Welfare Effects of a Carbon Tax in the Long-Distance Passenger Market

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Roadmap

Motivation

Key Issues:

- Transport is the largest source of greenhouse gas emissions in France.
- Several public policy instruments: carbon tax, investment in low-carbon modes, standards, bans.
- Political feasibility is a central concern.

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Objectives of the study:

- Assess the impact of introducing a carbon tax while accounting for modal substitution (air/car $\rightarrow$ rail).
- Examine the role of rail price regulation and the implications of electric vehicles.
- Decompose effects on all components of social welfare.

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Scope of the study:

- Long-distance transport in France.
- Paris–Marseille TGV line (2019 passenger traffic).
- Inclusion of car and air alternatives (bus and ridesharing marginal).

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Welfare decomposition:

- Effect on passengers: fare increases, disutility from forgone trips and shift to less preferred modes of transportation
- Effect on operators: profit changes (higher marginal costs, induced change in competition).
- Reduction in negative externalities: environmental and fiscal.

Literature Review

A substantial literature, but focused on specific angles:

- Airport “feed-in” rail traffic: Givoni & Banister 2006; Socorro & Viecens 2013.
- Routes where rail is relatively polluting (Paris–London): Givoni 2007; D’Alfonso et al. 2016.
- Mode-specific analyses: Fukui & Miyoshi 2017 (US air); Jiang 2021 (air–rail only).

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Studies on the impact of HSR on CO_2:

- In general, positive effects: Dalkic et al. 2017 (Turkey, modest effect because share of air transport negligible); Strauss et al. 2021 (China).
- In some rarer cases, negative effects (airline strategic reactions in case of railway subsidies): Gu & Van 2022; Wang et al. 2025.

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No comprehensive welfare analysis of a carbon tax with significant modal substitution across road/rail/air.

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1. Motivation and Literature Review
2. Demand Modelling
3. Supply Modelling and Calibration
4. Simulation

Discrete Choice Model

Simple logit specification:

(a) Each mode i provides deterministic utility Ψ_i ("quality index") depending on the characteristics of the transport mode (time to travel, frequency..);

(b) Each user j has an idiosyncratic preference term ϵ_{ij} for each mode i;

(c) ϵ_{ij} follow a Gumbel distribution.

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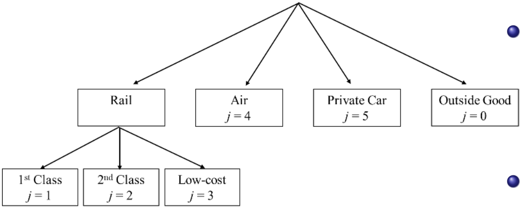
We use a nested logit model:



- Distinction between first and second class Inoui and low-cost Ouigo,
- Hierarchy of choices : first mode, then choice between different types of train tickets that are more substitutable ($\rightarrow$ correlation between the corresponding random variables ϵ_{ij})
- Includes an "outside good" corresponding to the alternative of not traveling.

Data and Demand Equations

Paris–Marseille data (2019):

Transport alternative	Annual number of passengers	Market Share (without OG)	Price in €	Marginal Costs in €
Rail 1st Class	451067	8.3%	62.3	45
Rail 2nd Class	1407107	26.0%	53.4	38
Rail Low Cost	1260150	23.2%	30.5	24
Air	591438	10.9%	110.7	70
Private Vehicle	1649816	30.4%	88.6	88.6

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Demand equations:

$$\ln(s_j) - \ln(s_0) = \Psi_j - hp_j + \sigma \ln(s_{j|rail}), \quad j = 1, 2, 3$$

$$\ln(s_j) - \ln(s_0) = \Psi_j - hp_j, \quad j = 4, 5$$

where s_j market share when taking into account the outside good.

$\rightarrow$ 8 Unknowns: s_0 (outside good), h ($\simeq$ marginal utility), σ (correlation inside the nest) and the 5 quality parameters Ψ_i.

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Supply Modelling

Importance of rail price regulation:

- Government monitors average fares and enforces affordability constraints (price level of discounted tickets or low-cost offers). Some offers face explicit price caps.
- Result from Cherbonnier et al. (2017): without regulation, observed prices cannot be rationalized.

Supply Modelling

Importance of rail price regulation:

- Government monitors average fares and enforces affordability constraints (price level of discounted tickets or low-cost offers). Some offers face explicit price caps.
- Result from Cherbonnier et al. (2017): without regulation, observed prices cannot be rationalized.

