Competition and Industry Structure for International Rail Transportation *

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Abstract

This paper investigates various options for the organization of the railway industry when network operators require the access to multiple national networks to provide international (freight or passenger) transport services. The EU rail system provides a framework for our analysis.

Returns-to-scale and the intensity of competition are key to understanding the impact of vertical integration or separation between infrastructure and operation services within each country in the presence of international transport services. We also consider an option in which a transnational infrastructure manager is in charge of offering a coordinated access to the national networks. In our model, it turns out to be an optimal industry structure.

1 Introduction

According to the so-called Second Railway Package of the European Union, the Rail freight market across the EU Member States and Switzerland is liberalized, adopting an open access regime in each country. Since 2010, international passenger services is also open to competition within the European Union as part of the Third Railway Package. These

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decisions are aimed at fostering this rail activity which represents a significant part of railways' revenues and market shares - more precisely, ten percent of railway undertakings' passenger turnover and twenty percent of international traffic. While international rail services face a fierce competition from low-cost airlines, it is deemed that they would profit from the enlargement of the European high-speed network and its interconnection if intramodal competition is implemented. To do so, it is required that all Member States grant the right of access to their rail infrastructure. Now, this policy raises in particular the question of designing what could be the optimal organization of the European rail industry, i.e., the industrial structure that would yield the highest level of consumer welfare. We provide some insights on this key question by developing a model allowing explicitly for an international (i.e., between countries) competition with the railway industry in the background.

The traditional model of railway organization in Europe involves a single firm in charge of both the fixed infrastructure, i.e., the network of rail tracks and its associated equipment of signals and stations, and the operational services, which include rolling stock management and all the transport services. More precisely, the firm is vertically integrated. The main reason advanced to support this organization is that there is a need for cooperation between the two layers.

Along these lines, a few econometric analysis of railroad cost functions document the existence of cost complementarities between infrastructure and operations. Ivaldi and McCullough (2001) manage to account for the vertical structure of railroads, which allow them to evaluate the cross-elasticities between the infrastructure output and the different service operations by fitting a translog cost function to a panel dataset of U.S. freight railroads. A recent article by Ivaldi and McCullough (2008) tests for sub-additivity in the cost function between infrastructure and freight operations. The results indicate that firms running each activity separately would have up to 24 percent higher operational costs than a vertically integrated firm. A study by Cantos (2001) undertakes a similar approach to Ivaldi and McCullough (2001) for European services. Using a translog cost function, the author analyzes economies of scope between infrastructure output and transport operations (passenger and freight) for 12 major European railways along the 1973 -1990 period. The main finding is that the marginal cost of passenger output is increasing with the level of infrastructure value while the opposite result is obtained for freight operations. Other evidence comes from Mizutani and Shoji (2001), who studied the case of Kobe-Kosoku Railway in Japan. They found that vertically separated firms cost 5.6 percent more than an integrated system.[1]

[1]Shires et al. (1999a) compared the cost of the Swedish operator after a reform involving vertical separation, and found that operating costs have been reduced by 10 percent. However, it is difficult to know to what extent such reductions were due to vertical separation per se rather than to other aspects

These results just indicate that vertical disintegration might be costly from a technical point of view. They must be balanced with gains that could be expected from managing the rail infrastructure separately from the different rail service operations. In particular, from a regulatory perspective, it could be more difficult for authorities to obtain the information required for effective regulation of access than in the disintegrated case. With separation, all firms that would enter the market are treated on an equal footing and face the same rules of access. Moreover, it could be easier to compare productivity and performance of the firms operating on the same track. Separation is viewed as a way to foster competition to the benefit of customers, not in the sense that all prices would be lowered but in the perspective of a higher level of consumer surplus.

It remains that a well-known advantage of vertical integration is its diminished incentives for double marginalization, so it may be that some kinds of anti-competitive behavior become less likely under integration even though the authorities' ability to monitor them is diminished. This is probably why most countries - apart a few examples like France, Japan, The Netherlands, UK - have still maintained an integrated industry or have adopted a partial disintegration where the vertically integrated incumbent is challenged by new entrants.

With these economic results and facts in mind, we question here the relevance of the European reform of the *international* rail service contained in the Third Railway Package. Indeed, most empirical and theoretical analyses on the costs and benefits associated to integration do not consider international services which require the use and access to several infrastructure networks. Our objective is to shed light on both the working of competition and the optimal industry organization for the international rail services, i.e., to provide a theoretical setup to understand and explain the issues at stake. Incidentally, at this stage, we expect that this model would draw directions for future empirical research.

In this perspective, we develop a model to analyze these issues. With references to the EU directives on liberalization and unbundling, which, in particular, allows for different degrees of separation, we consider a model in which two (downstream) railroad operators compete on a final market to provide transport services to end-users; since inter-modal competition is also important, we assume that end-users could also travel by another transport mode, which we take to road for instance. Our focus is on international transport services, that is, transport services from one country to the other. Therefore, to provide one unit of transport services, transport operators have to get access to both infrastructures; the pricing of a given network is under the control of a country-specific (upstream) infrastructure manager.

Our analysis emphasizes two elements: The nature of the returns-to-scale and the

of the reforms.

nature of the final services provided by the transport operators. More precisely, we consider that either the upstream segment (network) or the downstream segment (transport operator) can exhibit some increasing or decreasing returns-to-scale. As we show in the sequel, the optimal industry organization depends on these returns-to-scale, in particular at the level of the upstream sector.

We study two polar cases. First, we consider that final transport services are purely local: To complete one unit of services, each transport operator must access only one network. Second, we assume that services are purely international in the sense that, in order to complete one unit of transport services, each operator must access both networks. Contrasting these two scenarios allows to understand how the railway organization should be amended with the development of international transportation.

The analysis undertaken here shows that, when the industry features downstream returns-to-scale only, then vertical integration ought to be favored with respect to any other organizational choices which would imply some form of separation. This holds true whatever the nature of the final transport services, that is, whether we consider purely local or purely international services.

With upstream returns-to-scale, the analysis becomes less clear-cut. With purely local services, integration is preferred to separation when the returns-to-scale parameter, weighted by the intensity of competition on the final market, is not too large. With purely international services, a somewhat similar conclusion emerges: Integration (in both countries) dominates provided that the returns-to-scale parameter is not too large; when it increases, a mixed industry organization, in which one firm is integrated whereas the other is separated, becomes optimal; when it further increases, separation in both countries becomes optimal.

As an implication, when the share of international services becomes greater with respect to the total level of transport services, our analysis argues that some kind of separation tends to be preferred when the infrastructure is characterized by decreasing returns-to-scale; integration would be optimal, by contrast, under increasing returns-to-scale at the infrastructure level. Importantly, note that the competitive environment must be taken into account in such a reasoning.

Concerning international services, whether it is for freight or passengers, the incumbents of different countries sometimes have cooperative agreements to provide combined services whose revenues they share, based on some rule in a transparent way for the users. Allowing the railroad operators to coordinate their pricing decisions on the final market has the obvious drawback of increasing their market power.

Another option, much less discussed in the academic literature, is to allow some coordination between national infrastructure managers. We compare the situations of vertical integration or vertical separation in both countries with the situation in which both national infrastructure managers are merged into a single entity, called the *transnational infrastructure manager*. The creation of a transnational infrastructure manager always dominates the situation with vertical separation in both countries since the horizontal externalities between the national access pricing decisions are now perfectly internalized. The comparison with the case of vertical integration in both countries is less immediate: Vertical integration allows to alleviate the double marginalization problem within each country (a vertical externality is internalized) but the horizontal externality between national infrastructure managers remains; with a transnational infrastructure manager, the horizontal externality is internalized, but not the vertical ones. With the specification of our model, we found that the situation with a transnational infrastructure manager always dominates any other industry organization. This result holds whatever the nature of the returns-to-scale on the upstream and the downstream segment.

Our analysis departs from the traditional analysis of vertical integration by considering, first, increasing or decreasing returns-to-scale at the various segments of the industry, and, second, final services which require the access to several networks whose access is controlled by non-cooperative infrastructure managers. We build on Bassanini and Pouyet (2005) and Agrell and Pouyet (2004). While these papers are more interested in the optimal regulation of the industry, we leave aside such issues and consider that regulatory choices are limited to the decision to integrate or separate the industry. However, we consider that railroad operators are imperfectly competitive, which seems a sensible assumption in the railway industry.

Section 2 introduces the notations, the setup and the basic ingredients of the model. Section 3 presents the main results in a local competition environment where there is only one network. It is used as a benchmark. The main results of international competition are derived in Section 4. Then we discuss the case for a transnational infrastructure manager in Section 5. We finally draw some concluding remarks in Section 6.

2 Model

The basic setting we consider is the following. There are two countries, denoted by 1 and 2. In each country, there is an infrastructure manager in charge of the pricing of access to the national railway network. Final customers have unit demands for (round-trip) transport services from one country to the other and can use different transport modes.

Market for transport services. There are two railway operators, one in each country, also denoted by 1 and 2 (the historical incumbent in country i is called 'operator' i), which offer international transport services to final customers. These railway operators compete in prices on the final market (that we describe below). Let p_i be the price set by the railway operator in country $i = 1, 2$ for one unit of transport service.

