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Dieselization, emissions and rebound effect in cars: theory and applications to Europe

Presentation based on '**The Diesel-gasoline dilemma and the fuel efficiency paradox**', by R.M González, G. Marrero & J. Rodríguez-López, Mimeo

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The Issues & Outline

1. Facts in EU (about passenger cars): dieselization process, fuel prices & taxes, km. travelled and CO2 emissions

2. The empirical evidence (short panel): dieselization Vs. CO2 emissions? The efficiency Vs. rebound trade-off

3. A neoclassical dynamic model with gasoline and diesel cars: optimal fuel (gasoline-diesel) tax policy (no macro-theoretical papers about this issue)

Introduction

- Road transport contributes one-fifth of EU's total CO_2 emissions (80% road transport), the second biggest after power generation.
- In 1990-2010, emissions from road transport increased 22.6% in EU, while GHG fell 15.4%. Solutions to emissions reduction in Cars?
- Technology and incentive issues: small and low penetration of biofuels and electric vehicles in road transport in EU
- Alternative: since diesel is more efficient (liters/km) than gasoline, a Dieselization policy (incentive diesel against gasoline) may reduce emissions

Introduction

Focus on passenger cars, leaving aside freight transport and alternative ways to road transport (bus, train) … several reasons:

1. Most incentives to diesel is related to passenger cars (in fuel and in purchase)
2. In terms of modelization, the use of passenger cars (demanded by the consumers) generates services enhancing utility, while most freight transport (heavy and light trucks) is demanded by firms and is a capital input affecting the production function
3. Mixing freight with passenger cars would generate misleading conclusions

Introduction

Data on passenger cars: j=1: diesel; j=2: gasoline (difficult task)

A. Prices & tax data: mainly from Ministerio de Industria, Energía y Turismo

- Prices with and without taxes (including special & indirect): Pfj & tfj
- Still looking for: prices of new vehicles (PXj); taxes/subsidies (tXj)

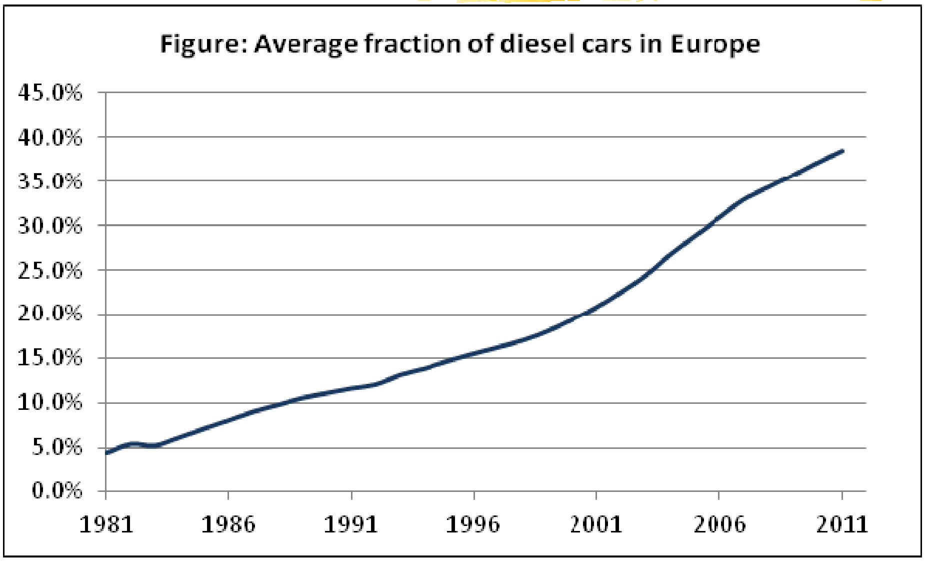
B. Consumption, cars & mobility data: Odyssee-Mure /)
http://www.indicators.odyssee-mure.eu/online-indicators.html

- Fuel consumption (Mtoe by fuel): *Fj*, j=1,2
- Stock (Fleet) of cars (M): *qj*, j=1,2
- New sales (M): *xj*, j=1,2
- Fuel efficiency (liters/100Km): *fj*, j=1,2
- Mobility (km-travelled/car-year): *ñj*, j=1,2
- CO2 emissions (total and per car) (tco2 and tco2/veh),

C. Other data from Eurostat, PWT 7.1., and Others: Population (N); real GDP ppp-adjusted (Y); Needed for calibration: cost of repair & manteinance, other taxes, etc.

