

How efficient are intercity railway prices and frequencies in Europe? Comparing a corridor in Belgium and in France

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Online appendices

A. Detailed data

The specification of the gross utility function defined in Eq. (1) used in the empirical exercise in Sections 5 and 6 is:

$$\begin{aligned}
 U_{i,j} = & q_{i,j} + [a_{i,j}^{CAR,P} x_{i,j}^{CAR,P} - 0.5b_{i,j}^{CAR,P} (x_{i,j}^{CAR,P})^2] \\
 & + [a_{i,j}^{CAR,OP} x_{i,j}^{CAR,OP} - 0.5b_{i,j}^{CAR,OP} (x_{i,j}^{CAR,OP})^2] \\
 & + [a_{i,j}^{RAIL,P} x_{i,j}^{RAIL,P} - 0.5b_{i,j}^{RAIL,P} (x_{i,j}^{RAIL,P})^2] \\
 & + [a_{i,j}^{RAIL,OP} x_{i,j}^{RAIL,OP} - 0.5b_{i,j}^{RAIL,OP} (x_{i,j}^{RAIL,OP})^2] \\
 & - e_{i,j}^{CAR,P/CAR,OP} x_{i,j}^{CAR,P} x_{i,j}^{CAR,OP} - e_{i,j}^{CAR,P/RAIL,P} x_{i,j}^{CAR,P} x_{i,j}^{RAIL,P} \\
 & - e_{i,j}^{CAR,P/RAIL,OP} x_{i,j}^{CAR,P} x_{i,j}^{RAIL,OP} - e_{i,j}^{CAR,OP/RAIL,P} x_{i,j}^{CAR,OP} x_{i,j}^{RAIL,P} \\
 & - e_{i,j}^{CAR,OP/RAIL,OP} x_{i,j}^{CAR,OP} x_{i,j}^{RAIL,OP} - e_{i,j}^{RAIL,P/RAIL,OP} x_{i,j}^{RAIL,P} x_{i,j}^{RAIL,OP}.
 \end{aligned}$$

$a_{i,j}^{m,k}$, $b_{i,j}^{m,k}$ and $e_{i,j}$ are parameters to be calibrated. This is the same specification as in in Börjesson, et al. (2017).

Data have been collected for year 2012. When data were not available for this year, we chose data whose publication date is close to this year.

Table 7 reports technological and rail cost data which are identical for the two corridors. Peak period is four hours long, two hours during the morning peak (7am to 9am) and two hours during evening peak (5pm to 7pm). The total (fixed + variable) cost of a train has been computed by considering a cost of 10M euros per carriage, a lifespan of 30 years, a discount rate of 4 per cent and 350 days of use per year. The total cost is equally split between fixed cost and variable cost in the baseline. The variable cost takes the form of a cost per seat per train. We assume a train operating cost of 12 euros per km, based on the Belgium data in Steer Davis Gleave (2015). The train fuel consumption is kept voluntarily low because in Belgium and France a non-negligible part of the lines are electrified. The environmental and accident externalities for train and car have been found in the Update of the Handbook of External Costs of Transport.¹ The car fuel consumption corresponds to an average consumption of 7 liters per km.

Parameters	Notation	Value	
Peak period length (hours)	h^P	4	
Off-peak period length (hours)	h^O	15	
Cost of train (€/train/day)	μ_1^{RAIL}	1 650	
Train operating cost (€/km)	μ_2^{RAIL}	12	
Train fuel consumption (l/km)	v^{RAIL}	1	
Train environmental + accident externalities (€/km)	ι^{RAIL}	0.494	
Car fuel consumption (l/km)	v^{CAR}	0.07	
Car environmental + accident externalities (€/km)	ι^{CAR}	0.012	
Rail crowding cost (hours/users/m ²)	η^{RAIL}	0.16	
Rail scheduling cost (hours/runs/hour)	δ	0.24	
Rail delay cost (hours \times runs/hour)	θ^{RAIL}	0.22	
Values of time (€/hour)	α_i	Peak	Off-peak
Active +		17.6	12.6
Active -		14	10
Students		14	10
Retired		9.5	6.8

Table 1: Parameters whose value is the same for all cases

¹ https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf

The rail crowding cost coefficient has been obtained by a linear approximation of the travel time multipliers estimated by Kroes, et al. (2013). The scheduling cost coefficient has been computed in the $\alpha - \beta - \gamma$ framework by using the estimations produced by Wardman, et al. (2012). The rail delay cost efficient we use is from Pérez Herrero, et al. (2014).