As inter-modal competition is important in the transport sector, we consider that those railway operators face downstream competition by road. Let p_0 be the price for one unit of transport service using road instead of either of the railway operators. Since road transportation is carried out by many uncoordinated players, we assume that competition between these players drives road price close to its marginal cost; hence, p_0 stands for the marginal cost of transportation.[2]

In other words, the vector of downstream prices is denoted by $p \equiv (p_0, p_1, p_2)$.

In order to obtain closed-form solutions, we adopt the Hotelling-Salop model of price competition with differentiated products. We assume that there is a unit mass of consumers which is uniformly distributed around a unit circle. The two railway operators and the 'fictitious road actor' are located symmetrically on this circle. A consumer located at a given point x on the circle has a unit demand for transport services. To fulfill this demand, the consumer can use the services of either the railway operators or the road operator. The consumer's utility when using the service of transport operator i is given by $u - p_i - td(x, i)$ where u is the gross utility for the consumer associated to the transport service,[3] p_i is the price paid to the transport operator i and $td(x, i)$ is the so-called 'transportation cost' (which might be slightly misleading in the context of competition between transport operators!): This cost stems, for instance, from the discrepancy between the services that the consumer located in x would ideally desire and the service actually offered by transport operator i. Behind this modeling is the idea that transport products are differentiated (both in terms of geographical convenience and in terms of product lines) and final customers have heterogenous needs. The extent of the differentiation between products is given by parameter t; the inverse of t, $1/t$, characterizes the intensity of competition between transport operators on the final market.

Let us now determine the pattern of demands. Suppose, for instance, that x is the distance between the consumer and railway operator 1, and $1/3 - x$ is the distance to transport operator 2. That consumer has three options: either he chooses railway operator 1 and gets a utility level $u - p_1 - tx$, or he chooses the services of railway operator 2 and earns a utility level $u - p_2 - t(1/3 - x)$, or, finally, he chooses road and obtains utility $u - p_0 - \min\{1/3 + x; 2/3 - x\}$.[4] For each consumer, we can characterize the optimal

[2]Moreover, to streamline the welfare analysis, we assume that road transport operators make no profit.

[3]Parameter u is assumed to be large enough in order to ensure that the market is fully covered in the various configurations that we study later on.

[4]Around a circle there are two ways for a consumer to 'travel' until the points where the transport operators are located. To minimize transportation costs, that consumer always chooses the path of smallest length.

choice of transport mode and, in the event the consumer chooses railway, the optimal choice of railway operator. This allows to determine the following demand pattern:

$$D_i(p) = \frac{1}{3} - \frac{2p_i - p_j - p_k}{2t},$$

for $i, j, k \in \{0, 1, 2\}$ and $i \neq j \neq k$.

The transport operators. Since we consider international transport services, for each unit of service provided to the customers, a transport operator has to get access to the network of both countries. Hence, the profit of the railway operator in country i writes as follows:[5]

$$\pi_{di}(p) = p_i D_i(p) - C_d(D_i(p)) - (a_1 + a_2) D_i(p),$$

where $D_i(p)$ is the final demand that addresses transport operator i when downstream prices are given by p, $C_d(D_i(p))$ is the cost associated to that level of final demand, and a_i is the unit access price set in country i. Since access to both networks is required to complete one unit of final service, that transport operator pays access charges in both countries.

The infrastructure managers. In each country, the pricing of the access to the railway network is decided by an infrastructure manager. The profit of the infrastructure manager in country i writes as follows:[6,7]

$$\pi_{ui}(a_i, a_j, p) = a_i \sum_{k=1,2} D_k(p) - C_u\left(\sum_{k=1,2} D_k(p)\right).$$

Indeed, since each unit of international transport services requires to use both national infrastructures, the total quantity of transport services which uses the network in country i is $\sum_{k=1,2} D_k(p)$. The cost function associated to the management of the network is given by $C_u(.)$.

Regulatory choices. Our analysis assumes that both the upstream and the downstream segments are not regulated: Infrastructure managers, as well as railroad operators, choose their prices in order to maximize their profits. Regulatory choices only bear on the decision to integrate or separate vertically the industry.

[5] Subscript 'd' stands for 'downstream'.
[6] Fixed infrastructure costs play no role in our analysis and hence are omitted.
[7] Subscript 'u' stands for 'upstream'.

Welfare. Total welfare is defined in our context as the sum of consumers' surplus, the railway operators' and the infrastructure managers' profits. As usual, consumers' surplus is defined as the gross utility minus the price and the transportation cost.

We will sometimes be interested in defining the welfare of a given country, say in country i. In that case, we assume that half of the customers are part of country i's constituency, the remaining part belonging to the other country. Therefore, welfare in country i is defined as half the total surplus of consumers, plus the profits of transport operator i and of infrastructure manager i.[8]

The vertical and horizontal organization of the industry. In each country, we shall consider the possibility of 'vertical integration' or 'vertical separation' between the upstream infrastructure manager and the downstream network operator. Under vertical separation in country i, the access price a_i and the final price p_i are decided so as to maximize the profit of the joint entity formed by the corresponding infrastructure manager and railway operator. By contrast, under vertical separation in country i, the infrastructure manager and the transport operator decides non-cooperatively a_i and p_i respectively.

The timing. The timing we consider goes as follows. In a first step, access prices are decided. Then, in a second stage, railway operators choose their prices. Organization choices, if any, are decided before the setting of access charges and final prices.

Figure 1 summarizes the main ingredients of our model.

Cost functions and returns-to-scale. In order to assess the impact of the returns-to-scale in the industry on the optimal organization of the railway sector, we use the following specification:

- $C_d(q) = c_d q + c_{dd} q^2$, where c_d is strictly positive (and sufficiently large to ensure that the downstream marginal cost is positive) and c_{dd} can be either positive or negative. Therefore, c_{dd} is an indicator of the nature of the returns-to-scale in the downstream segment of the railway industry.

- $C_u(q) = c_u q + c_{uu} q^2$, where c_u is strictly positive (and sufficiently large to ensure that the upstream marginal cost is positive) and c_{uu} can be either positive or negative. Therefore, c_{uu} is an indicator of the nature of the returns-to-scale in the upstream segment of the railway industry.

[8]We feel confident that our results do not depend too strongly on the specification of the countries' welfare.

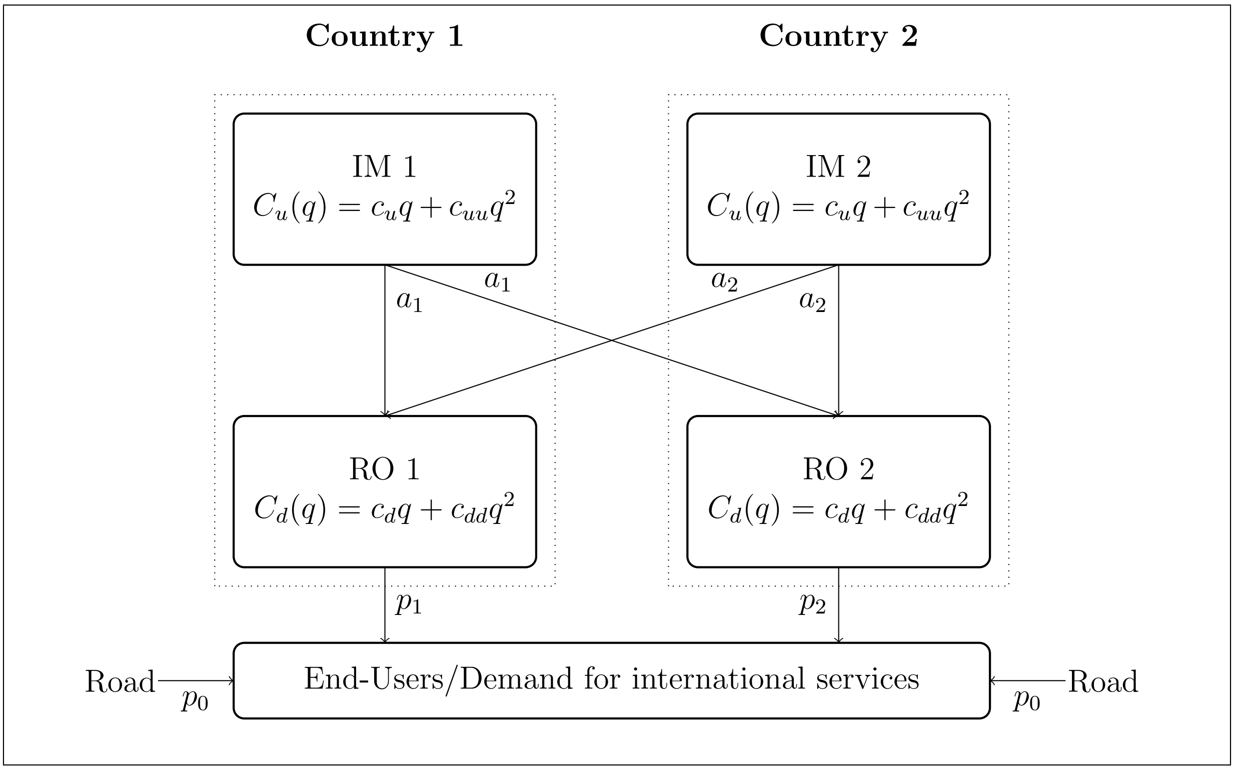

Figure 1: Structure of the model ('IM' stands for 'infrastructure manager' and 'RO' stands for 'railway operator').