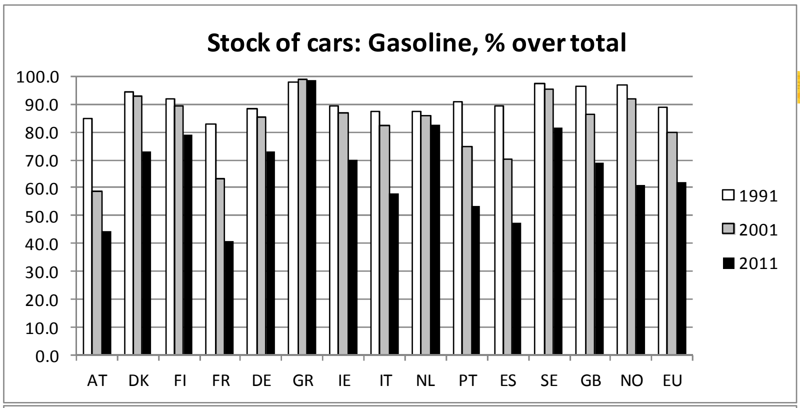
1. Facts in EU (about passenger cars): dieselization process, fuel prices & taxes, km. travelled and CO2 emissions

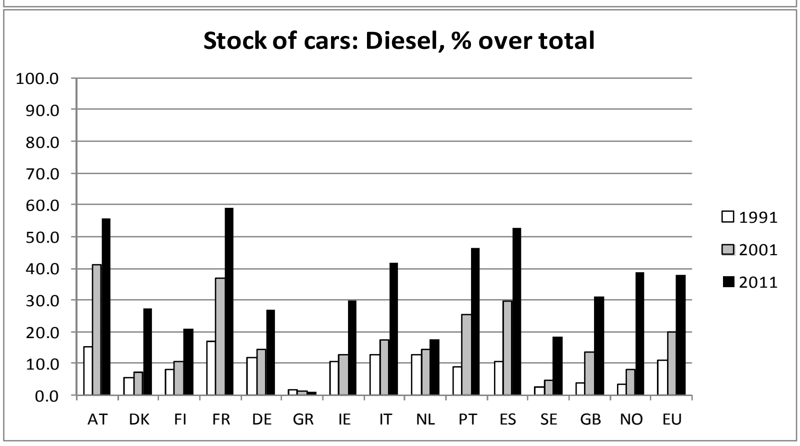
Fact 1. Intensive Dieselization process in Europe



On average in EU the diesel ratio has increased from 5% in 1981, about 21% in 2001 (20 yrs) and almost 40% in 2011 (10 yrs)

Fact 1. Intensive Dieselization process in Europe





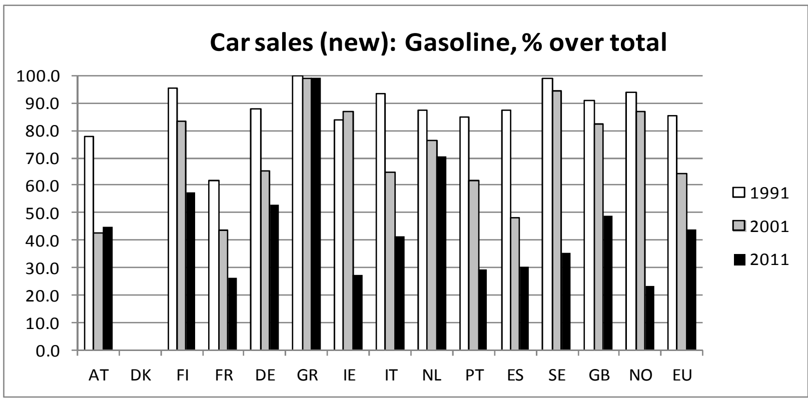
Focus on 1991-2011-2011 (main EU countries): the % of diesel has increased, while that of gasoline decreased