The off-peak values of time are officially recommended values used in France (Quinet, 2013). The peak values of time have been obtained by using a factor 1.4 (Abrantes and Wardman, 2011).

We assume that the four categories are uniformly represented among the population of each of the city. Table 2 gives the modal shares per period distribution for the 4 types of users in the initial equilibrium. These numbers have been inferred from different sources (Cornelis, et al. (2012); DREAL (2014); Duabresse et al. (2015); AURG and SMTC (2015); Andries (2016)).

		Active +	Active -	Students	Retired	Total
Distribution trips from A						
Train	Peak	5.6%	4.6%	9.3%	3.1%	22.6%
	Off-peak	3.7%	3.1%	6.2%	7.2%	20.2%
Car	Peak	13%	10.2%	4.2%	3.5%	30.9%
	Off-peak	8.7%	6.8%	2.8%	8.1%	26.4%
Total		30.9%	24.7%	22.4%	21.9%	100%
Distribution trips from B						
Train	Peak	3.5%	4.3%	8.6%	2.9%	19.3%
	Off-peak	2.3%	2.9%	5.8%	6.7%	17.6%
Car	Peak	13.8%	11.1%	5.2%	3.9%	34%
	Off-peak	9.2%	7.4%	3.5%	9.1%	29.1%
Total		28.8%	25.7%	23%	22.5%	100%

Table 2: Trips characteristics

Table 9 presents the geographical and physical characteristics of the two corridors. The road distance between cities as well as the road free travel times have been obtained through website

Google Maps. The rail distances between cities have been retrieved from Wikipedia pages dedicated to the railway stations.^{2 3 4} The rail average speeds have been retrieved from the timetables. The road congestion cost coefficient has been calibrated such that it reproduces the observed travel time while using a linear congestion function.

	Notation	Belgium	France
City A		Bruges	Grenoble
City B		Ghent	Bourgoin
City D		Brussels	Lyon
Population living in A	N_A	100 000	700 000
Population living in B	N_B	200 000	60 000
Number of daily trips			
From A	X_A	40 000	20 000
From B	X_B	110 000	20 000
Distance AB rail (km)	d_{AB}^{rail}	52	88
Distance BD rail (km)	d_{BD}^{rail}	40	42
Distance AB road (km)	d_{AB}^{road}	44	50
Distance BD road (km)	d_{BD}^{road}	56	64
Average free train speed (km/hour)		69	87
Average free car speed (km/hour)		78	92
Road congestion cost (hours /veh/road capacity)	θ^{road}	0.2	0.6

Table 3: General parameters whose value is corridor specific

Table 10 displays detailed transport data which are corridor specific. Comparable rail access (or infrastructure) charges excluding mark-ups for Belgium and France have been found in European Commission (2019). This source assures comparability. The marginal cost of rail access is much higher in Belgium than in France. Train capacities (number of seats per train) and frequencies have been computed from the description of the rolling stocks used on each of the lines and on the supplied service.^{5 6} Different materials are used, so these figures have to

² [https://fr.wikipedia.org/wiki/Ligne_50A_\(Infrabel\)](https://fr.wikipedia.org/wiki/Ligne_50A_(Infrabel))

³ https://fr.wikipedia.org/wiki/Gare_de_Bourgoin-Jallieu

⁴ https://fr.wikipedia.org/wiki/Gare_de_Grenoble

⁵ [https://fr.wikipedia.org/wiki/InterCity_\(Belgique\)](https://fr.wikipedia.org/wiki/InterCity_(Belgique))

⁶ https://fr.wikipedia.org/wiki/Ligne_Lyon_-_Grenoble

be interpreted as average. Trains in Belgium are slightly larger than in France. Road capacity per hour corresponds to three lanes highway. Fuel prices and excises have been compiled from the Europe's Energy Portal.⁷ As there is no the same proportion of diesel and unleaded vehicles in both countries, we weighted prices and excise with respect to the shares of the vehicle types per country given by the European Automobile Manufacturers Association.⁸