Each transport mode requires a specific supply model:

- Car: non-strategic; users bear cost.
- Air: strategic profit maximisation.
- Rail: single strategic operator with average-fare and low-cost constraints:

$$\max_{p_1,p_2,p_3} \sum_{i=1}^{3}(p_i - c_i)s_i N - \mu\left(\sum_{i=1}^{3} p_i s_{i|rail} - \bar{p}\right) - \lambda(p_3 - \bar{p}_3)$$

μ and λ : shadow cost of regulation

Calibration

Step 1:

- Five unknowns: outside good s_0, marginal utility h, correlation coefficient σ, and the two regulatory parameters μ and λ
- Four first order equations derived from the profit maximization of the rail operators (3 prices) and the air operator (1 price);

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One parameter chosen externally: $s_0 = 75\%$ (+ sensitivity tests)

- Size of leisure market without s_0 according to 2019 data : 5.4 millions trips
- $s_0 \simeq 75\%$ using rough estimation of potential market share (population's size + average long distance trips, cf. for instance Hsiao & Hansen 2011)
- Consistent with seeking to obtain 70% travel renunciation and 30% modal shift in case of negative shocks on rail supply, in line with observed behaviors

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- Four first order equations derived from the profit maximization of the rail operators (3 prices) and the air operator (1 price);

Step 2:

- Infer Ψ_i from demand ($\Psi_0 = 0$ and $s_0 = 75\%$)
- Check elasticities consistent with existing literature

Parameter calibration

Name	Symbol	Value
Quality Rail 1st Class	ψ_1	-0.216
Quality Rail 2nd Class	ψ_2	-0.353
Quality Rail Low Cost	ψ_3	-0.939
Quality Air	ψ_4	-0.506
Quality Private Vehicle	ψ_5	-0.039
Marginal utility of income	h	0.025
Degree of correlation	σ	0.923

Roadmap

Set of Simulations

Scenarios:

- Carbon price raised to 130 or 190€ (EPA 2023).
- With/without electric car.
- With/without rail regulation.

Carbon values:

- Externality: 190€/tCO2 (EPA).
- Road carbon cost: 44.6€/tCO2 (2019, since Yellow Vests).
- Rail/air: 25€/tCO2 (EU ETS 2019).

Emissions per passenger (ADEME):

- Air: 152 kg
- Car: 66.1 kg (avg nb passengers INSEE)
- Rail: 1.725 kg.

Simulation 1: Implementing a Carbon Tax

Scenarios: 130€ and 190€/tCO2 (railway regulation maintained, no EV)

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Scenarios: 130€ and 190€/tCO2 (railway regulation maintained, no EV)

Main effects:

- Airlines pass tax through to fares → traffic collapses (–30% then -50%).
- Car traffic falls moderately;
- Limited shift to rail (+20%) → many forgone trips (1/2 millions)

		Reference	Scenario 1 Carbon tax 130€/tCO$_2$	Scenario 2 Carbon tax 190€/tCO$_2$
Internal market share (%)	Rail 1st Class	8.4	9.2	9.6
	Rail 2nd Class	26.3	28.4	29.7
	Rail Low Cost	23.5	25.5	26.7
	Air	11.0	8.1	6.7
	Private Vehicle	30.8	28.8	27.2
Price	Rail 1st Class	62.3	62.3	62.3
	Rail 2nd Class	53.4	53.4	53.4
	Rail Low Cost	30.6	30.6	30.6
	Air	110.7	126.3	135.3
	Private Vehicle	88.6	94.2	98.2
# Passengers (Million)	Rail	3.1	3.4	3.7
	Air	0.6	0.4	0.3
	Private Vehicle	1.7	1.5	1.3
	Non-travelling	16.1	16.4	16.6

Simulation 1: Implementing a Carbon Tax

Assumptions: Social cost of carbon 190€, opportunity cost of public funds 0.2

$$\Delta W = \Delta CS + \Delta Profit + (1 + 0.2)\Delta TaxCO2 - \Delta CO2 \times 190$$

Simulation 1: Implementing a Carbon Tax

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$$\Delta W = \Delta CS + \Delta Profit + (1 + 0.2)\Delta TaxCO2 - \Delta CO2 \times 190$$

- Negative but small impact on total welfare in the 190€ scenario;
- Relatively strong effect on externalities (-30% GHG emissions);
- Offset but a strong negative effect on consumer surplus (forced sobriety) and airline profits:

	Scenario 1		Scenario 2	
	Carbon tax 130€/tCO_2		Carbon tax 190€/tCO_2	
Change	Million €	Percent	Million €	Percent
Consumer surplus	-16.5	-6.8	-25.3	-10.4
Rail operator's profit	+0.2	+0.4	+0.2	+0.6
Airline's profit	-7.7	-31.9	-10.9	-45.3
Tax revenue	+14.0	+193.7	+20.0	+276.2
Environmental externalities	-7.7	-19.9	-11.6	-29.8
Welfare	-2.3	-0.8	-4.4	-1.6
Welfare under cost of public funds	+0.6	+0.2	-0.4	-0.1

Note: Changes are computed with respect to the reference situation.

