample.

Although we aim to model the whole rail system costs for each country, there are some small vertically integrated systems not covered by our dataset (e.g. in Switzerland). Further, where we had a lack of data on new entrants' costs, we scaled up the data based on the incumbent companies' costs and their corresponding passenger and freight market share, with the model then including total industry train-km, rather than only incumbent train-km. This approach assumes that each operator's cost structure is proportional to its share of rail output, allowing us to reconcile the difference between incumbent-only cost reporting and the total system cost required for a system-level cost function. This adjustment was applied only where new entrants represented a non-trivial share of the market but did not publish separate cost data, and where

[2] The values of infrastructure investment for 2012-2017 were out of line with the values for all other years for Portugal, so the dataset only updates Portugal data to 2011.

[3] "Energy Prices and Taxes" by International Energy Agency (IEA)

system-wide cost information could not be obtained directly from official sources. In all other cases, where complete industry-level cost data were available, no scaling was required. This approach follows that in Mizutani et. al. (2015), and the adjustments affect only a very small proportion of observations in the dataset. While this scaling method is not perfect, since it implicitly assumes similar cost structures for incumbents and new entrants, it provides a pragmatic and transparent solution given the limitations of available data. Concerning data calibration, we also compared the data from different sources (i.e. Eurostat and individual company accounts like Network Rail in GB) and adjusted and calibrated any missing or problematic data.

We captured variables representing technological change over time[4], the share of freight rail revenue and rail internal competition (in passenger and freight rail, respectively) as the control variables. In line with the literature, inter-modal competition is not captured. Any effects, if they exist, would be indirect, and also not possible to measure in a variable with data compiled at the national level (competition effects would be highly route-dependent). Wider factors such as economic recessions were captured via the output measures in the cost function. While the inclusion of high-speed rail was considered, comparable data across countries were not available with sufficient detail or consistency to allow for robust modelling.

The rail infrastructure investment intensity was captured by three new variables *I(a/b/c)* to measure the current-period infrastructure expenditure flows (these being important to consider investment coordination under different vertical structures). Here we used either train-kms, route length (kms) or population as the denominator to normalise them. The infrastructure investment data covered both infrastructure enhancement and renewal (those were not separately identified in the OECD dataset of Transport Infrastructure Investment and Maintenance). As defined in the dataset, it contains the capital expenditure on new railway infrastructure [5] or extension of existing railways (including high-speed rail), including reconstruction, renewal (major substitution work on the existing infrastructure which does not change its overall performance) and upgrades (major modification work improving the original performance or capacity of the infrastructure). They are not averaged across years, and as current outlays, they do not enter the depreciation-based capital-cost component of the dependent variable. Unfortunately, the dataset does not allow for a disaggregated breakdown between maintenance and renewal (M&R) versus new line enhancements, so we are unable to test their effects separately.

For the countries with multiple rail companies (e.g. Switzerland, Hungary and Japan), the total investments in each country were split/allocated to each company in the country in proportion

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[4] The share of electrified track was found to better reflect technological progress than a simple time trend.

[5] Here, the word "Infrastructure" includes land, permanent way constructions, buildings, bridges and tunnels, as well as immovable fixtures, fittings and installations connected with them signalisation, telecommunications, catenaries, electricity sub-stations, etc.) as opposed to rolling stock.

to its monetary revenue. This reflects the financial contribution of each operator to the system and follows the approach used in Mizutani et al. (2015). Given the much smaller size of the new entrants in Switzerland and Hungary (compared to their original incumbents), Japan is the only country affected by this approach. We think this is a sensible approach given that revenue is the main source of infrastructure investment and the railways in Japan are mostly passenger services (freight rail does not hold infrastructure). Besides, we also tested the infrastructure investment allocation based on train-km, which yielded a very similar model result. *I(a)* is equal to the total infrastructure investment divided by total train-km, *I(b)* is equal to the total infrastructure investment divided by total route-km and *I(c)* is equal to the total infrastructure investment divided by the total number of inhabitants (which is the same for all the companies within one country).

To consider potential endogeneity, we tested the use of lagged investment intensity variables and found that the results were not sensitive to whether lagged values were used. This supports the common assumption in the rail cost literature that investment activity is largely exogenous, as governments and economic regulators typically set funding envelopes, service levels, timetables, and multi-year infrastructure plans. While the exogeneity of outputs in translog cost functions has been debated in the wider econometric literature (e.g. Kumbhakar, 1991; Lijesen, 2013), railways differ from unregulated sectors: outputs and investment levels are usually determined by public authorities rather than firms optimising in the short run. Accordingly, train density and investment intensity are generally treated as predetermined system characteristics (e.g. Caves et al., 1985; Coelli et al., 2005; Mizutani & Uranishi, 2013), and our robustness tests support this interpretation.

Finally, the investment variables on the right-hand side do not overlap with the dependent variable: investment variables measure current-year expenditure flows, whereas capital costs in the dependent variable reflect the depreciation-based user cost of the existing capital stock. The investment variables were also normalised and interacted with the structural dummies. This distinction avoids double-counting and is consistent with standard practice in rail cost-function studies, where institutional factors enter as exogenous cost shifters rather than as input quantities. Investment intensity thus represents a characteristic of the current-period system rather than a factor of production.

All of the cost-relevant data were collected from UIC and converted to 2005 prices. We collected total industry costs as infrastructure costs plus train operating company costs, as noted. While calculating the price, we also considered the average price for the whole industry/company. For example, labour price is calculated at the industry level by dividing the total labour costs of both the infrastructure manager and the train operating companies by the total number of employees in the rail sector. Labour cost covers wages and salaries plus social security costs. Material cost includes all the purchases of commodities and external services used as inputs in the production process. Energy cost covers both electricity and fuel costs. Capital cost includes depreciation, financial expenses and the total cost of the infrastructure manager (with Infrastructure charges deducted). Since we compute total industry costs as infrastructure costs plus train operating company costs, capital costs for infrastructure are included irrespective of whether the railway is vertically separated or not. However, in the case of vertically separated railways, there is a need to strip out transfer payments (track access charges) to avoid double-counting. This follows the same approach as in Mizutani et. al. (2015). Further details on the definitions can be found in Mizutani et. al. (2015).