3 Local competition

In this section, we consider only 'local competition'. More precisely, we assume that there is only one network, say network i, to which both railway operators must have access if they want to provide transport services to final customers. In other words, we let aside the international setting to return to a standard model of competition in one country.

3.1 Downstream returns-to-scale

We start our analysis with the case in which only the downstream sector exhibits returns-to-scale. Hence, the infrastructure profit associated to network i writes as:

$$\pi_{ui}(a_i, p) = (a_i - c_u) \sum_{k=1,2} D_k(p).$$

The profit of the railway operator j writes now as follows:

$$\pi_{dj}(a_i, p) = (p_j - c_d - a_i) D_j(p) - c_{dd} D_j(p)^2,$$

for $j \in \{1, 2\}$.

Some assumptions are needed to ensure that the various optimization under consideration in this section are 'well-behaved'. A sufficient condition is the following:

Assumption 1. *Parameters are such that* $c_{dd}/t \geq -1/2$.

Under this assumption, all the second-order conditions, as well as the positivity conditions, are satisfied at equilibrium. Basically, this assumption requires that returns-to-scale on the downstream sector, weighed by the intensity of competition, be not too increasing. Notice that this assumption implies in particular that, under all the various configurations studied in this section, the final prices are strategic complements.[9]

Vertical separation. To begin with, suppose that the management of the railway infrastructure is separated from the provision of services using this infrastructure.

At the last stage of the game, the problem of transport operator j is to determine its price p_j in order to maximize its profit $\pi_{dj}(a_i, p)$. The corresponding necessary first-order condition can be written as follows:

$$D_j(p) + (p_j - c_d - a_i - 2c_{dd}D_j)\,\frac{\partial D_j}{\partial p_j}(p) = 0. \tag{1}$$

We are now interested in understanding how the various parameters of interest of the model, e.g., the nature of the returns-to-scale and the intensity of downstream competition embodied in c_{dd} and t respectively, affect the downstream railway operators' pricing policies (for a given access charge). The impact of c_{dd} is relatively straightforward: *Ceteris paribus*, an increase in c_{dd} leads to an increase of the marginal cost function and, therefore, to a softer behavior of the downstream-only transport operator. The effect of parameter t is less obvious, for this parameter affects the demand faced by the downstream firm, which has a feedback effect on the firms' costs.

To grasp a better intuition, it is interesting to further rewrite Equation (1) as follows:

$$\frac{p_j - c_d - a_i}{p_j} = \frac{1}{\varepsilon_j}\left(1 + \frac{2c_{dd}}{t}\right), \tag{2}$$

where $\varepsilon_j(p) \equiv -[p_j \partial D_j/\partial p_j]/D_j$ is the own price elasticity of the demand faced by transport operator j.

Equation (2) shows that the ratio c_{dd}/t is critical to assess the pricing strategy of a downstream-only railway operator. Starting from a situation in which there are no returns-to-scale on the downstream sector, we observe that if $c_{dd}/t > 0$ (respectively, $c_{dd}/t < 0$), then downstream firm j will behave less (respectively, more) aggressively on

[9] Since we consider constant returns-to-scale on the upstream sector, and since demands are linear in the final prices, the strategic interaction between final prices is always determined by the same condition and does not depend on whether some firms are vertically integrated or not.

the final market. This is reinforced by the intensity of competition. Intuitively, a more aggressive pricing strategy allows to reap the cost reductions associated to increasing downstream returns-to-scale.

Solving for the subgame under consideration, we obtain the downstream-only railway operators' prices, for a given access charge paid to infrastructure manager i, denoted by $p_i^{\text{sep}}(a_i)$ and $p_j^{\text{sep}}(a_i)$.

We can now solve the infrastructure manager's problem specified as follows:

$$\max_{a_i} (a_i - c_u) \sum_{k=1,2} D_k(p^{\text{sep}}(a_i)).$$

Obviously, since it has a monopoly position over the network, the infrastructure manager imposes a strictly positive markup on the access charge. Since the demand for access is derived, from the technological strict complementarity, from the demand for final services, the infrastructure manager must anticipate the impact of the access price on the demand faced by the downstream operators. This is highlighted in the first-order condition associated to the previous problem, that is to say:[10]

$$\sum_{k=1,2} D_k + (a_i - c_u) \sum_{k=1,2} \sum_{k'=1,2} \frac{\partial D_k}{\partial p_{k'}^{\text{sep}}} \frac{dp_{k'}^{\text{sep}}}{da_i} = 0. \tag{3}$$

Simple manipulations, reported in the Appendix, lead to the expression of the optimal access charge that we denote by a_i^{sep}. It increases with the infrastructure manager's marginal cost c_u. More interestingly, an increase in the price of road p_0 leads to a larger access charge too since this leads to a softer competition on the final market and larger demands for the railway operators. Finally, when railway operators become less efficient (i.e., when c_d increases), the demand for network access decreases, which leads the infrastructure manager to reduce the access charge.

We do not detail the determination of the equilibrium in that case. This is relegated in the Appendix.

Vertical integration. Consider now the situation in which the downstream railway operator i is vertically integrated with the infrastructure manager, but that downstream transport operator j is not.

At the last stage of the game, the vertically integrated entity sets its final price so as

[10]For simplicity, we drop the arguments of the functions without loss of generality.

to maximize its total profit $\pi_{di}(a_i, p) + \pi_{ui}(a_i, p)$, or:

$$\max_{p_i} (p_i - c_d - a_i)D_i(p) - c_{dd}D_i(p)^2 + (a_i - c_u) \sum_{k=1,2} D_k(p).$$

The associated first-order condition is given by:

$$D_i + (p_i - c_d - a_i - 2c_{dd}D_i) \frac{\partial D_i}{\partial p_i} + (a_i - c_u) \left(\frac{\partial D_i}{\partial p_i} + \frac{\partial D_j}{\partial p_i} \right) = 0.$$

By contrast, transport operator j, which remains separated, sets its price so as to maximize its profit $\pi_{dj}(a_i, p)$. For given access price a_i and downstream price p_j, the first-order condition is the same as previously (i.e., Equation (1)).

By analogy with the case of vertical separation, let $p_i^{\text{int}}(a_i)$ and $p_j^{\text{int}}(a_i)$ be the equilibrium prices set by the railway operators for a given access charge a_i. How do the pricing policies of the integrated and the separated operators compare, for a same level of access charge?

Suppose that there would be no downstream operator j. Then, in this context, we would obtain the standard argument that vertical integration ought to be preferred to separation since it allows to eliminate the vertical double marginalization problem: An independent infrastructure manager tends to apply its own (access) markup in order to obtain some profits, which distorts excessively the price of the downstream operator. Obviously, this effect is present in our analysis. The key question, however, concerns the impacts of this double marginalization phenomenon in a context in which several downstream firms compete.

Suppose, as a second benchmark, that the infrastructure manager always breaks even, or $a_i = c_u$ so that no profit is made on the infrastructure. Then, both the integrated firm i and firm j would face the same total marginal cost of producing the final service and would thus behave in the same way.

When $a_i > c_u$, two effects are at work. On the one hand, the integrated firm faces a smaller total marginal cost; it is then encouraged to adopt a more aggressive behavior than its non integrated rival. However, in order to protect the access revenue, the integrated firm is willing to increase its final price to protect the final demand of its integrated competitor; this leads it to adopt a less aggressive behavior on the downstream market. Overall, since $\frac{\partial D_i}{\partial p_i} + \frac{\partial D_j}{\partial p_i} = -\frac{1}{2t} < 0$, the former effect is stronger than the latter, i.e., vertical integration leads, for a given access price a_i, to a smaller downstream price of transport operator i, or:

$$p_i^{\text{int}}(a_i) \leq p_i^{\text{sep}}(a_i).$$

By the strategic complementarity between final prices, this leads the non integrated firm

j to price less aggressively when its rival is integrated than when it is non integrated, or:

$$p_j^{\text{int}}(a_i) \leq p_j^{\text{sep}}(a_i).$$

Notice that the previous comparisons considers that the access charge is the same under integration and separation. To obtain a clear-cut comparison of the equilibrium final prices under integration and under separation, we must first understand how the access pricing policy is affected by the organization of the industry.

Therefore, consider now the setting of access charge by the integrated firm. The first-order condition is given by:

$$-D_i + \sum_{k=1,2} D_k + (p_i - c_d - a_i - 2c_{dd}D_i)\frac{\partial D_i}{\partial p_j}\frac{dp_j^{\text{int}}}{da_i} + (a_i - c_u)\sum_{k=1,2}\frac{\partial D_k}{\partial p_j}\frac{dp_j^{\text{int}}}{da_i} = 0. \quad (4)$$

Comparing Equations (3) and (4), which govern the pricing of access under separation and integration respectively is not entirely straightforward, since this comparison entails different strategic effects. Overall, we show in the Appendix that the access price is always smaller under integration than under separation, or:

$$a_i^{\text{int}} < a_i^{\text{sep}}.$$

From the previous discussion, this implies that final prices are also smaller under integration than under separation:

$$p_i^{\text{int}} \leq p_i^{\text{sep}} \quad \text{and} \quad p_j^{\text{int}} \leq p_j^{\text{sep}}.$$

Hence, it appears that, in this case with local final services and competition on the downstream sector, the comparison between integration and separation is as expected: the double marginalization issue leads to excessive access and downstream prices under separation.