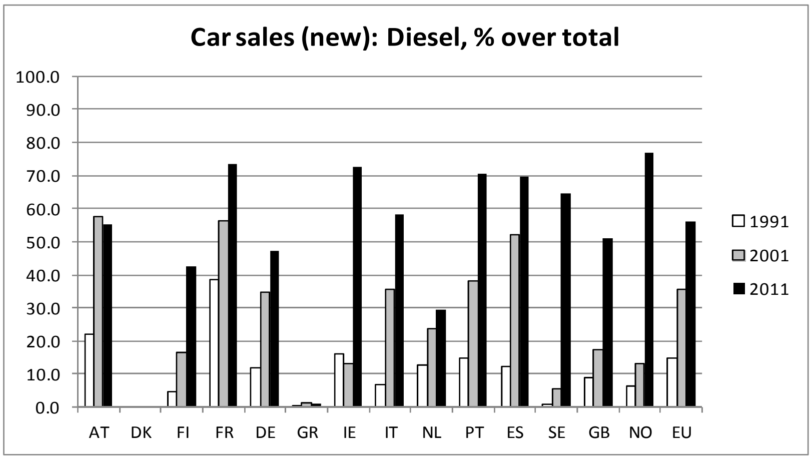
Spain, France, Austria and Portugal show the highest change in the mix of cars

Spain: about 10% in 1991 of the fleet was of diesel in Spain; now, it more than 50%

Some exceptions is Greece and Netherlands (small change)

Fact 1. Intensive Dieselization process in Europe





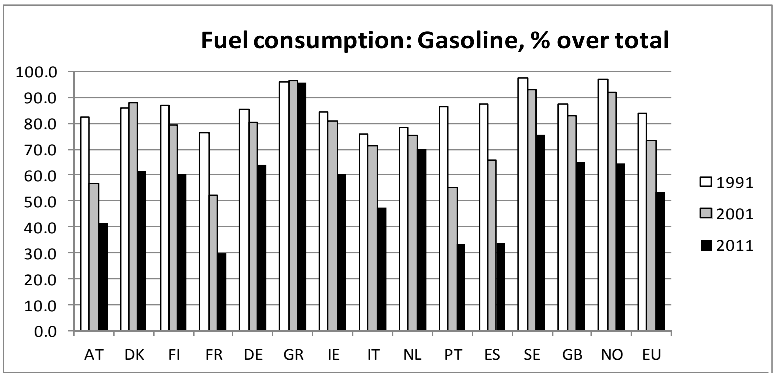
The intensive dieselization process can also be seen in 'car sales' …

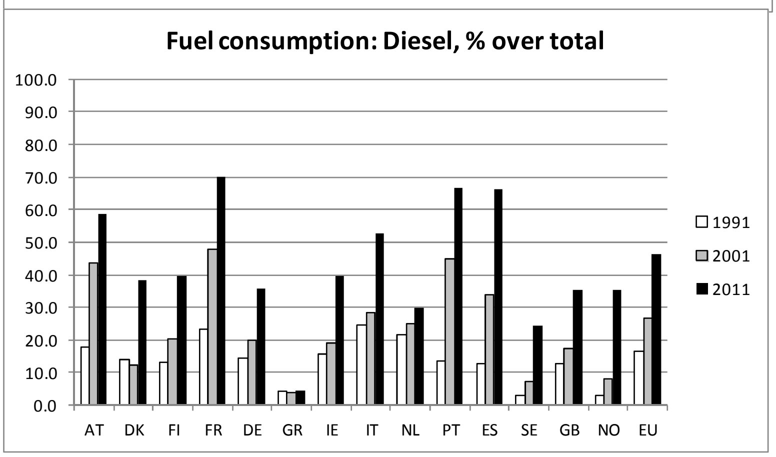
Spain: the diesel to gasoline ratio was about 10% in 1991 and almost 70% in 2011

The case of Netherland: stronger evidence of dieselization in sales … replacement of old diesel cars

Greece is still the exception.