We noticed that high-speed rail (HSR) investment can be substantial in some countries; however, consistent cross-country and time-series data on HSR network length or HSR-specific expenditure are not available. On the other hand, countries with substantial HSR development typically exhibit higher capital charges per route-km due to the greater capital intensity of HSR infrastructure. These effects are reflected both in the capital-cost component of the dependent variable and in higher observed capital prices per route-km on the right-hand side of the model. In addition, the investment-intensity variables *I(a)-I(c)* reflect total national infrastructure expenditure, which includes HSR construction, upgrades, and renewals where applicable. This approach is consistent with earlier rail cost studies, e.g. Mizutani et. al. (2015), which have faced similar data limitations and have relied on capital-cost differences rather than explicit HSR-km variables.

As part of the model validation process, a multicollinearity check was conducted across all explanatory variables. The analysis identified a correlation (0.55) between the freight traffic share interaction and infrastructure investment intensity interaction (i.e. *R*Dhc* and *I(a)*Dhc*). While not severe, this overlap raised concerns about coefficient stability and interpretability, and was a key consideration in refining the final model specification as discussed in section 4.

Table 3: Definition of the variables used for the estimation of the cost function

Variable	*Description*	*Unit*	*Mean*	*Standard Deviation*	*Minimum*	*Max*
TC	Sum of labour, energy, material and capital costs	€ million	4,922	6,417	107	34,198
cL	Labour cost	€ million	1,563	1,963	28	9,932
cE	Energy cost	€ million	210	260	2	1,413
cM	Material cost	€ million	1,292	1,718	33	10,134
cK	Capital cost	€ million	1,499	2,071	7	14,421
wL	Labour costs per employee	Euro	44,007	22,039	3,215	99,994
wE	Energy price per 1000 TOE	Euro	722,005	266,813	269,886	1,818,221
wM	Material costs per rolling stock	Euro	103,880	111,883	2,169	620,612
wK	Capital costs per route length	Euro	231,798	332,268	5,349	2,408,668

Qp	Passenger-km	1000 km	22,262	30,012	75	135,098
Qf	Freight tonne-km	1000 km	12,937	18,391	62	115,652
R	Freight revenues to total revenues	%	0.799	0.123	0.062	0.990
N	Total route km	Km	7,815	8,599	220	41,718
V	Train-km per route length per day	-	64	37.165	8.160	172.349
T	Percentage of electrified line	%	54	24.876	0	100
Dvs	Vertical separation dummy	-	0.277	0.448	0	1
Dhc	Holding company dummy	-	0.141	0.348	0	1
CMP	Passenger competition	-	0.686	1.113	0	4
Dcf	Freight competition dummy	-	0.375	0.484	0	1
Dhs	Horizontal separation dummy	-	0.340	0.474	0	1
S(L)	Share of labour input expenditure	-	0.364	0.122	0.081	0.685
S(E)	Share of energy expenditure	-	0.052	0.030	0.011	0.210
S(M)	Share of material expenditure	-	0.284	0.110	0.017	0.701
S(K)	Share of capital expenditure	-	0.299	0.159	0.035	0.769
I(a)	Rail Infra Investment (euro per train-km)	€/ km	10,079	10,597	196	109,323
I(b)	Rail Infra Investment, (euro per line-km)	€/ km	234,393	270,417	1,542	1,701,087
I(c)	Rail Infra Investment (USD) per inhabitant[6]	$/inhabitant	109	103.78	1.03	751.39

3.2 Empirical model

In this study, we used a translog cost function to investigate the cost impact of infrastructure investment intensity associated with rail structural reform. The translog cost function is most

[6] The unit of this variable has not been converted to Euro, given that we think the impact of exchange rate is minor and the same across most of the countries. So, it would not affect the model results.

commonly used in the rail cost and rail reform literature (see, e.g. the early work of Caves et al. (1985), and also Coelli et al. (2005), Mizutani and Uranishi (2013)) due to its flexible form. Since our purpose is investigating the effect of differences in alternative railway industry structures on system costs (on average), we do not consider stochastic frontier alternatives since we are not further interested in how efficiency performance varies in relative terms for specific countries within each structure. Besides, frontier models require distributional assumptions about the inefficiency term, which may influence the coefficients associated with structural-regime variables.

The model follows a standard cost function specification where (in logs) cost is a function of multiple outputs (passenger and freight), network size (in order to distinguish between economies of scale and density), electrification to represent technical change and a set of input prices, with details provided below. This is a standard approach to modelling total rail industry costs (which is our aim) in the general rail cost literature (see e.g. the early work of Caves et. al. 1985 and also in the rail reform literature (see e.g. Mizutani et. al. 2015).

We then include the following test variables in the cost function (see also Table 4):

- VS dummy (*Dvs*): takes the value of 1 in the case of full VS of operations and infrastructure for a given observation in each year; zero otherwise.
- HC dummy (*Dhc*): In each year, takes the value of 1 in the case where an HC structure is present for a given observation in each year; zero otherwise.
- VI dummy (*Dvi*): this variable is omitted to avoid perfect collinearity. All cost effects are therefore measured relative to the VI structure.
- In addition to the above dummy policy variables, we also include interaction terms. The interaction term between the industry structure forms (*Dvs* and *Dhc)* and infrastructure investment intensity *(I(a,b,c))* aims to investigate how the effect of industry structure on cost varies according to the infrastructure investment intensity. We introduce the interaction term between the industry structure forms (*Dvs* and *Dhc*) and train density (*V*) to test whether the most cost-effective solution is different for more and less dense systems. We also introduce the interaction term between the industry structure forms (*Dvs* and *Dhc*) and revenue freight proportion (R) to see how the effects of these industry structures are affected by the relative level of freight running on the network[7]. The interaction of dummies focuses on the test variables of interest, namely train density and infrastructure investment intensity (*V* and *I*) in order to test the hypotheses explained in the paper – i.e. how the cost impact associated with vertical separation changes with the intensity of infrastructure investment.

[7] Although this interaction is omitted in the later stage due to multilinearity, which will be explained in the next section with more details.

- Horizontal (passenger-freight) separation dummy (*Dhs*): takes the value of 1 where horizontal separation took place (i.e. freight and passenger rail operation are separated); zero otherwise.
- Passenger competition measure (*CMP*): this variable is used to measure the level of competition in passenger railways, with: 0 = no competition at all; 1 = competition is possible; 2 = competition has happened but is minor compared to the whole network (i.e. 10%); 3 = competition has happened and is major compared to the whole network (i.e. 25%+); and 4 = all services are submitted to competition (as it is in Britain). This approach follows that in Mizutani et. al. (2015).
- Freight competition dummy (*Dcf*): this variable takes the value of 1 when freight competition took place (i.e. actual freight entry); zero otherwise.