Comparisons. Let us now compare vertical integration and vertical separation with local competition and when only the downstream segment of the railway industry exhibits increasing or decreasing returns-to-scale.

Proposition 1. *With local services and downstream returns-to-scale, from the viewpoint of both the industry's profit and consumers' surplus, vertical integration of the infrastructure manager with one downstream operator dominates vertical separation.*

This result should not come as a surprise in light of our previous discussions since vertical integration leads, for a given access charge, to smaller downstream prices, and, at equilibrium, to a lower access price than separation. While this clearly benefits customers, it also benefits the industry through a reduction of the double marginalization phenomenon.

The next proposition studies the incentives of the entity 'infrastructure manager and transport operator i' to be integrated or separated.

Proposition 2. *With local services and downstream returns-to-scale, from the view point of the infrastructure manager i and the transport operator i, integration dominates separation. The non-integrated railway operator j prefers its rival to be integrated rather than separated from the infrastructure manager if and only if $c_{dd}/t \geq 1.80$ (approximation).*

That the integrated entity gains from vertical integration stems for the vertical double marginalization which is removed under integration. More interestingly, the non-integrated entity may also see its profit increase from the vertical integration of its downstream rival with the infrastructure manager: indeed, integration leads to less (respectively, more) profit for the downstream transport operator i (respectively, the infrastructure manager) than separation. An intuition for this result may be the following. While integration leads to a more intense downstream competition, as c_{dd}/t increases, the difference between the access charge under separation and under integration increases. At some point, the latter effect offsets the former and the non-integrated railway operator prefers its downstream rival to be integrated rather than separated.

3.2 Upstream returns-to-scale

We now consider another situation in which the downstream sector features constant returns-to-scale (i.e., $c_{dd} = 0$), but the upstream part exhibits either increasing or decreasing returns-to-scale (i.e., c_{uu} is either negative or positive). Again, we are interested in understanding the impact of the vertical organization of the railway sector on the industry performance, in presence of both intra- and inter-modal competition when final services are purely local.

The following assumption is required to ensure that all the optimization problems, as well as positivity conditions, are met at equilibrium.

Assumption 2. *Parameters are such that $c_{uu}/t \geq -1/2$.*

As in the case of downstream returns-to-scale only, this assumption requires that the returns-to-scale on the upstream segment, weighed by the intensity of competition, be not too strong.

Vertical separation. At the last stage of the game, the problem of railway operator j writes simply as follows:

$$\max_{p_j} \pi_{dj}(p, a_i) = (p_j - c_d - a_i) D_j(p).$$

The first-order condition associated to the previous problem can be rewritten as follows:

$$\frac{p_j - c_d - a_i}{p_j} = \frac{1}{\varepsilon_j}, \tag{5}$$

where ε_j is defined as in the previous section.

Solving for the equilibrium of that subgame, we obtain the prices denoted by $p_i^{\text{sep}}(a_i)$ and $p_j^{\text{sep}}(a_i)$. Actually, these prices coincide with those obtained in Section 3 with $c_{dd} = 0$ since, under separation, the downstream railway operators, for a given access charge, are not directly affected by the presence of upstream returns-to-scale.

Let us now focus on the problem of the infrastructure manager:

$$\max_{a_i} \pi_{ui}(a_i) = (a_i - c_u) \sum_{k=1,2} D_k(p^{\text{sep}}(a_i)) - c_{uu} \left[\sum_{k=1,2} D_k(p^{\text{sep}}(a_i)) \right]^2 .$$

The first-order condition associated to the previous maximization problem writes as follows:

$$\sum_{k=1,2} D_k + \left[a_i - c_u - 2c_{uu} \sum_{k=1,2} D_k \right] \left[\sum_{k=1,2} \sum_{k'=1,2} \frac{\partial D_k}{\partial p_{k'}} \frac{\partial p_{k'}^{\text{sep}}}{\partial a_i} \right] = 0.$$

The first bracketed term is the direct effect of access pricing: for a given level of demand for network access, an increase in the access charge leads to an increase in the margin earned by the infrastructure manager. The second term is the strategic effect of access pricing. As intuition suggests, an increase in the access charge increases the marginal cost faced by the downstream railway operators and, therefore, increases the final prices set by those operators. This, in turn, affects the demand for transport services of final customers and, by technological complementarity, the demand for access to the network managed by infrastructure manager i.

To derive some intuitions about the role of returns-to-scale on the setting of the access charge, let us introduce the following notations: $\hat{D}(a_i) \equiv \sum_{k=1,2} D_k(p^{\text{sep}}(a_i))$ is the demand for access to the network for a given access price a_i. By analogy, let us denote by $\hat{\varepsilon}(a_i) \equiv -(a_i \partial \hat{D}(a_i)/\partial a_i)/\hat{D}(a_i)$ the elasticity of the demand for access (which is derived from the demand for final transport services) with respect to the access charge a_i. This elasticity accounts for the behavior of the downstream railway operators. Then, we obtain that the optimal access price is given by the following condition:

$$\frac{a_i^{\text{sep}} - c_u}{a_i^{\text{sep}}} = \frac{1}{\hat{\varepsilon}(a_i^{\text{sep}})} \left(1 + \frac{4}{3}\frac{c_{uu}}{t}\right). \tag{6}$$

As Equation (6) highlights, the infrastructure manager applies a markup which depends both on the elasticity of the demand for access and on the nature of the returns-to-scale on the upstream segment. With increasing returns-to-scale, i.e., $c_{uu} < 0$, the access markup is small since the infrastructure manager wants to generate sufficiently large a demand for its services in order to exploit these returns-to-scale; a reverse conclusion holds with decreasing returns-to-scale (i.e., $c_{uu} > 0$).

Using the specification of our model, we obtain the equilibrium access price in that case, which we denote by a_i^{sep}. The equilibrium downstream prices are then given by $p_i^{\text{sep}} = p_i^{\text{sep}}(a_i^{\text{sep}})$ and $p_j^{\text{sep}} = p_j^{\text{sep}}(a_i^{\text{sep}})$.

Vertical integration. Let us now focus on the case in which the railway operator i is vertically integrated with the infrastructure manager.

At the last stage of the game, the integrated entity sets its final price p_i so as to maximize its total profit, or:

$$\max_{p_i} \, (p_i - c_d - a_i)\, D_i(p) + (a_i - c_u) \sum_{j=1,2} D_j(p) - c_{uu} \left[\sum_{j=1,2} D_j(p)\right]^2. \tag{7}$$

The first-order condition associated to (7) is given by:

$$D_i + (p_i - c_d - a_i)\frac{\partial D_i}{\partial p_i} + \left[a_i - c_u - 2c_{uu} \sum_{k=1,2} D_k\right] \sum_{k=1,2} \frac{\partial D_k}{\partial p_i} = 0. \tag{8}$$

The programme of the non-integrated entity is as previously and will not be repeated here. Denote by $p_i^{\text{int}}(a_i)$ and $p_j^{\text{int}}(a_i)$ the final prices of the transport operators at the equilibrium of that subgame with upstream returns-to-scale and local services, that is, the prices solution of (8) and (5).

Let us compare the downstream pricing policies under integration and under separation for a given access price set by the infrastructure manager. In the Appendix, we show that:

$$p_i^{\text{int}}(a_i) \leq p_i^{\text{sep}}(a_i) \quad \text{and} \quad p_j^{\text{int}}(a_i) \leq p_j^{\text{sep}}(a_i).$$

The intuition is similar to the case of downstream returns-to-scale: for a given access price, vertical integration allows to get rid of the vertical double marginalization problem.

Focusing now on the first stage of the game, the integrated entity decides its access charge so as to maximize:

$$\max_{a_i} \left[p_i^{\text{int}}(a_i) - c_d - a_i\right] D_i(p^{\text{int}}(a_i)) + (a_i - c_u) \sum_{k=1,2} D_k(p^{\text{int}}(a_i)) - c_{uu} \left[\sum_{k=1,2} D_k(p^{\text{int}}(a_i))\right]^2.$$

Using the Envelope Theorem, the corresponding first-order condition can be rewritten as follows:

$$-D_i + \sum_{k=1,2} D_k + \left(p_i^{\text{int}} - c_d - a_i\right) \frac{\partial D_i}{\partial p_j} \frac{dp_j^{\text{int}}}{da_i} + \left[a_i - c_u - 2c_{uu} \sum_{k=1,2} D_k\right] \sum_{k=1,2} \frac{\partial D_k}{\partial p_j} \frac{dp_j^{\text{int}}}{da_i} = 0. \tag{9}$$

The optimal access price is then denoted by a_i^{int}. The equilibrium downstream prices are thus given by $p_i^{\text{int}} = p_i^{\text{int}}(a_i^{\text{int}})$ and $p_j^{\text{int}} = p_j^{\text{int}}(a_i^{\text{int}})$.

Computations performed in the Appendix show that the comparison between equilibrium access charges is given by:

$$a_i^{\text{int}} \leq a_i^{\text{sep}} \Leftrightarrow \frac{c_{uu}}{t} \leq 0.07 \text{ (approximation)}.$$

The intuition for this result may be explained as follows. Let us first notice that $dp_i^{\text{int}}/da_i \geq 0$ implies that $c_{uu}/t \leq 3$.[11] Indeed, this comes from the fact that, from the viewpoint of the integrated firm i, downstream prices may be perceived as strategic substitutes or complements depending on whether the ration c_{uu}/t is rather small or large.[12] The nature of the returns-to-scale on the upstream sector has thus a strong impact on the competition on the final market.