Fact 1. Intensive Dieselization process in Europe



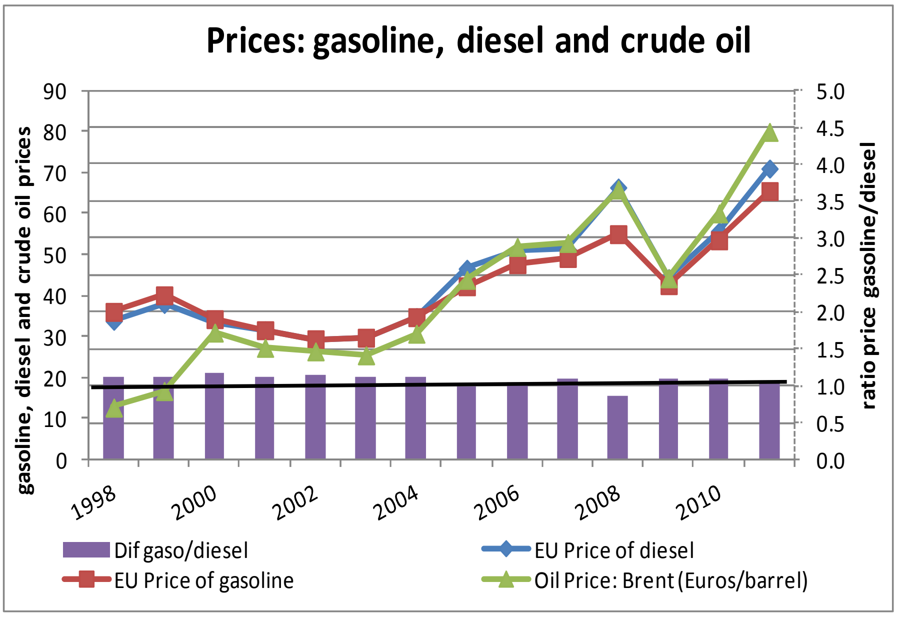


… and in relative fuel consumption

For example: in Spain, diesel-gasoline was 10% in 1991 and now it is almost 70%

Fact 2. Fuel (diesel & gasoline) prices and taxes

Final fuel prices share a **common factor**: **crude oil**

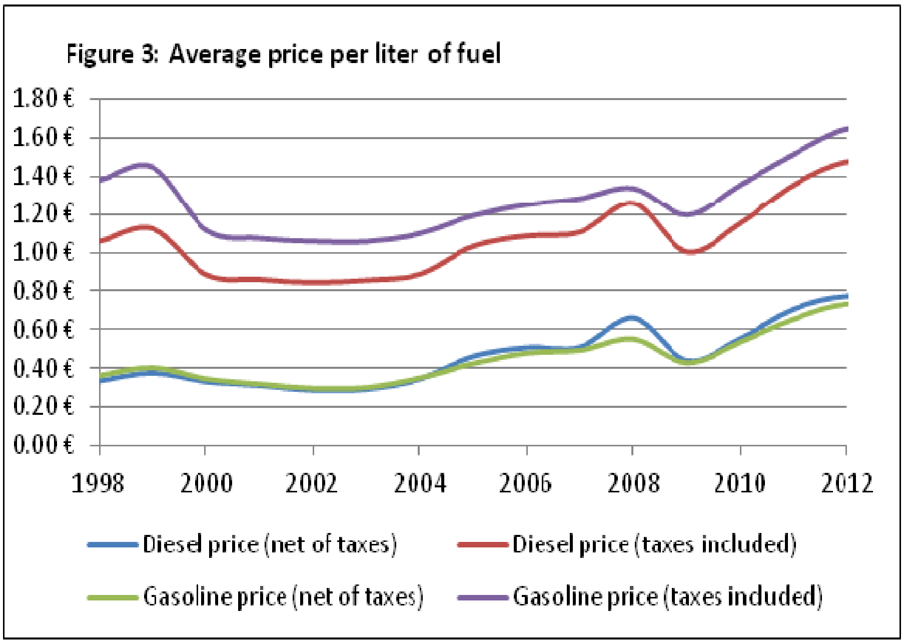


Common fact in most EU countries

The gasoline/diesel price ratio (NET of taxes) fluctuates around 1, with small variance