Simulation 2: Deregulation of railway

Scenarios: no railway price regulation with or without a carbon tax at 190€/tCO2

Main effects:

- Impact of deregulation : +50% increase in prices (low cost vanishes) →-1.3M rail trip → shifting: 67% outside good / 9% car / 24% air (reversely negative impact of rail regulation on air traffic contrary to Gu & Wan 2022)
- Impact of carbon tax: full passthrough on air + increase in railway prices → No shift to rail (-6%) → 1 millions forgone trips

		Reference	Scenario 3	Scenario 4
			Deregulation	Deregulation and Carbon tax 190€/tCO_2
Market share (%)	Rail 1st Class	8.4	14.7	17.5
	Rail 2nd Class	26.3	24.6	29.4
	Rail Low Cost	23.5	1.2	1.5
	Rail	58.2	39.7	48.3
	Air	11.0	15.9	10.2
	Private Vehicle	30.8	44.4	41.5
Price	Rail 1st Class	62.3	87.9	88.3
	Rail 2nd Class	53.4	80.9	81.3
	Rail Low Cost	30.6	66.9	67.3
	Air	110.7	110.8	135.3
	Private Vehicle	88.6	88.6	98.2
# Passengers (Million)	Rail	3.1	1.75	1.65
	Air	0.6	0.7	0.35
	Private Vehicle	1.7	2.0	1.4
	Non-travelling	16.1	17.0	18.0

Simulation 2: Deregulation of railway

Assumptions: Social cost of carbon 190€, opportunity cost of public funds 0.2

$$\Delta W = \Delta CS + \Delta Profit + (1 + 0.2)\Delta TaxCO2 - \Delta CO2 \times 190$$

- Deregulation severely harm welfare (strong negative effect on both consumer surplus and externalities);
- True even if increase in railway profit allows for a 1-1 reduction in State subsidies;
- Positive effect of carbon tax on welfare (higher stake in reducing air marketshare) although slightly less impact on GHG emission than in the previous scenario

	Scenario 3		**Scenario 4**	
	Deregulation		**Deregulation and Carbon tax 190€/tCO$_2$**	
Change	Million €	Percent	Million €	Percent
Consumer surplus	-67.8	-27.8	-93.6	-38.4
Rail operator's profit	+30.6	+81.0	+34.6	+91.8
Airline's profit	+2.0	+8.3	-9.8	-40.7
Tax revenue	+0.5	+7.2	+21.7	+299.5
Environmental externalities	+2.6	+6.7	-9.9	-25.5
Welfare	-37.3	-13.5	-37.2	-13.5
Welfare under cost of public funds	-37.2	-13.5	-32.9	-11.9

Note: Changes are computed with respect to the reference situation.

Simulation 3: Widespread adoption of electric vehicles

<u>Scenarios:</u> Electric vehicles with or without a carbon tax at 190€/tCO2

Main effects:

- Switch to electric vehicles : slightly lower cost (current carbon tax)
- Similar impact of carbon tax on air market share;
- But positive (instead of negative) impact of car transportation
  → far less forgone trips (0.1M)

		Reference	Scenario 5	Scenario 6
			EV	EV and Carbon tax 190€/tCO_2
Market share (%)	Rail 1st Class	8.4	8.2	8.7
	Rail 2nd Class	26.3	25.5	26.8
	Rail Low Cost	23.5	22.8	24.1
	Air	11.0	10.7	6.1
	Private Vehicle	30.8	32.7	34.4
Price	Rail 1st Class	62.3	62.3	62.3
	Rail 2nd Class	53.4	53.4	53.4
	Rail Low Cost	30.6	30.5	30.5
	Air	110.7	110.7	135.3
	Private Vehicle	88.6	85.0	85.0
# Passengers (Million)	Rail	3.1	3.07	3.17
	Air	0.6	0.6	0.3
	Private Vehicle	1.7	1.75	1.85
	Non-travelling	16.1	16.0	16.1

Simulation 3: Widespread adoption of electric vehicles

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$$\Delta W = \Delta CS + \Delta Profit + (1 + 0.2)\Delta TaxCO2 - \Delta CO2 \times 190$$

- Shift to electric vehicles results in a significant reduction in GHG emissions (twice more than a Pigovian tax in the reference scenario);
- Carbon tax: reduction of GHG emissions (not very far from reference scenario) → with negative impact on welfare partly due to lower consumer surplus (but both are twice less than in reference scenario)

	Scenario 5		**Scenario 6**	
	EV		**EV and Carbon tax 190€/tCO_2**	
Change	Million €	Percent	Million €	Percent
Consumer surplus	+6.2	+2.5	-4.7	-1.9
Rail operator's profit	-0.3	-0.7	-0.7	-1.8
Airline's profit	-0.2	-0.7	-11.2	-46.6
Tax revenue	-4.9	-67.4	+3.0	+41.7
Environmental externalities	-20.9	-53.7	-28.6	-73.6
Welfare	+21.7	+7.5	+15.0	+5.7
Welfare under cost of public fund	+20.7	+7.5	+15.6	+5.7

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In a perfectly competitive market, the optimal tax is the Pigouvian tax that internalizes pollution costs.