Suppose that upstream returns-to-scale are decreasing ($c_{uu} \geq 0$). In order to reduce the cost of providing access, the integrated firm wants to reduce the demand faced by railroad operator j, which might be done by increasing the access price a_i. Such a strategy relaxes the competition on the downstream market. This explains that the integrated firm has more incentives to distort upwards the access price for strategic reasons than the separated infrastructure manager. As a result, the equilibrium final prices under separation and integration compare as follows:

$$p_i^{\text{int}} \leq p_i^{\text{sep}} \quad \text{and} \quad p_j^{\text{int}} \leq p_j^{\text{sep}} \Leftrightarrow \frac{c_{uu}}{t} \leq 0.90 \text{ (approximation)}.$$

Hence the final price of downstream operator i is always smaller under integration than under separation since the access charge is merely a transfer price for the integrated entity. More interestingly, the final price of the downstream operator j may be larger under

[11] $p_j^{\text{int}}(.)$, $p_i^{\text{sep}}(.)$ and $p_j^{\text{sep}}(.)$ all increase with a_i.
[12] The exact threshold is 1.

integration than under separation of downstream operator i with infrastructure manager i; the intuition relies on the fact that when c_{uu}/t is sufficiently large, then the access price is larger under integration than under separation, which increases the marginal cost of railway operator j and allows to benefit from the returns-to-scale.

Comparison. The next proposition studies the incentives of the entity 'infrastructure manager cum transport operator i' to be integrated or separated.

Proposition 3. *With local services and upstream returns-to-scale, from the viewpoint of the infrastructure manager and the transport operator i, integration dominates separation. The non-integrated railway operator j always prefers its rival to be separated rather than integrated from the infrastructure manager.*

The previous proposition shows that integration is preferred by railway operator i and infrastructure manager i, exactly as in the case of downstream returns-to-scale. However, and contrary to the case of downstream returns-to-scale, railway operator j prefers separation over integration. Indeed, under integration, it faces a tougher competition on the final market and has to pay a larger access price.

We now study the impact of integration and separation on industry's profit, consumers' surplus and welfare.

Proposition 4. *With local services and upstream returns-to-scale:*

- *From the viewpoint of the industry's profit, vertical integration of the infrastructure manager with one downstream operator dominates vertical separation if and only if $c_{uu}/t \leq 2.42$ (approximation).*
- *From the viewpoint of consumers' surplus, vertical integration always dominates separation.*
- *From the viewpoint of social welfare, vertical integration dominates separation if and only if $c_{uu}/t \leq 13.20$ (approximation).*

This result should be clear from the previous analysis. As usual, vertical integration removes one vertical double marginalization problem - a positive effect on welfare. With upstream returns-to-scale, however, and in particular with strongly increasing returns, the integrated firm may overcharge the non-integrated downstream firm in order to protect both its retail and its access revenues - a negative effect on welfare.

4 International competition

We come back to our initial setting and we account for the existence of international transport. The main changes with respect to the framework developed in the last section are as follows: First, we consider that to complete one unit of international service, a railway operator must access to both national networks; second, there is an infrastructure manager in both countries.

The timing of the game under consideration is the following. At the first stage of the game, infrastructure managers choose simultaneously and non-cooperatively their access charges. Then, at the second stage of the game, transport operators simultaneously and non-cooperatively choose their final prices.

To ensure that the games we study are well-behaved, we maintain the assumption that parameters are such that $c_{dd}/t \geq -1/2$ (respectively, $c_{uu}/t \geq -1/2$) in the case of downstream returns-to-scale (respectively, upstream returns-to-scale).

4.1 The horizontal double marginalization problem

In this new context, infrastructure managers generate externalities on each other. Indeed, when deciding of the charge to access its network, an infrastructure manager does not take into account the impact of such a decision on the profit of the network manager in the other country. Since infrastructure managers offer complementary inputs to the downstream sector (because a railroad operator must access both networks to provide international transport services), this non-internalized externality typically results in excessive access charges at equilibrium, which ultimately increases final prices. This externality is of a different nature than the vertical double marginalization that we have emphasized in the previous section.

Hence, when thinking about the optimal design of the industry, both the vertical double marginalization problem (i.e., within a country between an infrastructure manager and the downstream operators) as well as the horizontal double marginalization issue (i.e., across national infrastructure managers) have to be accounted for. As we illustrate below, this may change the relative merits of integration and separation.

Essentially three possible industry organizations are thus possible: both countries choose vertical integration (denoted with an index ii), both countries choose vertical separation (denoted with an index ss), or one country chooses integration and the other chooses separation (denoted with an index is or si depending on which country decides to integrate/separate).

4.2 Downstream returns-to-scale

Our first result concerns the optimal organization of the railway industry, among the three possible ones.

Proposition 5. *With international transport services and downstream returns-to-scale, from the perspective both of the industry's profit and of consumers' surplus, it is optimal to have vertical integration in both countries.*

Proposition 5, together with Proposition 1, shows that whatever the nature of final transport services (i.e., local or international) vertical integration in both countries ought to be favored when only the downstream sector features returns-to-scale. Moreover, the nature (i.e., increasing or decreasing) of the returns-to-scale does not play a significant role in this assessment.

In order to grasp some intuition about this result, let us compare the situation in which both industries are integrated with the situation in which they are both separated. Remind that, were the downstream sector perfectly competitive, integration would be equivalent to separation whatever the nature of the downstream services (i.e., local or international). Comparing the access and downstream prices under integration and separation with international services, we obtain:

$$p_1^{ii} = p_2^{ii} \leq p_1^{ss} = p_2^{ss} \text{ and } a_1^{ii} = a_2^{ii} \geq a_1^{ss} = a_2^{ss}.$$

In words, with international services, integration leads to higher access prices but lower final prices than separation. With local services only, downstream prices were lower under integration than under separation, but a reverse conclusion held for the access prices. The conclusion immediately follows: The horizontal double marginalization across infrastructure managers is exacerbated under integration, leading to excessive access price. However, under integration, the vertical double marginalization is removed, leading ultimately to smaller final prices.

A detailed comparison between the case of integration in both countries and the situation with integration in one country and separation in the other is not very illuminating and bears some qualitative resemblance with the previous comparison.

While the optimal organization is clearly defined in the presence of downstream returns-to-scale only, one is left wondering whether countries or national industries will manage to reach this socially desirable outcome if they can decide non-cooperatively of the organization of their respective industries. We investigate this issue in the following proposition.

Proposition 6. *With international transport services and downstream returns-to-scale, suppose that, prior to the setting of access charges and final prices, each national industry decides non-cooperatively integration or separation. Then, separation is a dominant strategy and the unique Nash equilibrium features separation in both industries.*

Proposition 6 shows that industries are caught in a prisoner's dilemma when they have to choose their internal organization. Indeed, we show in the Appendix that, for any choice of organization made by industry j, industry i prefers to be vertically separated as this allows to increase more the infrastructure's profit than the reduction in the profit made by the corresponding transport operator. These free-riding incentives push each national industry to choose vertical separation, leading to a sub-optimal choice at the equilibrium.

Proposition 6 also shows that delegating the choice of the industry's organization to the industry is probably not a good idea. One is left asking whether a national government, which would be interested in its country's welfare only, would choose the socially optimal industry organization.

Proposition 7. *With international transport services and downstream returns-to-scale, suppose that, prior to the setting of access charges and final prices, each country decides non-cooperatively integration or separation. Then, separation is a dominant strategy and the unique Nash equilibrium features separation in both industries.*

Proposition 7 highlights that the very same free-riding incentives that national industries have when choosing their vertical organization is present when countries, instead of industries, have to make this decision.

4.3 Upstream returns-to-scale

We now tackle the same set of questions but under the assumptions that only the upstream segment of the industry exhibits returns-to-scale.

As a first step, let us determine the optimal organization. It turns out that different cases have to be considered depending on the value of c_{uu}/t.

Proposition 8. *With international transport services and upstream returns-to-scale:*

- *From the perspective of the industry's profit, integration in both countries is optimal when $c_{uu}/t \leq 1$; otherwise, separation in both countries is optimal.*
- *From the perspective of consumers' surplus, if $c_{uu}/t \leq 0.30$ (approximation), then integration in both countries is optimal; if $0.30 \leq c_{uu}/t \leq 1.65$, then integration in one country and separation in the other country is optimal; finally, when $c_{uu}/t \geq 1.65$, separation in both countries is optimal.*

- *From the viewpoint of total welfare, if* $c_{uu}/t \leq 0.85$*, then integration in both countries is optimal; if* $0.85 \leq c_{uu}/t \leq 1.05$*, then integration in one country and separation in the other is optimal; finally, when* $c_{uu}/t \geq 1.05$*, separation in both countries is optimal.*

In order to understand the various forces at play in that case, we look at the impact of the choice of organization on, first, the level of access prices, and, second, on the level of final prices. Again, as in the case of downstream returns-to-scale, for conciseness we limit our attention to the comparison between integration and separation in both countries.