	Notation	Belgium	France
Rail access charges (€ /km)		8.1	2.9
Train capacity (seats/train)	S^{RAIL}	650	600
Rail frequency (train/hour)			
Peak	$V^{RAIL,P}/h^P$	4	2
Off-peak	$V^{RAIL,O}/h^O$	2	1
Road capacity (veh/hour)			
A → B	S_{AB}^{road}	6 000	6 000
B → D	S_{BD}^{road}	6 000	6 000
Fuel price ⁹ (€ /l)	p^{fuel}	1.28	1.2
Fuel excise (€ /l)	κ^{fuel}	0.51	0.52
Road tolls (€)			
A → B	τ_{AB}^{CAR}	0	6.7
B → D	τ_{BD}^{CAR}	0	3.5
Train fares (€)			
Peak A → B	$p_A^{RAIL,P}$	2.5	5.0
B → D	$p_B^{RAIL,P}$	1.9	2.3
Off-peak A → B	$p_A^{RAIL,O}$	2.1	7.5
B → D	$p_B^{RAIL,O}$	1.9	3.3

Table 4: Transport parameters whose value is corridor specific

Road tolls for France have been retrieved from a local newspaper article.¹⁰ We met difficulties in estimating the average fare paid by train users: some users buy an annual or season ticket, some others pay full price for a one way trip... Consequently, we chose to retain

⁷ <https://www.energy.eu/fuelprices/>

⁸ <http://www.acea.be/statistics/tag/category/passenger-car-fleet-by-fuel-type>

⁹ Includes VAT and excise.

¹⁰ <http://www.ledauphine.com/isere-nord/2012/01/31/si-vous-entrez-a-villefontaine>

the price of an annual ticket.¹¹ ¹² This price is spread on 250 working days and 2 trips a day. As the annual ticket is usually the cheapest one, we apply on it a multiplicative coefficient of two.

B. Elasticities and cross elasticities

Tables 11, 12, 13 and 14 present the price elasticities and diversion factors χ to other modes and this for the 4 categories of users. These data are consistent with the literature (Mayeres (2000); Litman (2004); Oum, et al. (2008); Dargay and Clark (2012)). In the absence of more locally differentiated data, we use for the two corridors the same demand and price elasticity data. This makes the corridors more comparable but also loses some realism.

Active +		Peak		Off-peak	
		Rail	Car	Rail	Car
<i>Elasticities</i>					
Elasticity of demand wrt generalized cost		-0.3	-0.3	-0.6	-0.6
<i>Fraction of increased transit coming from</i>					
Peak	Rail	-	End.	End.	End.
	Car	0.5	-	End.	End.
Off-peak	Rail	0.15	0.15	-	End.
	Car	0.15	0.15	0.5	-
Increased overall travel demand		End.	End.	End.	End.

Note: "End." means that the number is endogenously determined.

Table 5: Cost-elasticities and origins of increased transit of the representative individual of the active + population

¹¹ <http://www.belgianrail.be/en/tickets-railcards/age/adults-seniors/frequent/section-season-ticket.aspx>

¹² <https://www.ter.sncf.com/auvergne-rhone-alpes/tarifs/devis/recherche?oldRegion=RAL>

Active -		Peak		Off-peak	
		Rail	Car	Rail	Car
<i>Elasticities</i>					
Elasticity of demand wrt generalized cost		-0.2	-0.2	-0.6	-0.6
<i>Fraction of increased transit coming from</i>					
Peak	Rail	-	End.	End.	End.
	Car	0.7	-	End.	End.
Off-peak	Rail	0.05	0.05	-	End.
	Car	0.05	0.05	0.7	-
Increased overall travel demand		End.	End.	End.	End.

Note: "End." means that the number is endogenously determined.