The cost function used in this study is a multiple-output model in which the output measures are passenger-km and tonne-km, respectively. The inputs of the cost function include the price of the labour[8], energy, material and capital inputs. The specification for the econometric model is shown below:

$$\ln\mathrm{TC} = \alpha_0 + \sum_m \alpha_m lnQ_m + \sum_j \beta_j lnw_j + \gamma_N lnN + \tau_T lnT + {}^1\!/_2 \sum n \sum m\, \alpha_{mn}(lnQ_m)(lnQ_n) +$$

$$\sum j \sum m\, \alpha_{mj}(lnQ_m)(lnw_j) + \sum m\, \alpha_{mN}(lnQ_m)(lnN) + \sum m\, \alpha_{mT}(lnQ_m)(lnT) +$$

$${}^1\!/_2 \sum k \sum j\, \beta_{jk}(lnw_j)(lnw_k) + \sum j\, \beta_{jN}(lnw_j)(lnN) + \sum j\, \beta_{jT}(lnw_j)(lnT) + {}^1\!/_2\, \gamma_{NN}(\mathrm{lnN})^2 +$$

$$\gamma_{NT}(lnN)(lnT) + {}^1\!/_2\, \tau_{TT}(ln\mathrm{T})^2 + (d_{VS1} + d_{VS2}lnV + d_{VS3}lnR + d_{VS4}lnI)D_{vs} + (d_{HC1} +$$

$$d_{HC2}lnV + d_{HC3}lnR + d_{HC4}lnI)D_{hc} + D_{hs} + D_{cf} + CMP$$

Where: *TC* = total cost; *Qp* = quantity of passenger rail output; *Qf* = quantity of freight output; *wL* = labour input price; *wE* = energy input price; *wM* = materials input price; *wK* = capital price *N* = total route length; *T* = technology (% of electrified route length); *V* = train density; *R* = proportion of revenue made up by freight; *I* = rail infrastructure investment level; *Dvs, Dhc, Dhs, Dcf, CMP* are the dummy variables that have been explained earlier. The parameters of d_{VS1}, d_{HC1} are the parameters for the dummy variables to be estimated. Restrictions on the input factor prices are introduced to satisfy the homogeneity conditions (such as the linear homogeneity of degree one) in the cost function:

[8] The types of input factor prices used depend on data availability, and are consistent with those that have been used in Mizutani, F. and S. Uranishi (2013).

$$\sum_j \beta_j = 1, \sum_k \beta_{jk} = 0, \sum_j \beta_{jN} = 0, \sum_j \beta_{jT} = 0, \sum_j \beta_{jT} = 0, \sum_j \alpha_{Yj} = 0, \sum_j \alpha_{mj} = 0, \beta_{jk} = \beta_{kj}\ , \beta_{jN} = \beta_{Nj}, \beta_{jT} = \beta_{Tj}, \alpha_{Yj} = \alpha_{jY}, \alpha_{YN} = \alpha_{NY}, \alpha_{YT} = \alpha_{TY}, \alpha_{mn} = \alpha_{nm}, \alpha_{mj} = \alpha_{jm}, \alpha_{mN} = \alpha_{Nm}, \alpha_{mT} = \alpha_{Tm}, \gamma_{NT} = \gamma_{TN}$$

When Shephard's Lemma was applied to the cost function, we obtained the input share equation as follows:

$$\mathrm{S}_j = \beta_j + \sum_m \alpha_{mj} lnQ_m + \sum_k \beta_{jk}(lnw_k) + \beta_{jN}(lnN) + \ \beta_{jT}(lnT)$$

Where *Sj*: input j's share of the total cost.

We estimated the model using the seemingly unrelated regression (SUR) method. Prior to estimation, we divided all of the observations of each variable by the sample mean, except for the dummy variables. All of the models were estimated using the STATA software.

4. Econometric Results

We first discuss the broad features of the econometric results before focusing on the results of policy interest.

4.1 General discussion on the econometric results

Our preferred model specification is shown below, building on the past literature and in particular the model structure estimated in Mizutani et. al. (2015). Additionally, and representing the important departure point from previous literature, we introduce our new variable of interest, namely the investment intensity interaction control variables.

The coefficients on the key variables, such as the output measures, input factor prices and network variables, show reasonable signs across all three cases. The goodness-of-fit in the regressions is acceptably high for the models (pseudo R2 is over 0.97). Given that we imposed restrictions on the cost model, the symmetry and homogeneity conditions of the input factor prices are satisfied automatically. The concavity of the input prices was tested in Stata using the Hessian matrix[9].

Table **4** reports the estimation results for the preferred specification (Case 1) using *I(a)* and the corresponding robustness tests using *I(b)* and *I(c)*. The three investment-intensity definitions produce highly consistent results.

Given that we have divided all of the observations of each variable by the sample mean for normalisation, the economies of scale and density can be derived from the coefficients of the variables. Based on this approach, we compute the scale elasticity at the sample mean based on the sum of the coefficients on the outputs Qp, Qf and network length (N) to be 1.03, implying returns to scale of 1/1.03= 0.97. The density elasticity is based on the sum of the coefficients on the output elasticities (holding network length constant) and is equal to 0.43, implying returns to density of 1/0.43=2.33. Overall, we therefore find broadly constant returns to scale, combined with economies of density, which is in line with the literature on vertically-integrated railways (see, for example, Smith, 2006).

One difference in our work, as compared to Mizutani et. al. (2015), is that we drop the interaction term between vertical structure and freight traffic proportion as this term becomes statistically insignificant. Further, the results were sensitive to whether the freight traffic proportion was expressed as a share of revenue as compared to a share of train-km, which we consider weakens the case for the inclusion of this relationship in the model. While tests

[9] The condition holds for 12% of the observations; Mizutani and Uranishi (2013) and Baum and Linz (2009) also note that the concavity condition does not hold for much of the sample. However, there is no straightforward means of imposing global concavity, and such imposition can undermine the flexibility of the translog model (see Coelli et. al., 2005, page 229). See also Ryan and Wales (2000).

without the investment variables show that the interaction term becomes more statistically significant, its coefficient is smaller (0.09 vs. 0.12 in the Mizutani et. al. 2015 study), and its significance diminishes when investment is accounted for, suggesting instability and a limited marginal contribution. Given this sensitivity and the fact that the freight share interaction and our investment intensity interaction are to some extent correlated ([0.55] between *R*Dhc* and *I(a)*Dhc*), we chose to exclude the freight share variable from the final model specification. This adjustment helps ensure model robustness and does not materially affect our main findings related to infrastructure investment, and freight tonne-km remains in the model as one of the two core outputs.