Fact 2. Fuel (diesel & gasoline) prices and taxes

Final fuel prices show a clear **differential factor**: **taxes**



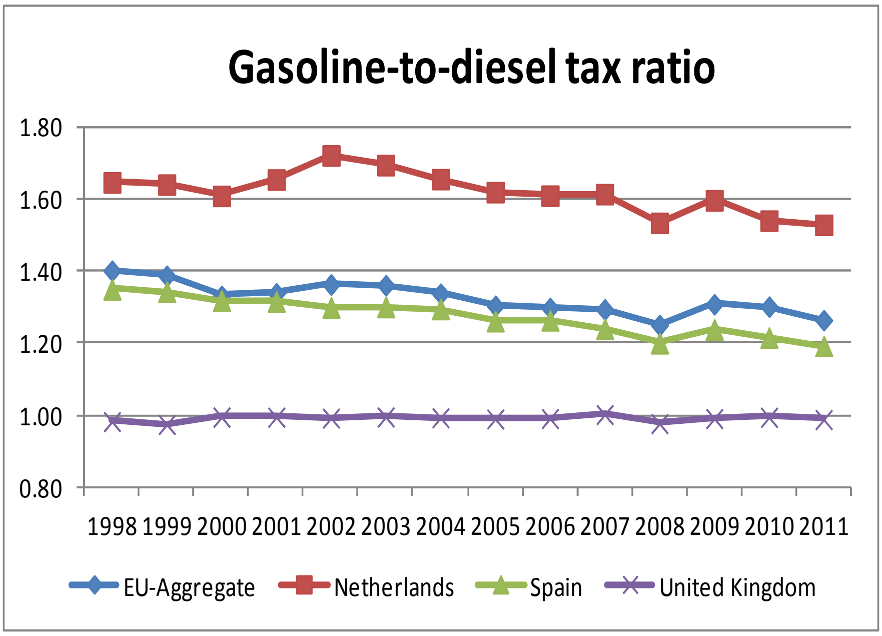
While prices (net of taxes) show an overlapping evolution …

… prices including taxes show a permanent gap, though reducing the gap

Moreover: taxes represent a considerable fraction in final prices: 68% in 1998 & 49% in 2013 (diesel); 74% in 1998 & 57% in 2013 (gasoline).

Fact 2. Fuel (diesel & gasoline) prices and taxes

Aggressive policy favoring diesel against gasoline: taxing higher gasoline than diesel and subsidizing the purchase of new diesel cars

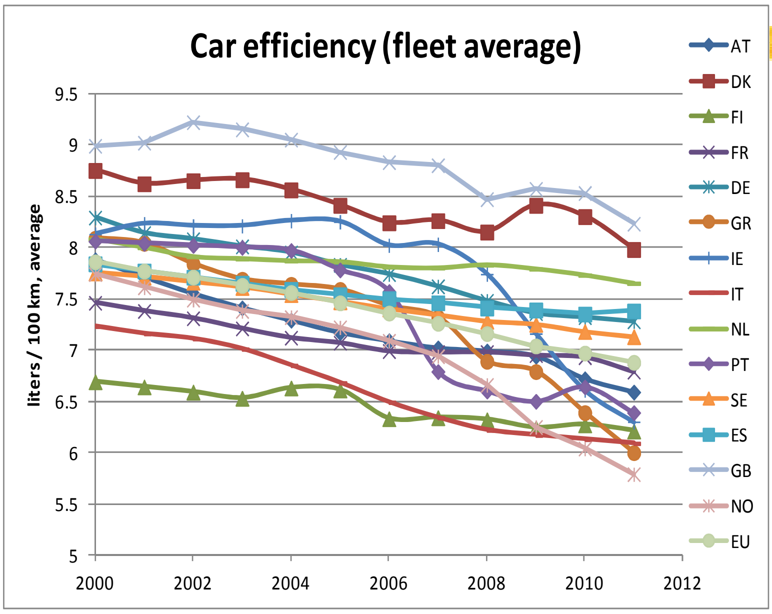


The ratio clearly above 1: gasoline taxation about 30% higher on average

An exception is UK

In general, downward trend, but still above 1 (about 20% on average in 2011)