Table 6: Cost-elasticities and origins of increased transit of the representative individual of the active – population

Students		Peak		Off-peak	
		Rail	Car	Rail	Car
<i>Elasticities</i>					
Elasticity of demand wrt generalized cost		-0.3	-0.3	-0.7	-0.7
<i>Fraction of increased transit coming from</i>					
Peak	Rail	-	End.	End.	End.
	Car	0.2	-	End.	End.
Off-peak	Rail	0.1	0.1	-	End.
	Car	0.1	0.1	0.3	-
Increased overall travel demand		End.	End.	End.	End.

Note: "End." means that the number is endogenously determined.

Table 7: Cost-elasticities and origins of increased transit of the representative individual of the students population

Retired		Peak		Off-peak	
		Rail	Car	Rail	Car
<i>Elasticities</i>					
Elasticity of demand wrt generalized cost		-0.5	-0.5	-0.7	-0.7
<i>Fraction of increased transit coming from</i>					
Peak	Rail	-	End.	End.	End.
	Car	0.2	-	End.	End.
Off-peak	Rail	0.3	0.3	-	End.
	Car	0.3	0.3	0.6	-
Increased overall travel demand		End.	End.	End.	End.

Note: "End." means that the number is endogenously determined.

Table 8: Cost-elasticities and origins of increased transit of the representative individual of the retired population

C. First-best optimum

a. Objective function

The Lagrangian function is as follows

$$\begin{aligned}
 \mathcal{L} = & \sum_i \sum_j N_{i,j} \times \left[\underbrace{U_{i,j}}_{\text{Users srplus}} + \underbrace{\sum_m \sum_k x_{i,j}^{m,k} \times NMUC_{i,j}^{m,k}}_{\text{Users non-monetary costs}} \right] \\
 & + \underbrace{\Pi^{RAIL}}_{\text{Rail company profit}} - \underbrace{\sum_m \sum_k EXT^{m,k}}_{\text{Pollution and accident externalities}} \\
 & + \underbrace{\kappa^{fuel} \times \left[(V^{RAIL,P} + V^{RAIL,OP}) \times v^{RAIL} \times d_{AD}^{rail} + \sum_k \sum_j V_j^{CAR,k} \times v^{CAR} \times d_{jD}^{road} \right]}_{\text{Revenue of the fuel tax}} \\
 & + \underbrace{\sum_k \sum_j V_j^{CAR,k} \times \tau_j^{CAR,k}}_{\text{Revenue of the road tolls}} \\
 & + \underbrace{\sum_i \sum_j \lambda_{i,j} \times \left(R_{i,j} - q_{i,j} - \sum_m \sum_k x_{i,j}^{m,k} \times MUC_j^{m,k} \right)}_{\text{Revenue of the road tolls}}
 \end{aligned}$$

We derive \mathcal{L} with respect to $\lambda_{i,j}$:

$$\begin{aligned}
 \frac{\partial \mathcal{L}}{\partial \lambda_{i,j}} &= R_{i,j} - q_{i,j} - \sum_m \sum_k MUC_j^{m,k} x_{i,j}^{m,k} \\
 \Leftrightarrow q_{i,j} &= R_{i,j} - \sum_m \sum_k MUC_j^{m,k} x_{i,j}^{m,k}
 \end{aligned}$$

The revenue is fully spent.

b. Optimal quantity of the numeraire good consumed

Optimal quantities of the numeraire goods is given by:

$$\frac{\partial \mathcal{L}}{\partial q_{i,j}} = N_{i,j} \frac{\partial U_{i,j}}{\partial q_{i,j}} - \lambda_{i,j}.$$

Recalling that $\frac{\partial U_{i,j}}{\partial q_{i,j}} = 1$, it implies

$$\lambda_{i,j} = N_{i,j}. \quad (\text{App. 1})$$

c. Optimal train fares

To find the optimal level of train fares, we derive \mathcal{L} with respect to $x_{i,j}^{RAIL,k}$.