Table 4: Estimation results of the total cost function

Variables	*Case 1 – I(a)*	*Sensitivity test - I(b)*	*Sensitivity test - I(c)*
Qp	0.1106 ***	0.1106 ***	0.1029 ***
Qf	0.3187 ***	0.3188 ***	0.3230 ***
wL	0.3170 ***	0.3170 ***	0.3175 ***
wE	0.0379 ***	0.0379 ***	0.0378 ***
wM	0.3223 ***	0.3223 ***	0.3224 ***
wK	0.3228 ***	0.3228 ***	0.3223 ***
N	0.5992 ***	0.5991 ***	0.6019 ***
T	0.0491	0.0487	0.0479
*Qp*Qf*	-0.0467 **	-0.0468 **	-0.0530 ***
Qp Qp*	0.0700 ***	0.0701 ***	0.0768 ***
Qf Qf*	0.0135	0.0135	0.0079
*Qp*wL*	0.0373 ***	0.0373 ***	0.0373 ***
*Qp*wE*	0.0141 ***	0.0141 **	0.0145 ***
*Qp*wM*	0.0078	0.0078	0.0070
*Qp*wK*	-0.0593 ***	-0.0593 ***	-0.0587 ***
*Qf*wL*	0.0329 ***	0.0329 ***	0.0331 ***
*Qf*wE*	-0.0001	-0.0001	0.0006
*Qf*wM*	0.0380 ***	0.0380 ***	0.0358 ***
*Qf*wK*	-0.0709 ***	-0.0709 ***	-0.0694 ***
*Qp*N*	-0.0516 *	-0.0515 *	-0.0570 **
*Qf*N*	0.1483 ***	0.1485 ***	0.1628 ***
*Qp*T*	-0.0523 *	-0.0524 *	-0.0615 **
*Qf*T*	0.0056	0.0057	0.0120
wL wL*	0.1399 ***	0.1399 ***	0.1394 ***
wE wE*	0.0495 ***	0.0495 ***	0.0490 ***
*wM*wM*	0.1113 ***	0.1112 ***	0.1101 ***
wK wK*	0.1669 ***	0.1669 ***	0.1660 ***
*wL*wE*	-0.0047	-0.0047	-0.0046
*wL*wM*	-0.0451 ***	-0.0451 ***	-0.0449 ***
*wL*wK*	-0.0901 ***	-0.0901 ***	-0.0898 ***

*wE*wM*	-0.0171 ***	-0.0171 ***	-0.0167 ***
*wE*wK*	-0.0278 ***	-0.0278 ***	-0.0277 ***
*wM*wK*	-0.0491 ***	-0.0491 ***	-0.0485 ***
*wL*N*	-0.0998 ***	-0.0998 ***	-0.0998 ***
*wE*N*	-0.0185 ***	-0.0185 ***	-0.0192 ***
*wM*N*	-0.0241 *	-0.0241 *	-0.0215 *
*wK*N*	0.1423 ***	0.1423 ***	0.1405 ***
*wL*T*	-0.0271 ***	-0.0271 ***	-0.0268 ***
*wE*T*	0.0036	0.0036	0.0026
*wM*T*	-0.0044	-0.0044	-0.0016
*wK*T*	0.0279 ***	0.0279 ***	0.0258 ***
*N*N*	-0.1733 **	-0.1737 **	-0.1799 **
*T*T*	0.1742 ***	0.1742 ***	0.1794 ***
*N*T*	-0.0456	-0.0457	-0.0417
Dvs	-0.0900 ***	-0.0908 ***	-0.0864 **
*V*Dvs*	0.3187 ***	0.4161 ***	0.3204 ***
*R*Dvs*	Omitted	Omitted	Omitted
*I(i)*Dvs*	-0.0990 ***	-0.0983 ***	-0.1060 ***
Dhc	-0.0486	-0.0485	-0.0595 *
*V*Dhc*	0.1397 ***	0.1320 *	0.1671 ***
*R*Dhc*	Omitted	Omitted	Omitted
*I(i)*Dhc*	0.0075	0.0076	-0.0093
Dhs	-0.2964 ***	-0.2964 ***	-0.2862 ***
CMP	0.0007	0.0008	-0.0022
Dcf	0.0467 *	0.0467 *	0.0611 **
_cons	0.4003 ***	0.4002 ***	0.3929 ***
Log of likelihood	3375.922	3375.692	3388.46
Pseudo R2	0.978	0.978	0.978
Observations	653	653	659

The model shows the consistent negative cost impact of the interaction of our three measures of investment *I(a), I(b),* and *I(c),* with the VS dummy variable (negative coefficients for *I(a/b/c)*Dvs* with 1% statistical significance). There was little to choose between the three different versions of the investment variable in terms of the sizes, signs and statistical significance of the parameters of interest or the log-likelihoods. However, compared with *I(b)* and *I(c)*, we consider that *I(a)* has a more reasonable definition of infrastructure investment intensity because it considers train kilometres as the denominator. Given that infrastructure investment should aim to enhance the efficiency of rail operations (influenced by both the track and trains), investment per train-km is more appropriate to reflect the intensity of infrastructure investment on a railway system. We therefore consider *I(a)* to be the appropriate one to illustrate the cost impact in different rail industry structures, though, as noted, the results are not sensitive to the choice of measure. We also tested a number of alternative models to reflect possible lags in the impact of infrastructure investment (3 to 5 year lags), but the results were not sensitive, so we selected the models without lags as in Table 4.

4.2 Discussion of model results

In this section, we first discuss how our results are according to the two contributions of the paper. We start by comparing our results to the past literature, reflecting the substantial update to the dataset to reflect more recent data and thus a more complete view of the impact of railway reforms. We then turn to focus on investment coordination/misalignment costs and how these might vary across different vertical structures.

Comparison to past literature

As noted earlier we make a substantial update to the data used in the past railway cost function literature, extending datasets as far as 2017. This both increases the sample size and gives a more up-to-date view on the impact of rail reforms given that in some countries the reforms were implemented in the late noughties and beyond.

Our model provides support for some of the key findings from the past literature (van de Velde et al. (2012) and Mizutani et. al. (2015)). In particular, we find a strong (and statistically significant) cost-reducing impact of horizontal separation (passenger and freight separation). This could be explained by several cases in which cost reductions took place because freight divisions were sold to new owners rather than as a direct consequence of horizontal separation. Further, our model confirms the results of past studies showing limited impacts of competition on costs, which is consistent with the findings in van de Velde et al. (2012). The earlier studies (e.g. Mizutani and Uranishi, 2013; Mizutani et al., 2015) also highlighted the potential role of the freight–passenger mix in influencing the cost effects of vertical separation. In our extended dataset, freight share is highly correlated with investment intensity, and the estimated coefficients were sensitive to the definition of the freight-share measure (revenue-based versus train km-based). Given this instability, these terms were omitted from the final specification. Freight-mix effects, therefore, remain an important topic for future research.