Computations reveal that the total level of access charges paid, at equilibrium, by the downstream sector (i.e., $a_1 + a_2$) is always larger under integration in both countries than under separation in both countries:

$$a_1^{ii} + a_2^{ii} \geq a_1^{ss} + a_2^{ss} \Leftrightarrow c_{uu}/t \geq -0.377(\text{approximation}).$$

Therefore, integration in both countries tends to lead to larger access prices than separation when (competition-adjusted) returns-to-scale are decreasing or moderately increasing.

Regarding the final prices, we obtain the following comparison:

$$p_1^{ii} + p_2^{ii} \geq p_1^{ss} + p_2^{ss} \Leftrightarrow c_{uu}/t \geq 1.$$

Hence, three zones of parameters seem to emerge. With sufficiently increasing returns-to-scale, access prices are lower under integration and lead to lower final prices. Low access prices indeed allow to reduce the horizontal double marginalization problem across infrastructure managers, and integration allows to reduce the vertical double marginalization within each country. As a result, integration in both countries is the socially optimal organization.

With moderate returns-to-scale, there is a tension. Access prices tend to be larger under integration, but final prices tend to be smaller. For this range of parameters, integration tends to be preferred by the industry, whereas consumers tend to prefer a mixed regime in which one firm is integrated whereas the other is separated.

Finally, with sufficiently decreasing returns-to-scale, separation is preferred as this leads to lower access and final prices.

We now focus on the industries' incentives to choose integration or separation in a non-cooperative way.

Proposition 9. *With international transport services and upstream returns-to-scale, suppose that, prior to the setting of access charges and final prices, each national industry* *decides non-cooperatively either integration or separation. Then, the equilibrium is characterized as follows:*

- *If* $c_{uu}/t \leq -0.25$*, then the equilibrium is unique and involves both industries choosing integration.*
- *If* $-0.25 \leq c_{uu}/t \leq -0.15$*, then there exist two asymmetric equilibria in which one industry chooses integration whereas the other chooses separation.*
- *If* $c_{uu}/t \geq -0.15$*, then the equilibrium is unique and involves both industries choosing separation.*

Proposition 9 shows that, again, there remains some discrepancy between the private and the social incentives towards the choice of organizations, although to a less dramatic extent than in the case of downstream returns-to-scale.[13] Indeed, in the case where c_{uu}/t is large enough ($c_{uu}/t \geq 1.05$), the Nash equilibrium in organization choices by national industries coincide with the socially optimal choice, namely separation in both countries. Similarly, when c_{uu}/t is small enough ($c_{uu}/t \leq -0.25$), then the Nash equilibrium in organization choices is integration in both countries, which coincides with the socially optimal outcome. Otherwise, for values of c_{uu}/t in between, private incentives are biased towards excessive separation.

5 A transnational infrastructure manager

We now investigate the following scenario, whose relevance might be reinforced with the development of international transport services: The management of the networks is delegated to a single infrastructure manager, which is kept separated from the downstream railway operators. Clearly, the advantage of the creation of a such a unique transnational infrastructure manager is to alleviate the horizontal double marginalization phenomenon, i.e., the fact that national infrastructure managers do not account for the negative externalities they create on each other via their access pricing decisions.

In the following, we shall compare this situation with a unique infrastructure manager with other possible organizations studied in the previous section. Note that we do not consider here the issue of the sustainability of such an organization since we consider only the sum of the national industries' profit or the sum of the countries' welfare and leave aside the issue of the sharing of the unique infrastructure manager's profit across countries or industries.

We obtain the following comparison.

[13] Qualitatively similar conclusions would be obtained had we assumed that the choice of integration/separation in a country is made by the government of that country.

Proposition 10. *Whatever the nature of the returns-to-scale (either downstream or upstream), from the viewpoint of both the sum of the industries' profit or the sum of the countries' welfare, the creation of a unique transnational infrastructure manager is always the best organizational choice.*

This proposition shows that distortions arising from the horizontal double marginalization are so important that getting rid of them, through the creation of a unique infrastructure manager, offsets any potential losses due to non-integrated vertical double marginalization externalities.

We can qualify this result by introducing a slightly different model. Instead of assuming that transport operators compete in prices on the final market, let us assume that they compete in quantities. Denote by q_i and q_j the quantities set by railway operator i and j respectively, and $q = q_i + q_j$. The (inverse) demand function is assumed to be linear: $P(Q) = \alpha - \beta q$. In this context, the strategic effects are profoundly modified as quantities tend to be strategic substitutes in a Cournot framework. Nevertheless, we can show[14] that from the viewpoint of consumers' surplus, the creation of a transnational infrastructure manager always dominates separation in both countries (that is, whatever the nature of the returns-to-scale). More interestingly, it also dominates integration in both countries if and only if $B^2 - 4c_{uu}c_{dd} \geq 0$. From the viewpoint of the industry profit, no general lessons can be drawn unfortunately.

Again, costs and demands parameters are key to understanding the role of the vertical organization of the industry. Note that the previous condition implies that, as long as one segment of the industry features constant returns-to-scale, then a transnational infrastructure manager dominates integration in both countries. It would be worth investigating whether other specifications of the nature of the competition between railroad operators (i.e., Cournot or Bertrand with product differentiation) affect our results significantly or not.

6 Conclusion

The message conveyed in this paper can be summarized as follows. While the economic literature has paid a great amount of attention to the pros and cons of vertical integration/separation in network industries, relatively little is known when, first, the upstream as well as the downstream segments exhibit increasing or decreasing returns-to-scale and, second, when the transport operators may require access to several networks. The need to access several networks gives rise to a horizontal double marginalization problem since a

[14]The proofs are available from the authors upon request.

given infrastructure manager does not take into account the impact of its pricing decisions on the profit of the other infrastructure manager.

The analysis undertaken here shows that, when the industry features downstream returns-to-scale only, then vertical integration ought to be favored with respect to any other organizational choices which would imply some form of separation. This holds true whatever the nature of the final transport services, that is, whether we consider purely local or purely international services.

With upstream returns-to-scale, the analysis becomes less clear-cut. With purely local services, integration is preferred to separation when the competition-adjusted returns-to-scale parameter, c_{uu}/t, is not too large. With purely international services, a somewhat similar conclusion emerges: integration (in both countries) dominates provided that c_{uu}/t is not too large; when c_{uu}/t increases, a mixed industry organization, in which one firm is integrated whereas the other is separated, becomes optimal; when c_{uu}/t continues to increase, separation in both countries becomes optimal. As an implication, when the share of international services becomes greater with respect to the total level of transport services, our analysis argues that some kind of separation tends to be preferred.[15] Importantly, note that the competitive environment, embodied in parameter t, must be taken into account in such a reasoning: greater competition between transport operators (including our fictitious operator 'road') should tend to favor integration over separation.

As argued at the end of the paper, our analysis bears on a archetypical model of the railway industry. Clearly, one should not take too literally our conclusions based on such a representation of the industry. However, the various effects (the two double marginalization phenomena, the strategic effects associated to access pricing) are present whatever the underlying theoretical model. An empirical validation appears to be the next step of this analysis. Such a validation would necessitate to evaluate the nature of the competition between transport operators, the nature of the returns-to-scale in the various segments of the industry, and should be differentiated depending on whether we consider local or international services. This is left for future research.

[15] In other words, the threshold of c_{uu}/t below which integration is optimal is smaller when services are international than when services are national.

7 References

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A Appendix

A.1 Local competition and downstream returns-to-scale only

To ensure that all the second-order conditions are satisfied at equilibrium, we assume from now on that $c_{dd}/t > -1/2$. Moreover, to ensure that all prices and demand are positive at equilibrium, we assume that $3(c_d + c_u) < 3p_0 + 2t$.

Finally, under the stated assumptions, the various subgames are stable in the sense of best-reply dynamics.

Straightforward computations lead to:

$$p_i^{\text{int}}(a_i) - p_i^{\text{sep}}(a_i) = \frac{2(3(c_d + c_u - p_0) - 2t)(c_{dd}/t + 1)}{3(2c_{dd}/t + 3)(6c_{dd}/t + 5)} < 0,$$
$$p_j^{\text{int}}(a_i) - p_j^{\text{sep}}(a_i) = \frac{(3(c_d + c_u - p_0) - 2t)(2c_{dd}/t + 1)}{6(2c_{dd}/t + 3)(6c_{dd}/t + 5)} < 0.$$

Straightforward computations lead to:

$$a_i^{\text{int}} - a_i^{\text{sep}} = \frac{(3(c_d + c_u - p_0) - 2t)(2c_{dd}/t + 1)^2(3c_{dd}/t + 2)}{6(108(c_{dd}/t)^3 + 364(c_{dd}/t)^2 + 387c_{dd}/t + 132)} < 0,$$
$$p_i^{\text{int}} - p_i^{\text{sep}} = \frac{(3(c_d + c_u - p_0) - 2t)(44(c_{dd}/t)^3 + 140(c_{dd}/t)^2 + 151(c_{dd}/t) + 54)}{3(2c_{dd}/t + 3)(108(c_{dd}/t)^3 + 364(c_{dd}/t)^2 + 387c_{dd}/t + 132)} < 0,$$
$$p_j^{\text{int}} - p_j^{\text{sep}} = \frac{(3(c_d + c_u - p_0) - 2t)(c_{dd}/t + 1)(2c_{dd}/t + 1)(14c_{dd}/t + 15)}{3(2c_{dd}/t + 3)(108(c_{dd}/t)^3 + 364(c_{dd}/t)^2 + 387c_{dd}/t + 132)} < 0.$$

A.1.1 Comparisons

Let us denote by Π^{int} and Π^{sep} the industry's profit (which is composed of the sum of the railway operators' profit and the infrastructure manager's profit) under integration and separation respectively.