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial x_{i,B}^{RAIL,k}} = & N_{i,B} \left(\frac{\partial U_{i,B}}{\partial x_{i,B}^{RAIL,k}} - NMUC_{i,B}^{RAIL,k} \right) \\ & - \sum_n \sum_r N_{n,r} \cdot x_{n,r}^{RAIL,k} \cdot \left[\frac{\partial X_B^{RAIL,k}}{\partial x_{i,B}^{RAIL,k}} \frac{\partial o_B^{RAIL,k}}{\partial X_B^{RAIL,k}} \cdot \frac{\partial discom_{n,B}^{RAIL,k}}{\partial o_B^{RAIL,k}} \right] \\ & + p_B^{RAIL,k} \frac{\partial X_B^{RAIL,k}}{\partial x_{i,B}^{RAIL,k}} - \lambda_{i,B} MUC_B^{RAIL,k} \end{aligned}$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial x_{i,A}^{RAIL,k}} = & N_{i,A} \left(\frac{\partial U_{i,A}}{\partial x_{i,A}^{RAIL,k}} - NMUC_{i,A}^{RAIL,k} \right) \\ & - \sum_n \sum_r N_{n,r} \cdot x_{n,r}^{RAIL,k} \cdot \left[\frac{\partial X_A^{RAIL,k}}{\partial x_{i,A}^{RAIL,k}} \frac{\partial o_{AB}^{RAIL,k}}{\partial X_A^{RAIL,k}} \cdot \frac{\partial discom_{n,A}^{RAIL,k}}{\partial o_A^{RAIL,k}} \right. \\ & \quad \left. + \frac{\partial X_B^{RAIL,k}}{\partial x_{i,A}^{RAIL,k}} \frac{\partial o_B^{RAIL,k}}{\partial X_B^{RAIL,k}} \cdot \frac{\partial discom_{n,B}^{RAIL,k}}{\partial o_B^{RAIL,k}} \right] \\ & + p_A^{RAIL,k} \frac{\partial X_A^{RAIL,k}}{\partial x_{i,A}^{RAIL,k}} - \lambda_{i,A} MUC_A^{RAIL,k} \end{aligned}$$

Recall that $\lambda_{i,j} = N_{i,j}$ from Equation (App. 1), that $MUC_j^{RAIL,k} = p_j^{RAIL,k}$, that $\frac{\partial U_{i,j}}{\partial x_{i,j}^{RAIL,k}} -$

$NMUC_{i,j}^{RAIL,k} = MUC_{i,j}^{RAIL,k}$ from Equation (11) and that $\frac{\partial X_j^{RAIL,k}}{\partial x_{i,j}^{RAIL,k}} = N_{i,j}^{RAIL,k}$. Setting Equations

above equal to zero and rearranging, we find the optimal fares of a journey by train

$$p_B^{RAIL,k} = \sum_n \sum_r N_{n,r} \cdot x_{n,r}^{RAIL,k} \cdot \left[\frac{\partial o_B^{RAIL,k}}{\partial X_B^{RAIL,k}} \cdot \frac{\partial discom_{n,B}^{RAIL,k}}{\partial o_B^{RAIL,k}} \right];$$

$$p_A^{RAIL,k} = \sum_n \sum_r N_{n,r} \cdot x_{n,r}^{RAIL,k} \cdot \left[\frac{\partial o_A^{RAIL,k}}{\partial X_A^{RAIL,k}} \cdot \frac{\partial discom_{n,A}^{RAIL,k}}{\partial o_A^{RAIL,k}} + \frac{\partial o_B^{RAIL,k}}{\partial X_A^{RAIL,k}} \cdot \frac{\partial discom_{n,B}^{RAIL,k}}{\partial o_B^{RAIL,k}} \right].$$

This can be simply rewritten as

$$p_j^{RAIL,k} = \frac{\partial o_j^{RAIL,k}}{\partial X_j^{RAIL,k}} DISCOM_{o_j^{RAIL,k}}^{RAIL,k}, \quad \forall k, j,$$

where $DISCOM_{o_j^{RAIL,k}}^{RAIL,k}$ is the variation in aggregated discomfort cost in rail during period k due to a change in the occupancy rate from j to D during period k .

d. Optimal train supply

To find the optimal train supply, we derive \mathcal{L} with respect to the number of runs operated, $V^{RAIL,k}$, and to the optimal number of seats per train, S^{RAIL} .