A strong theme from the past literature has been the cost impact of vertical separation as compared to vertical integration, as well as different forms of vertical separation (namely the holding company regime versus full, legal vertical separation), and also how train density can affect this comparison (see Mizutani and Uranishi (2013); van de Velde et al. (2012); Mizutani et. al., (2015)). The cost impact of the vertical structure was assumed to be driven by the difference in coordination mechanisms between the RU and IM. The coordination mechanism may generate transaction costs, which are the costs incurred in making an economic exchange (i.e. the costs of reaching an agreement with the selling party and the costs related to enforcing the realisation of the transaction, making sure the seller sticks to the contract. Applied to the railway world, this theory allows for developing a deeper understanding of the factors that may indicate which form of organisation is more suited to minimise transaction costs. This theory was discussed in van de Velde et al. (2012) and inspired by the Transaction Cost Economics theory, as developed by Williamson (1975; 2000), which pays explicit attention to transaction costs besides the actual production costs of a good or service. The past railway literature, like van de Velde et al. (2012) particularly highlights the misalignment of incentives that can occur in co-ordination in vertically separated environments. To specify such areas of transaction costs generated, we will focus on the variables of train density and infrastructure investment intensity.

Two figures, Figure 3 and Figure 4, are produced and shown below to illustrate the econometric model results. We consider the components of vertical separation ($(d_{VS1} + d_{VS2}lnV + + d_{VS4}lnI)D_{vs}$) and holding company ($(d_{HC1} + d_{HC2}lnV + d_{HC4}lnI)D_{hc}$) separately. The cost reduction effect of one structure compared to the other is then computed by taking the exponential form of each component and deducting it from one. In Figure 3, we assume average levels of investment intensity (i.e. $lnI = 0$) in both components because at that stage we want to highlight only the relationship with train density, as this has been the focus of the past literature. In Figure 4, we then show how the cost of vertical separation compares to vertical integration in relation to train density, but with three separate lines representing high, mean and low levels of investment intensity. For the holding company regime, a single line is shown as the cost effect of this form was not found to depend on investment intensity. The findings from each figure are discussed in turn below.

Figure 3 shows, first of all, how the two forms of vertical separation compare to vertical integration in terms of costs at different train densities (for now, holding infrastructure investment intensity per train-km at the sample mean). Where the VS (and HC) lines are above the origin this means that the VS and HC structures offer cost reductions (i.e. are less costly) than vertical integration for a given level of density. Figure 3 shows that the VS regime becomes a more expensive form of vertical structure than VI for busier railways, though does reduce costs for more lightly-used railways. This result is directionally the same as in van de Velde et al. (2012) and Mizutani et al. (2015). According to the transaction cost theory, this finding can be explained by the increasing transaction costs on a busier network. For example, the entailing costs for tasks such as maintenance scheduling and maintaining safety under a busy train operation schedule are more expensive for vertically separated structures.

The train density break-even point between the VS and VI regimes is 84.6 (1.33* sample mean of 63.6), where the VS curve crosses the horizontal axis. This result means that the VS regime (for now, with an average intensity of infrastructure investment per train-km) is more cost-efficient compared to the VI regime if train density is under 84.6 (train-km/route-km per day); after which VS starts to increase costs. We notice that the break-even point differs from past work (previously 0.99* sample mean[10]). Importantly, this means that our model suggests that

[10] See Mizutani et. al. (2015). The sample mean in that paper was similar to that in our paper.

VS is a viable vertical structure from a cost perspective for a wider range of (busier) railways.

Another key difference in our model compared to past work is that the cost impact of the HC regime, relative to VI or VS, is also found to vary with train density, as shown by the HC curve in Figure 3. However, the slope of the line for VS is steeper than that for HC. This means that cost is affected to a greater degree by train density in the VS regime than in the HC regime. As compared to VS, the HC regime is more expensive for lightly used railways but intersects the VS curve at 1.26 times the sample mean of 63.6 (equals 80.15 train-km/route-km per day). As train density increases above this level the HC is a more effective structural form than VS. If we assume that train density is a key driver for the misalignment costs between RU and IM (a higher train density leads to higher costs to solve the conflict issue between RU and IM), then the HC regime seems to have greater capability to reduce the misalignment costs compared to the VS regime.

This new finding supports the view advanced by van de Velde et al. (2012), which asserted that the misalignment issues between RU and IM exist in all types of rail industry structures. However, the HC regime has been found to solve these misalignments more effectively than a vertical separation regime did due to the higher cost break-even point for the HC regime as discussed above.

This comparison between the two different forms of vertical separation (holding company and full legal vertical separation) is important in the context of EU rail reforms because the European Commission has permitted both methods as a valid means of delivering a form of VS in line with EU legislation. It does suggest, though, that the choice of form of VS is important. Beyond a train density cut-off point of 80.15 (1.26 times 63.6), the HC regime would be the cheapest means of delivering vertical separation, whilst full legal separation might be preferred (from a purely cost-reducing perspective) for less well-utilised railways to the left of this cut-off point (see Figure 3). With train density higher than 90.31 (1.42 times 63.6), vertical integration seems to be the most cost-efficient regime compared to both the VS and HC forms of separation.

Investment coordination and vertical structure

In Figure 4, we turn to consider the relationship between the choice of vertical structure and different intensities of infrastructure investment (as measured by investment per train-km). The cost impact of infrastructure investment is complex. As one element of cost, infrastructure investment contributes to total cost, but important infrastructure investment may help to save operational costs. For example, rail electrification normally has high implementation costs, but it can reduce energy costs and operational costs, given that electric engines have higher energy efficiency and less need for maintenance. The locomotion costs associated with operating an electric train can be four times lower than a diesel train (International Transport Forum, 2020).

van de Velde et al. (2012) provided a hypothesis that where a railway is undertaking significant investment, this would lead to higher costs in the VS regime than in the HC or VI regimes due to the extra misalignment costs (investment coordination problems) generated, with the HC and VI regimes deemed to be better at coordinating investment. However, this hypothesis was not tested empirically in their work. In our study, we do find a clear difference in the cost impact of handling higher investments between the VS and HC regimes. However, the finding is the opposite of that expected by van de Velde et. al. (2012). The model results show a negative impact of the interaction between investment intensity (*I(a))* and *Dvs (*with 1% statistical significance). On the other hand, the coefficient on the interaction term *I(a)*HC* (holding company) is close to zero and not statistically significant. This means that a higher intensity of infrastructure investment in the VS regime leads to a reduction in overall system costs, whereas there is no such cost-reducing effect in the case of the holding company regime or vertically-integrated railways.