Tedious computations lead to the following comparison:

$$\begin{aligned}\Pi^{\text{int}} - \Pi^{\text{sep}} \propto &(11808(c_{dd}/t)^7 + 82752(c_{dd}/t)^6 + 244928(c_{dd}/t)^5 \\ &+ 397008(c_{dd}/t)^4 + 380730(c_{dd}/t)^3 + 216144(c_{dd}/t)^2 + 67329(c_{dd}/t) + 8892),\end{aligned}$$

which is positive over the relevant range of values for c_{dd}/t.

Denote similarly by S^{int} and S^{sep} the surplus of final customers (that the sum of the surplus of customers who use either railway operator 1, or railway operator 2 or road as a transport mode) under integration and separation respectively. Then, we obtain the following comparison:

$$\begin{aligned}S^{\text{int}} - S^{\text{sep}} \propto &(c_{dd}/t + 1)\left(3088(c_{dd}/t)^5 + 16368(c_{dd}/t)^4\right. \\ &\left.+34360(c_{dd}/t)^3 + 35808(c_{dd}/t)^2 + 18537c_{dd} + 3813\right),\end{aligned}$$

which is positive over the relevant range of values for c_{dd}/t.

This concludes the proof of Proposition 1.

Let us now focus on Proposition 2.

Denote by π_{di}^{int} and π_{ui}^{int} (respectively, π_{di}^{sep} and π_{ui}^{sep}) the profit of railway operator i and the profit of the infrastructure manager i under integration (respectively, under separation).

Then, we obtain the following comparison:

$$\left(\pi_{di}^{\text{int}} + \pi_{ui}^{\text{int}}\right) - \left(\pi_{di}^{\text{sep}} + \pi_{ui}^{\text{sep}}\right) \propto \frac{-5c_{dd}/t - 7}{(2c_{dd}/t + 3)^2} + \frac{(6c_{dd}/t + 5)(26c_{dd}/t + 23)}{108(c_{dd}/t)^3 + 364(c_{dd}/t)^2 + 387c_{dd} + 132},$$

which is positive over the relevant range of values for c_{dd}/t.

Finally, we also obtain:

$$\pi_{di}^{\text{int}} - \pi_{di}^{\text{sep}} \propto -\frac{c_{dd}/t+1}{(2c_{dd}/t+3)^2} + \frac{(2c_{dd}/t+1)(3c_{dd}/t+2)(6c_{dd}/t+5)^2(14c_{dd}/t+15)}{(108(c_{dd}/t)^3+364(c_{dd}/t)^2+387c_{dd}/t+132)^2} < 0,$$
$$\pi_{ui}^{\text{int}} - \pi_{ui}^{\text{sep}} \propto -\frac{1}{2c_{dd}/t+3} + \frac{(6c_{dd}/t+5)(8(c_{dd}/t)^2+22c_{dd}/t+13)(144(c_{dd}/t)^2+254c_{dd}/t+111)}{(108(c_{dd}/t)^3+364(c_{dd}/t)^2+387c_{dd}/t+132)^2} > 0,$$

over the relevant range of values for c_{dd}/t.

As regards the non-integrated railway operator, we obtain that:

$$\pi_{dj}^{\text{int}} - \pi_{dj}^{\text{sep}} \propto -\frac{1}{(2c_{dd}/t+3)^2} + \frac{4(3c_{dd}/t+2)^2(10c_{dd}/t+9)^2}{(108(c_{dd}/t)^3+364(c_{dd}/t)^2+387c_{dd}/t+132)^2},$$

which, over the relevant range of values for c_{dd}/t, is positive if and only if $c_{dd}/t \geq 1.80$ (approximation).

This concludes the proof of Proposition 2.

A.2 Local competition and upstream returns-to-scale only

To ensure that all the second-order conditions are satisfied at equilibrium, we assume from now on that $c_{uu}/t > -1/2$. Moreover, to ensure that all prices and demand are positive at equilibrium, we assume that $3(c_d + c_u) < 3p_0 + 2t$.

Finally, under the stated assumptions, the various subgames are stable in the sense of best-reply dynamics.

Let us start by comparing the downstream prices under integration and separation for a given access price. Straightforward computations lead to:

$$p_i^{\text{int}}(a_i) - p_i^{\text{sep}}(a_i) = \frac{2(3(c_d+c_u-p_0)-2t)}{5(c_{uu}/t+3)(2c_{uu}/t+3)} < 0,$$
$$p_j^{\text{int}}(a_i) - p_j^{\text{sep}}(a_i) = \frac{(3(c_d+c_u-p_0)-2t)}{10(c_{uu}/t+3)(2c_{uu}/t+3)} < 0.$$

Let us now compare the final price set by railway operator i when it is integrated and when it is separated:

$$p_i^{\text{int}} - p_i^{\text{sep}} = \frac{(3(c_d+c_u-p_0)-2t)(4(c_{uu}/t)^2+25(c_{uu}/t)+54)}{3(2c_{uu}/t+3)(28(c_{uu}/t)^2+147(c_{uu}/t)+132)},$$

which is negative over the relevant range of values for c_{uu}/t.

Let us focus now on the final price set by transport operator j under integration and separation:

$$p_j^{\text{int}} - p_j^{\text{sep}} = \frac{(3(c_d + c_u - p_0) - 2t)(-4(c_{uu}/t)^2 - 13(c_{uu}/t) + 15)}{3(2c_{uu}/t + 3)(28(c_{uu}/t)^2 + 147(c_{uu}/t) + 132)}.$$

The right-hand side is negative for $c_{uu}/t \leq 0.903$ (approximation) and positive otherwise.

Finally, as regards the access price under integration and separation, we obtain the following:

$$a_i^{\text{int}} - a_i^{\text{sep}} = \frac{(3(c_d + c_u - p_0) - 2t)(-20(c_{uu}/t)^2 - 77(c_{uu}/t) + 6)}{6(2c_{uu}/t + 3)(28(c_{uu}/t)^2 + 147(c_{uu}/t) + 132)}.$$

The right-hand side is negative for $c_{uu}/t \leq 0.076$ (approximation) and positive otherwise.

Let us denote by Π^{int} and Π^{sep} the industry's profit (which is composed of the sum of the railway operators' profit and the infrastructure manager's profit) under integration and separation respectively.

Tedious computations lead to the following comparison:

$$\Pi^{\text{int}} - \Pi^{\text{sep}} \propto -64(c_{uu}/t)^4 - 432(c_{uu}/t)^3 - 204(c_{uu}/t)^2 + 2715(c_{uu}/t) + 2964,$$

which is positive when $c_{uu}/t \leq 2.422$ (approximation) and negative otherwise.

Denote similarly by S^{int} and S^{sep} the surplus of final customers (that is, the sum of the surplus of customers who use either railway operator 1, or railway operator 2 or road as a transport mode) under integration and separation respectively. Then, we obtain the following comparison:

$$S^{\text{int}} - S^{\text{sep}} \propto 16(c_{uu}/t)^4 + 264(c_{uu}/t)^3 + 1761(c_{uu}/t)^2 + 4788(c_{uu}/t) + 3813,$$

which is always positive in the relevant range of values for c_{uu}/t.

Denote finally by $W^{\text{int}} \equiv S^{\text{int}} + \Pi^{\text{int}}$ and $W^{\text{sep}} \equiv S^{\text{sep}} + \Pi^{\text{sep}}$ the total welfare under integration and under separation respectively. We obtain the following comparison:

$$W^{\text{int}} - W^{\text{sep}} \propto -32(c_{uu}/t)^4 + 96(c_{uu}/t)^3 + 3318(c_{uu}/t)^2 + 12291(c_{uu}/t) + 10590,$$

which is positive if c_{uu}/t is smaller than 13.201 (approximation) and negative otherwise.

This concludes the proof of Proposition 4.

Let us now focus on the proof of Proposition 3.

We have:

$$(\pi_{di}^{\text{int}} + \pi_{ui}^{\text{int}}) - (\pi_{di}^{\text{sep}} + \pi_{ui}^{\text{sep}}) = \frac{(3(c_d + c_u - p_0) - 2t)(4(c_{uu}/t)^2 + 25(c_{uu}/t) + 37)}{12(2c_{uu}/t + 3)^2(28(c_{uu}/t)^2 + 147(c_{uu}/t) + 132)},$$

which is always positive over the range of relevant values for c_{uu}/t.

Moreover, we also obtain:

$$\begin{aligned}
\pi_{di}^{\text{int}} - \pi_{di}^{\text{sep}} &\propto \frac{-1}{(2c_{uu}/t+3)^2} + \frac{50(4(c_{uu}/t)+15)}{28(c_{uu}/t)^2+147(c_{uu}/t)+132} < 0, \\
\pi_{ui}^{\text{int}} - \pi_{ui}^{\text{sep}} &\propto \frac{560(c_{uu}/t)^3+4808(c_{uu}/t)^2+12447(c_{uu}/t)+8442}{36(2c_{uu}/t+3)(28(c_{uu}/t)^2+147(c_{uu}/t)+132)} > 0, \\
\pi_{dj}^{\text{int}} - \pi_{dj}^{\text{sep}} &\propto \frac{-1}{(2c_{uu}/t+3)^2} + \frac{16(2(c_{uu}/t)+9)^2}{28(c_{uu}/t)^2+147(c_{uu}/t)+132} < 0,
\end{aligned}$$

over the relevant range of values for c_{uu}/t.