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Discrete choice model : a customer i prefers option j over k if

$$\Psi_j - hp_j + \epsilon_{ij} > \Psi_k - hp_k + \epsilon_{ik}$$

A Pigovian tax τ on j changes customer's choice if it reverses this inequality

$\rightarrow$ if perfect competition (and no OCPF)

Positive impact on Welfare since the monetary equivalent of the corresponding loss of utility is always lower than the externality $\Rightarrow$ Pigovian tax optimal

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Imperfect competition in polluting modes ⇒ extra welfare loss from such modal shift ⇒ Pigovian tax overcorrective (and under-corrective in the opposite case)

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Imperfect competition in polluting modes $\Rightarrow$ extra welfare loss from such modal shift $\Rightarrow$ Pigovian tax overcorrective (and under-corrective in the opposite case)

What we obtain in the reference scenario:

- a Pigovian tax on all modes in overcorrective (optimal tax $<$ 100€/tCO2)
- a Pigovian tax only on car is undercorrective (optimal tax $>$ 250€/tCO2)

Conclusions

Main results:

- Pigouvian tax has marginal (slightly negative) welfare effect.
- Large CS losses → major political obstacle.
- Rail price regulation is crucial.
- EV development strongly improves welfare and lowers externalities.
- With EVs, carbon tax still has a positive impact on carbon emission, with twice less negative impact on welfare and consumer surplus (but becomes highly distortionary since it affects only air).

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- With EVs, carbon tax still has a positive impact on carbon emission, with twice less negative impact on welfare and consumer surplus (but becomes highly distortionary since it affects only air).

The optimal carbon taxation is not given by the Pigovian taxation as long as market distorsion (lack of competition) are present. Higher or lower depending on which sector (polluting or green) suffers from a lack of competition.

Given low modal substitutability in the medium run, effective climate policy requires combining: rail regulation, EV deployment, and aviation taxation — the latter being politically costly.

Annex

Travel renunciation and induced Demand

Extract from Givoni & Dobruszkes (2013) on share of induced demand (vs. modal shift) from the development of high speed train

- +20% for distances of around 200-300km, such as Rome-Naples
- +50% for longer distance such as the 470km Paris-Lyon route (Bonnafous 1987)

Table 4. Demand for HSR services as a percentage of passengers' mode of origin

Route	Year	Induced[a]	Rail	Planes	Cars	Coaches	Source
Paris–Bruxelles–Cologne/Amsterdam[b]	N.A.	11%	47%	8%	31%	3%	Segal (2006)
London–Paris/Lille/Brussels[c]	N.A.	20%	12%	49%	7%	12%	Segal (2006)
Paris–South-east	1984	49%		33%	18%		Bonnafous (1987)
Madrid–Seville	1994	26%	14%	32%	25%	3%	Vickerman (1997)
	1996	15%	18%	42%	20%	5%	EC (1998)
Rome–Naples	2007	22%	69%	1%[d]	8%	1%[d]	Cascetta et al. (2011)
Osaka–Hakata	1970s	6%	55%	23%	16%		Okabe (1979)[e]
Korea (first stage)	April 2004	N.A.	56%	17%	12%	15%	Suh, Yang, Lee, and Ahn (2005)
Wuhan–Guangzhou	2010	45%[f]	50%	5%	N.A.	N.A.	Bullock et al. (2012)

Back

Elasticities

Rail elasticity -0.98

- Relatively high with respect to general studies (e.g. Börjesson 2014, Wardman 2022..) but long-distance route with competition between rail and air
- Consistent with other studies on similar route : -1.25 for Cologne-Berlin (Ivaldi Vibes 2008) or -0.57 for Valencia-Madrid (Hoterlano et al. 106)

Own Price elasticity

Transport alternative	**Own Price Elasticity of Demand**	**Rail Aggregate Price Elasticity**
Rail 1st Class	-17,52	
Rail 2nd Class	-10,09	-0.98
Rail Low Cost	-6,21	
Air	-2,72	
Private Vehicle	-2.06	

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Specific focus on railway regulation:

- Previous works show that the rail operator's prices are significantly lower than what would be optimal for a monopolistic firm on the rail mode maximizing its unconstrained short-term profit (Cherbonnier et al. 2017)
- Explanation : current price regulation (on both average price and entry prices) and/or threat of a regulatory tightening
- Several variants of discrete choice models were tested, distinguishing among ticket types (first class, second class, low-cost).