We explore this point in more depth in Figure 4, which shows how the relationship between cost, vertical structure and train density varies for different levels of infrastructure investment intensity in the VS and HC regimes. We start by comparing VS with VI – here, Figure 3 shows that the train density break-even point for the VS regime can be shifted to the right by a higher level of infrastructure investment intensity. Compared to the minimum investment intensity, the break-even point under the maximum infrastructure intensity is more than three times higher (2.1* sample mean versus 0.61* sample mean)[11]. This indicates that when infrastructure investment intensity is high, the VS structure can operate the railway system more cost-efficiently than the HC and VI regimes with the same train density for a wide range of railways (with density levels up to more than twice the sample mean).

Note that there is only one line for the HC regime since there was found to be no significant relationship between HC cost impacts and the level of investment intensity. Importantly, the break-even point of 2.1* sample mean is even higher than the cost break-even point for the HC regime with an average investment intensity. It, therefore, appears that the cost advantage that the VS regime appears to hold in terms of coordinating higher investment outweighs its other coordination disadvantages (noted in the past literature and discussed above). The table below considers the cost effects of train density and investment intensity complementarily and illustrates the cost-effective range of train density for each vertical structure with mean, high and low infrastructure investment intensity. It shows that the break-even train density point for vertical separation can be influenced by investment significantly. From another perspective, it also demonstrates the appropriate (from a cost-saving perspective) vertical structure for different railway networks; that is, Vertical Separation is more suitable for networks with low train density and/or high infrastructure investment intensity. Vertical Integration is more suitable for networks with high train density and/or low infrastructure investment intensity, whilst Holding Company sits in the middle of Vertical Separation and Vertical Integration. See Table 5 below for examples of the indicative cost-effective vertical structure under different combinations of

[11] Note that the interaction term between D_{HC} and investment was not statistically significant, and as such the holding company break-even point does not vary with investment intensity as noted above

infrastructure investment intensity and train density level.

Table 5: The indicative cost-effective vertical structure under different levels of infrastructure investment and train density

Infrastructure Investment Intensity (annual)	High Train Density (110[12])	Medium Train Density (60)	Low Train Density (20)
High (≈ 44,700 €/train-km)	VI	VS	VS
Mean (≈ 9,500 €/train-km)	VI	VS	VS
Low (≈ 800 €/train-km)	VI	HC	HC

Although the estimated coefficients are discussed above in terms of statistical significance, their magnitudes also imply economically meaningful effects. For example, the estimate for the interaction term *I(a)*Dvs* (–0.099) implies that a 10% increase in infrastructure investment intensity is associated with approximately a 1% reduction in total system costs for the VS regime, holding other factors constant. Given the size of the industry in many of the countries in our dataset, even a 1% improvement represents several hundred million euros per year in cost savings. By contrast, no statistically significant relationship between investment intensity and total system cost is identified for the VI and HC regimes. For context, the average level of investment intensity for the VS regime is lower than the VI regime, indicating that the stronger cost-reducing effect in the VS regime does not simply reflect higher underlying investment levels.

The break-even analysis in Figure 3 and Figure 4 likewise highlights the economic magnitude of these effects. Higher investment intensity shifts the train-density threshold at which vertical separation becomes more cost-effective by more than three times higher (from 0.61* to 2.1* the sample mean). This shift represents a substantial change in the range of networks for which vertical separation minimises costs. In this way, the estimated effects are both statistically and economically significant.

These findings can be explained by the two following perspectives. Perspective A focuses on how infrastructure investment could alleviate some of the misalignment costs incurred by the vertically separated structure, thus viewing the impact of train density and infrastructure investment alongside one another. The conclusion of Mizutani et al. (2015) indicates that higher train density levels in the VS regime may increase costs due to the greater misalignment costs generated by disruptions. Building on this point, higher investment - whether through upgrading signalling systems, renewal of key assets, or capacity enhancements - reduces the likelihood and operational severity of such disruptions. For example, the European Rail Traffic Management System (ERTMS) has been introduced to European railways since the 1990s to replace more than 20 train control systems previously in use throughout Europe. The higher

[12] The unit is train-km per route-km per day

reliability rates and additional capacity brought by ERTMS may help to reduce the chance of disruption and reduce the cost of solving disruptions (ERTMS, 2014). In this case, infrastructure investment acts as a buffer that mitigates the real-time coordination burdens inherent in vertical separation. This effect then sees a bigger cost reduction in the VS regime, given that this regime suffered more due to the high misalignment costs of resolving such disruptions in the short term and through real-time coordination. Therefore, the extra misalignment costs generated by higher train density may be offset by the improvements in infrastructure quality when investment is sufficiently high.

An alternative explanation might also be put forward - perspective B explains the result by considering the cost efficiency of investment in the different operational regimes. As discussed in the work of van de Velde et al. (2012), the potential misalignment that appears in the investment coordination is related to the mismatch between the market needs and infrastructure investment, and between the infrastructure and rolling stock investments. This might suggest that more coordinated structures, such as the holding company regime, would be more efficient at managing infrastructure investment. However, on the other hand, vertical separation might lead to stricter planning and evaluation within the investment coordination process, given the scrutiny placed by regulators on the infrastructure manager in vertically separated environments. This may result in higher cost efficiency. Under this interpretation, vertical separation can sometimes deploy each unit of investment more effectively, precisely because investment decisions are subject to stronger external oversight and transparency requirements. In this case, the VS regime may be closer to the optimisation of the total investment needs in the industry than the other regimes.

Overall, the finding that higher infrastructure investment has a greater cost-reducing effect in the VS regime than in more integrated regimes could be seen to go against expectations as indicated by van de Velde, Nash et. al. (2012), which would see more integrated solutions such as the holding company or vertical integration as being more efficient in dealing with coordination of infrastructure investment. However, our findings suggest that once investment reaches a sufficiently high level, the VS regime is particularly effective at translating that investment into lower system costs. Several possible explanations have been put forward, based on the increased transparency and focus of the VS railway system, and the role of investment as an offsetting effect to the wider misalignment problems within the vertically separated structure. It is important to note that our analysis focuses on how effectively different structures translate a given level of investment into lower system costs, rather than on whether vertical separation increases or decreases the level of investment itself (see Pittman, 2017).