Fact 3. Efficiency (liters/100Km) gains in the Fleet



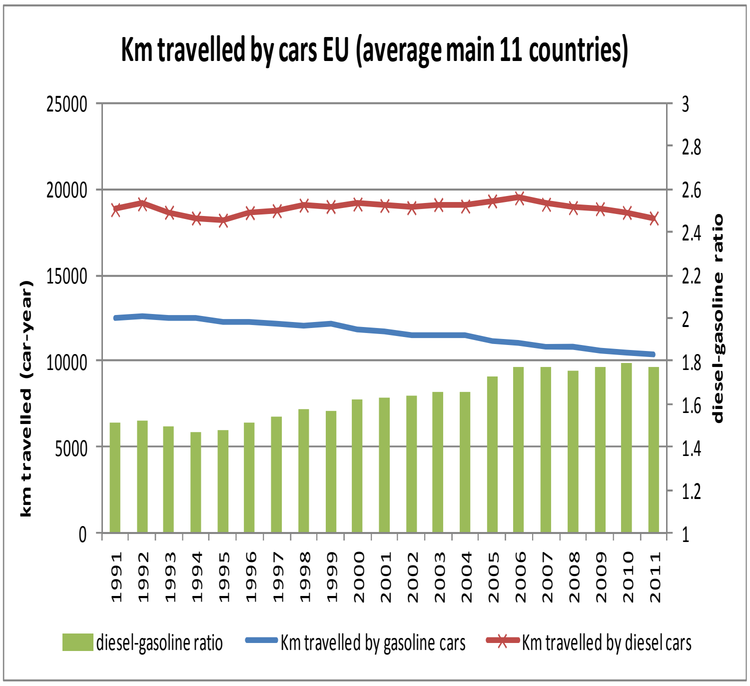
Fuel efficiency (liters/100km) gains in the period

Diesel is more efficient (17% more) than gasoline: 8.2 l/100km gasoline; 6.8 l/100km diesel (motivate and implication of dieselization: **good for reducing emissions**)

Other causes of Efficiency gains? renovation of the fleet + overall (common) technological change

Efficiency gain														
AT	DK	FI	FR	DE	GR	IE	IT	NL	ES	SE	GB	NO	PT	EU
11.2	6.4	4.3	5.9	8.6	20.4	19.3	10.7	3.5	16.5	3.9	5.8	7.9	18.2	8.9

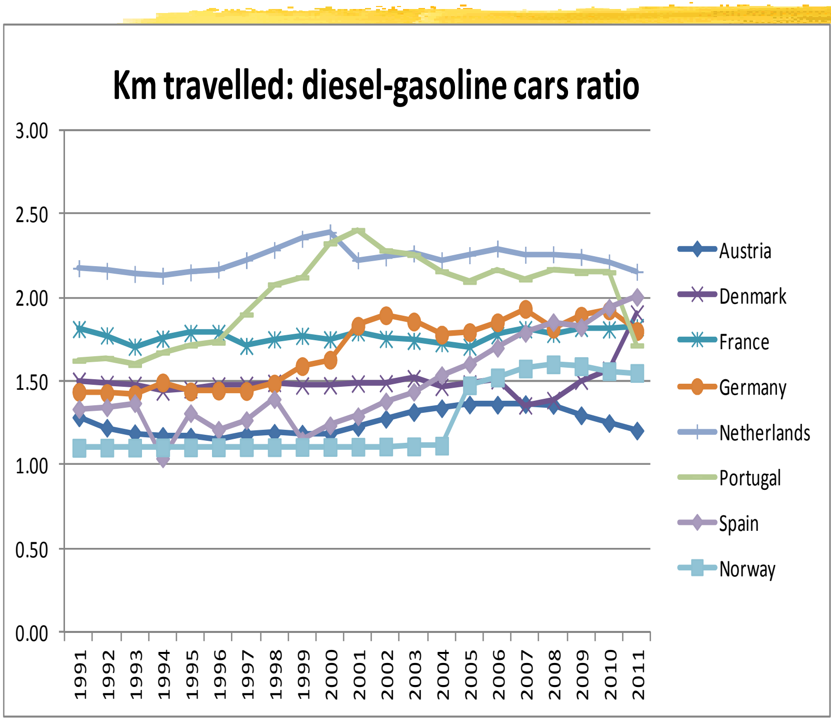
Fact 4. Increase in Km travelled (rebound)



Km travelled is higher for diesel than for gasoline.