A.3 International competition

A.3.1 Downstream returns-to-scale

By analogy with the notations adopted in the previous sections, denote by S^{ii}, Π_j^{ii} and $W_j^{ii} = \frac{1}{2}S^{ii} + \Pi_j^{ii}$ the surplus of consumers, the welfare and the industry profit in country j when the industry is vertically integrated in both countries. Similar notations are used for the other cases.

Comparing the cases of integration and separation in both countries, we obtain:

$$\begin{aligned}
p_1^{ii} - p_1^{ss} &= \frac{(3cd+6c_u-3p_0-2t)(16(c_{dd}/t)^2+30(c_{dd}/t)+15))}{9(2(c_{dd}/t)+3)(22(c_{dd}/t)^2+57(c_{dd}/t)+33)}, \\
a_1^{ii} - a_1^{ss} &= \frac{(3c_d+6c_u-3p_0-2t)(2(c_{dd}/t)^2+9(c_{dd}/t)+6)}{9(22(c_{dd}/t)^2+57(c_{dd}/t)+33)}.
\end{aligned}$$

The former expression is negative whereas the latter is positive over the relevant range of parameters.

Tedious computations lead to:

$$\begin{aligned}
\left(W_1^{ii}+W_2^{ii}\right) - (W_1^{ss}+W_2^{ss}) \propto{}& [16(c_{dd}/t)^2+30(c_{dd}/t)+15], \\
&\times [160(c_{dd}/t)^3+718(c_{dd}/t)^2+1017(c_{dd}/t)+447],
\end{aligned}$$

which is always positive over the relevant range of values for c_{dd}/t.

Moreover, we have:

$$\left(\Pi_1^{ii}+\Pi_2^{ii}\right) - (\Pi_1^{ss}+\Pi_2^{ss}) \propto \frac{4(5(c_{dd}/t)+7)}{(2(c_{dd}/t)+3)^2} + \frac{9(10(c_{dd}/t)+9)(34(c_{dd}/t)^2+85(c_{dd}/t)+48)}{(22(c_{dd}/t)+57(c_{dd}/t)+33)^2},$$

which is always positive over the relevant range of values for c_{dd}/t. This concludes the proof of Proposition 5.

Let us now focus on Proposition 7. After some cumbersome manipulations, and focusing on country 1 for instance, we obtain:

$$\begin{aligned}W_1^{ii} - W_1^{si} \propto &- [12201984(c_{dd}/t)^9 + 115468800(c_{dd}/t)^8 + 487134400(c_{dd}/t)^7 \\ &+ 1202368896(c_{dd}/t)^6 + 1912159632(c_{dd}/t)^5 + 2029666128(c_{dd}/t)^4 \\ &+ 1436101524(c_{dd}/t)^3 + 652322736(c_{dd}/t)^2 + 172413279(c_{dd}/t) + 20184255],\end{aligned}$$

which is negative over the relevant range of values for c_{dd}/t.

Similarly, we have:

$$\begin{aligned}W_1^{is} - W_1^{ss} \propto &- [165888(c_{dd}/t)^7 + 1021824(c_{dd}/t)^6 + 2581904(c_{dd}/t)^5 \\ &+ 3410624(c_{dd}/t)^4 + 2444184(c_{dd}/t)^3 + 842664(c_{dd}/t)^2 + 56385(c_{dd}/t) - 26820],\end{aligned}$$

which is negative over the relevant range of values for c_{dd}/t.

Similarly, one can show that:

$$\begin{aligned}&\Pi_1^{ii} - \Pi_1^{si} \propto \frac{(10(c_{dd}/t)+9)(34(c_{dd}/t)^2+85(c_{dd}/t)+48)}{(22(c_{dd}/t)^2+57(c_{dd}/t)+33)^2} \\ &- \frac{8(48672(c_{dd}/t)^5+238272(c_{dd}/t)^4+461296(c_{dd}/t)^3+442076(c_{dd}/t)^2+209934(c_{dd}/t)^4+39555)}{(720(c_{dd}/t)^3+2396(c_{dd}/t)^2+2532(c_{dd}/t)+861)^2},\end{aligned}$$

which is negative over the relevant range of parameters.

Moreover:

$$\begin{aligned}&\Pi_1^{is} - \Pi_1^{ss} \propto \frac{(-5(c_{dd}/t)-7)}{(2(c_{dd}/t)+3)^2} \\ &+ \frac{36(6(c_{dd}/t)+5)(26(c_{dd}/t)+23)(108(c_{dd}/t)^3+364(c_{dd}/t)^2+387(c_{dd}/t)^2+132)}{(720(c_{dd}/t)^3+2396(c_{dd}/t)^2+2532(c_{dd}/t)^2+861)^2}.\end{aligned}$$

which is also negative over the relevant range of parameters.

This concludes the proofs of Proposition 6 and Proposition 7.

A.3.2 Upstream returns-to-scale

We obtain the following comparison:

$$a_1^{ii} + a_2^{ii} - (a_1^{ss} + a_2^{ss}) \propto \frac{14(c_{uu}/t)^2 + 53(c_{uu}/t) + 18}{3(8(c_{uu}/t)+9)(4(c_{uu}/t)^2+48(c_{uu}/t)+33)},$$

which is positive for $c_{uu}/t \geq -0.377$.

Moreover:

$$p_1^{ii} + p_2^{ii} \geq (p_1^{ss} + p_2^{ss}) \Leftrightarrow c_{uu}/t \geq 1.$$

Let now us focus first on Proposition 8. Straightforward but tedious computations leads to the following (notations are identical to the ones adopted in the previous section):

$$\left(W_1^{ii}+W_2^{ii}\right)-\left(W_1^{ss}+W_2^{ss}\right)\propto(-cuu/t+1)[116(c_{uu}/t)^2+627(c_{uu}/t)+447].$$

Therefore, integration in both countries dominates separation in both countries when $c_{uu}/t \leq 1$.

We also obtain:

$$\begin{aligned}\left(W_1^{ii}+W_2^{ii}\right)-\left(W_1^{si}+W_2^{si}\right)\propto & 3136(c_{uu}/t)^7+140944(c_{uu}/t)^6+626460(c_{uu}/t)^5\\ & -2851977(c_{uu}/t)^4-20377926(c_{uu}/t)^3-25883568(c_{uu}/t)^2\\ & +16120566(c_{uu}/t)+19869165,\end{aligned}$$

which is negative if and only if $c_{uu}/t \in [0.86; 5.22]$ (approximation).

Finally, we have:

$$\begin{aligned}\left(W_1^{ss}+W_2^{ss}\right)-\left(W_1^{si}+W_2^{si}\right)\propto & 3136(c_{uu}/t)^5+72736(c_{uu}/t)^4+425076(c_{uu}/t)^3\\ & +657624(c_{uu}/t)^2-510489(c_{uu}/t)-771615,\end{aligned}$$

which is positive for $c_{uu}/t \geq 1.05$ (approximation) and negative otherwise (in the relevant range of values for c_{uu}/t.

As regards the access charges, we have:

$$\left(a_1^{ii}+a_2^{ii}\right)-\left(a_1^{ss}+a_2^{ss}\right)=\frac{2(3c_d+6c_u-3p_0-2t)[14(c_{uu}/t)^2+53(c_{uu}/t)+18)}{3(8(c_{uu}/t)+9)[4(c_{uu}/t)^2+48(c_{uu}/t)+33]},$$

which is always negative over the relevant range of values for c_{uu}/t.

Let us now focus on Proposition 9. This proposition is obtained from the characterization of the industries' incentives to integrate or separate non-cooperatively which are described in the next Lemma.

Lemma 1. *If one industry chooses integration, the other industry chooses integration if and only if* $\frac{c_u u}{t} \leq -0.25$.

If one industry chooses separation, the other industry chooses integration if and only if $\frac{c_u u}{t} \leq -0.15$.

Indeed, computations unveils the following comparisons. First:

$$\begin{aligned}
\Pi_1^{ii} - \Pi_1^{si} \propto & \frac{9(c_{uu}/t+9)(2(c_{uu}/t)^2+29c_{uu}/t+24)}{(4(c_{uu}/t)^2+48c_{uu}/t+33)^2} \\
& - \frac{4(2352(c_{uu}/t)^3+21128(c_{uu}/t)^2+56763(c_{uu}/t)+39555)}{(84(c_{uu}/t)^2+409(c_{uu}/t)+287)^2}, \\
\Pi_1^{is} - \Pi_1^{ss} \propto & - \frac{9(4c_{uu}/t+7)}{(8c_{uu}/t+9)^2} \\
& - \frac{4(28(c_{uu}/t)+115)(28(c_{uu}/t)^2+147(c_{uu}/t)+132)}{(84(c_{uu}/t)^2+409(c_{uu}/t)+287)^2}.
\end{aligned}$$

Therefore, we have $\Pi_1^{ii} \geq \Pi_1^{si} \Leftrightarrow c_{uu}/t \leq -0.25$ (approximation). Similarly, $\Pi_1^{is} \geq \Pi_1^{ss} \Leftrightarrow c_{uu}/t \leq -0.15$ (approximation). Proposition 9 immediately follows.