Figure 3: Cost reduction effect of the different regimes (VS and HC)

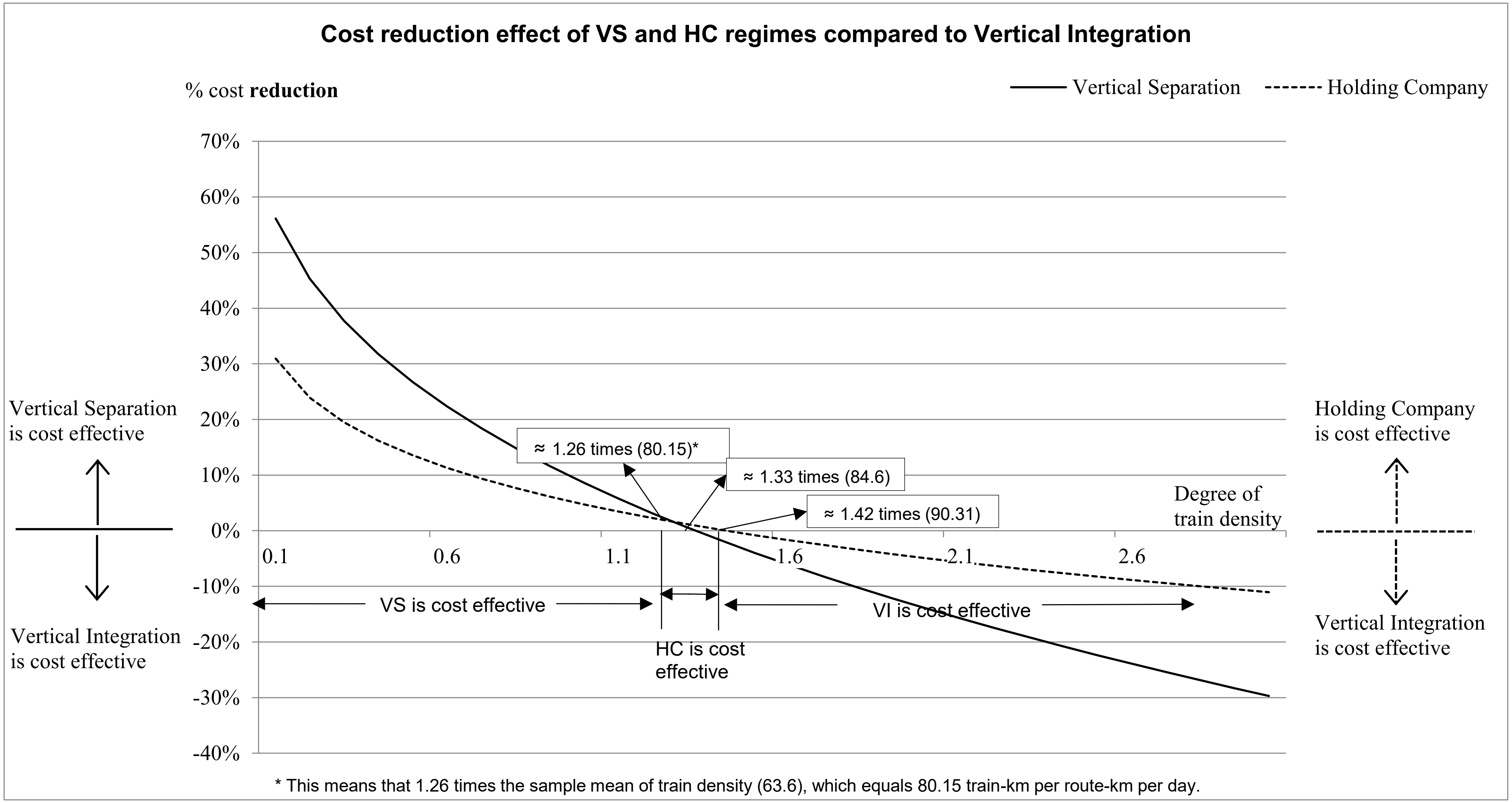
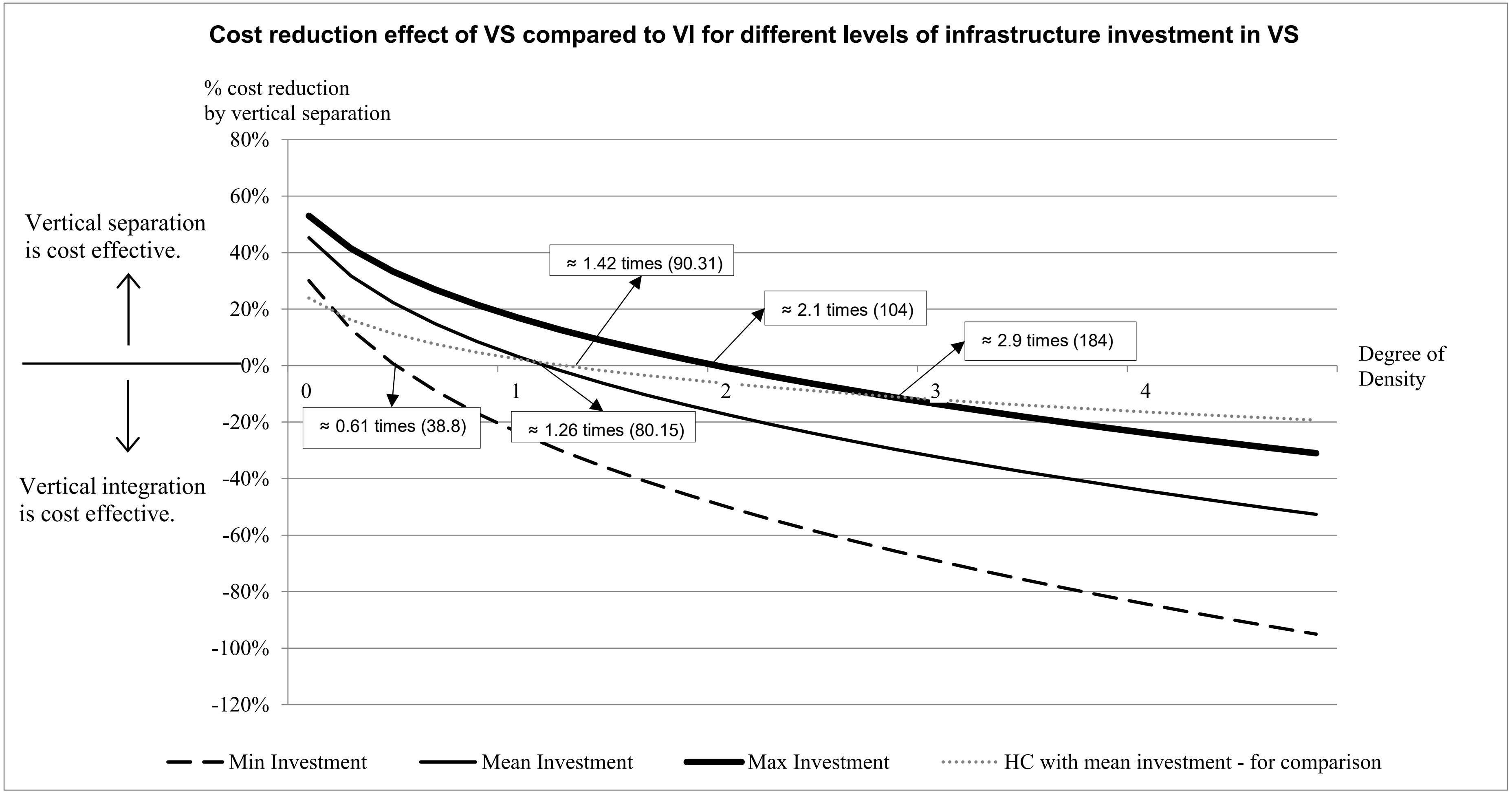