$$\frac{\partial \mathcal{L}}{\partial V^{RAIL,k}} = - \sum_i \sum_j N_{i,j} \cdot x_{i,j}^{RAIL,k} \cdot \left(\frac{\partial unrel_i^{RAIL,k}}{\partial V^{RAIL,k}} + \frac{\partial o_A^{RAIL,k}}{\partial V^{RAIL,k}} \frac{\partial discom_{i,j}^{RAIL,k}}{\partial o_A^{RAIL,k}} \right. \\ \left. + \frac{\partial o_B^{RAIL,k}}{\partial V^{RAIL,k}} \frac{\partial discom_{i,j}^{RAIL,k}}{\partial o_B^{RAIL,k}} + \frac{\partial sched_i^{RAIL,k}}{\partial V^{RAIL,k}} \right) \\ - \frac{\partial TC^{RAIL}}{\partial V^{RAIL,k}} - \frac{\partial EXT^{RAIL,k}}{\partial V^{RAIL,k}} + \kappa^{fuel} \times v^{RAIL} \times d_{AD}^{rail},$$

$$\frac{\partial \mathcal{L}}{\partial S^{RAIL}} = - \sum_i \sum_j N_{i,j} \cdot \sum_k x_{i,j}^{RAIL,k} \left(\frac{\partial o_A^{RAIL,k}}{\partial S^{RAIL}} \frac{\partial discom_{i,j}^{RAIL,k}}{\partial o_A^{RAIL,k}} + \frac{\partial o_B^{RAIL,k}}{\partial S^{RAIL}} \frac{\partial discom_{i,j}^{RAIL,k}}{\partial o_B^{RAIL,k}} \right) \\ - \frac{\partial TC^{RAIL}}{\partial S^{RAIL}}.$$

Setting Equations above equal to zero and rearranging, we find

$$\begin{aligned}
TC_{V_{RAIL,k}}^{RAIL} &= -UNREL_{V_{RAIL,k}}^{RAIL,k} - \sum_j \frac{\partial o_j^{RAIL,k}}{\partial V_{RAIL,k}} DISCOM_{o_j^{RAIL,k}}^{RAIL,k} - SCHEM_{V_{RAIL,k}}^{RAIL,k} \\
&\quad - EXT_{V_{RAIL,k}}^{RAIL,k} + FUEL_{V_{RAIL,k}}^{RAIL}, \forall k, \\
TC_{S^m}^{RAIL} &= - \sum_k \sum_j \frac{\partial o_j^{RAIL,k}}{\partial S^{RAIL}} DISCOM_{o_j^{RAIL,k}}^{RAIL,k}.
\end{aligned}$$

e. Optimal road tolls

To find the optimal level of travel quantities, we derive \mathcal{L} with respect to $x_{i,j}^{CAR,k}$

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial x_{i,j}^{CAR,k}} &= N_{i,j} \left(\frac{\partial U_{i,j}}{\partial x_{i,j}^{CAR,k}} - time_{i,j}^{CAR} - cong_{i,j}^{CAR,k} \right) - \sum_n \sum_r N_{n,r} \cdot x_{n,r}^{CAR,k} \cdot \frac{\partial cong_{n,r}^{CAR,k}}{\partial V_j^{CAR,k}} \\
&\quad - \frac{\partial EXT^{CAR,k}}{\partial V_j^{CAR,k}} + (\kappa^{gas} \times v^m \times d_{jD}^{road} + \tau_j^{CAR,k}) - \lambda_{i,j} MUC_j^{CAR,k}
\end{aligned}$$

Recall that $\lambda_{i,j} = N_{i,j}$ from Equation (App. 1), that $MUC_j^{CAR,k} = \kappa^{gas} + v^m \times d_{jD}^{road} + \tau_j^{CAR,k}$, and that $\frac{\partial U_{i,j}}{\partial x_{i,j}^{CAR,k}} - NMUC_{i,j}^{CAR,k} = MUC_{i,j}^{CAR,k}$ from Equation (11)). Setting Equations

above equal to zero and rearranging, we find the optimal tolls on road

$$\tau_j^{CAR,k} = CONG_{V_j^{CAR,k}}^{CAR,k} + EXT_{V_j^{CAR,k}}^{CAR,k} - FUEL_{V_j^{CAR,k}}^{CAR}, \quad \forall k, j.$$

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