Figure 4: Cost reduction effect of VS compared to VI, showing the minimum, mean and maximum infrastructure investment levels in the VS regime



5. Conclusions and policy implications

This study presents a new and up-to-date perspective on the impact of alternative railway vertical structures on rail system costs, focusing in particular on investment coordination/misalignment costs and how these vary under alternative vertical railway structures and taking account of the most recent data and experience of railway reforms in Europe. With the dataset updated to 2017 (previously 2010), a more robust result could be achieved to better reflect the cost impact of the rail reforms (especially the long-term effects) in the selected countries. For example, Spain and Hungary implemented their rail reforms in 2005 and 2007. It is expected that the impacts of reforms may appear gradually over several years, and it should be noted that rail reforms in Europe have not yet been completed. In addition to adding new data to increase robustness and take account of the most recent impacts of reforms, we also added new variables representing the level of infrastructure investment to explore investment coordination cost effects under alternative vertical structures.

Our study confirms some of the conclusions from the previous literature, thus increasing our confidence in those results. We found that the cost of the VS regime compared to vertical integration depends on the intensity of usage of the network. This is consistent with the findings of Mizutani et al. (2015). However, the precise cut-off points in terms of the level of train density at which different structures are optimal do change in our study, indicating that VS may be cost-reducing for a wider range of railways. With the new dataset, we also found this relationship between cost impacts and train density in the HC regime, although the train density for the cost break-even point (from cost reduction to cost increase) seems to be higher than that for the vertically separated organisations. This new finding shows that the HC regime can operate high-intensity services more cost-efficiently than the VS regime. More specifically, we found the most cost-effective range of train density for each regime. It shows that the VS regime is more cost-effective for the network with a train density of less than 80.15 train-km/route-km, while the HC regime is more cost-effective for the network with a train density higher than 80.15 but lower than 90.31 train-km/route-km. The full integration regime might be preferred (from a purely cost-reducing perspective) for railways utilised higher than 90.31 train-km/route-km.

As noted, in addition to re-visiting and updating previous effects relating to train density and the vertical structure, we further investigated the qualitative expectation from the literature that vertically separated structures lead to higher transaction costs due to long-term coordination effects (i.e. investment coordination); see van de Velde et al. (2012). In fact, our quantitative analysis results show the opposite finding, in that a higher intensity of infrastructure investment has a negative impact on railway system costs within the VS regime compared to both the holding company and vertical integration. This implies that the VS regime may be more efficient at implementing investment and achieving overall total system cost minimisation than more integrated railways.

Our findings on the differential cost impacts of infrastructure investment in VS versus HC can be explained in two possible ways. First, the cost impact of infrastructure investment needs to be explained along with train density. This means that a higher degree of infrastructure investment intensity helps to reduce the transaction costs generated in production (real-time) and timetable planning coordination. For example, an investment in new technology (like a real-time management system or a signalling system like ERTMS) can either reduce disruptions or reduce the cost of solving disruptions in the network. These beneficial (cost-reducing) effects will be greater in the case of the VS structure, which suffers from greater production/real-time misalignment problems.

Second, it could be the case that the VS structure has a higher cost efficiency in investment coordination due to the increased transparency and focus within the vertically separated structure, leading to wider and more involved discussions/evaluations (where the operator may also bring good ideas to the IM) within the investment process. For example, the IM, RU and regulators may be involved in this process, and the investment needs to be approved by all parties based on its BCR (benefit-cost ratio). However, this hypothesis requires further qualitative research to support it.

The policy implication of the results is that there is no “one-size fits all” choice of vertical structure in terms of cost minimisation, and the choice of structure is found to depend on the intensity of usage of the network and the intensity of infrastructure investment. Each structure has its own applicable (cost-effective) range of train density, which implies that the HC regime (or indeed full VI) is typically a better choice for intensely used networks than VS if train density is higher than 80.15 train-km/route-km per day. However, VS can bring cost benefits for more lightly used railways. That said, since structural change is difficult to implement and rarely revisited, the results are best interpreted as guidance for policymakers on how to optimise performance within existing structures. Further, taking into account investment intensity changes the relative cost rankings of the different vertical structures, with VS becoming an optimal choice for a wider range of railways, up to a density cut-off point of 104 train-km/route-km per day. Specifically, in the VS regime, higher infrastructure investment levels are shown to offset the coordination disadvantages commonly associated with vertical separation. These results, then, in part push back against previous hypotheses in the literature that VS systems are necessarily inefficient at coordinating investment, and instead highlight the importance of aligning investment strategies with network characteristics. Further qualitative research is needed to further interpret our findings.

This study has brought new insights concerning investment coordination effects and produced more up-to-date results on the cost impacts of rail reforms based on quantitative analysis. We also consider that new qualitative work (i.e. surveys/questionnaires for the relevant practitioners in the industry) to understand further how rail infrastructure investment is implemented and managed in different countries would be useful, in particular focusing on the differences between each type of investment (renewals versus enhancements) and the approval procedures, regulatory oversight and coordination activities (and misalignments) impacting on the VS, HC and VI regimes. Such qualitative work may investigate whether our hypotheses on explaining the econometric results are correct.

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