Moreover, the ratio has increased, on average, from 1.4 (1991) to about 1.8 (2011)

Fact 4. Increase in Km travelled (rebound)

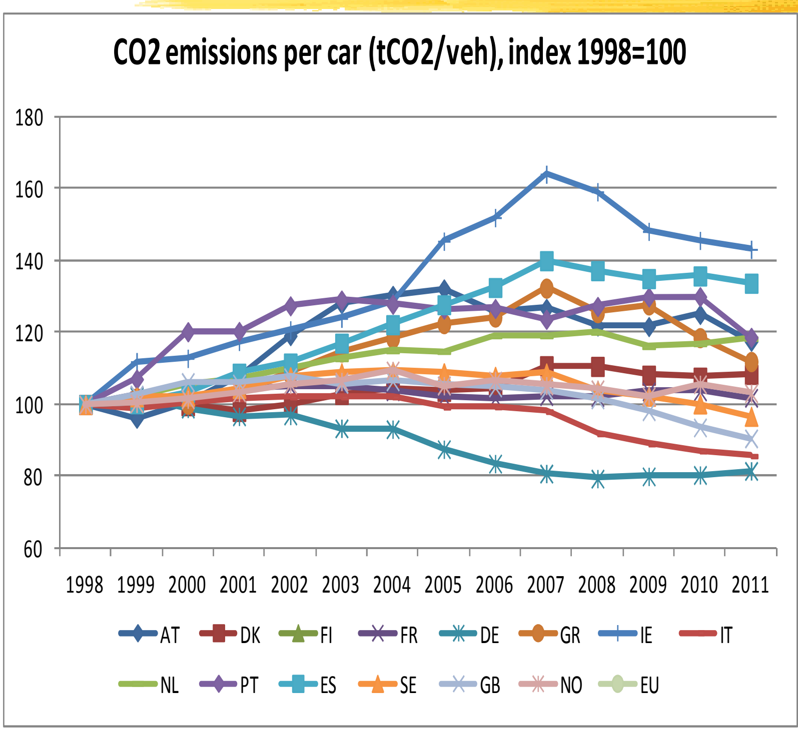


It is a common observation in all (richest) EU countries: the ratio > 1& has increased (highest increase in Spain: 1.1 (1998) to 2.0 (2011)

Rebound effect: more efficient and tax incentives (cheaper diesel) increase Km travelled (indirect effect). The root of the rebound is the change in the mix of cars

Other cause of that increase? increase in the stock of cars and/or in overall mobility (global macro factors);

Fact 5. CO2 emissions of (total) cars has increased



Expected output of **<u>dieselization</u>**: more efficiency, less CO2 emissions (specially per car)

However, in spite of efficiency gains, we observe an increase in overall emissions (in per capita) …

Moreover, emissions per car have increased in most countries

CO2 emissions and dieselization

IMPORTANT NOTE:

- Liters/Km is about 17% smaller for diesel (efficiency in fuel)
- However, CO2/liters is about 12-13% bigger for Diesel …
- As a result: **CO2/Km is just about 4-5% smaller for diesel!!!**

Not considering the rebound and other potential indirect effects of dieselization, **Diesel is good for fuel efficiency (reduce oil dependence); however, it is not that good for CO2 abatement**

CO2 emissions and dieselization

Summing-up:

- At least, 2 opposite effects on emissions of dieselization:

  i) positive: efficiency (liters/km; and less clear CO2/Km), direct impact (partial equilibrium)

  ii) negative: rebound, indirect effects (general equilibrium)
- Are they off-setting each other?
- Any winner?

CO2 emissions and dieselization

$$CO2 = \phi_1 f_1 \tilde{n}_1 q_1 + \phi_2 f_2 \tilde{n}_2 q_2$$

$$CO2 = \frac{CO2}{liters}\frac{liters}{km}\frac{km}{car}car$$

$$\Rightarrow$$

$$CO2 = \tilde{n}q\left(\phi_2 f_2 + s_1\left(\phi_1 f_1 - \phi_2 f_2\right)\right),$$

$$s_j = \tilde{n}_j q_j / \tilde{n}q, s_1 + s_2 = 1$$

$$f1 < f2; (ratio \simeq 0.83)$$

$$\phi_1 > \phi_2; (ratio \simeq 1.13)$$

$$\phi_1 f_1 < \phi_2 f_2 : (ratio \simeq 0.96)$$

D: meassure (or proxy) of dieselization

$$\partial CO2 / \partial D = \underbrace{\underbrace{\frac{\partial(\tilde{n}q)}{\partial D}}_{>0}\underbrace{\left(\phi_1 f_1 s_1 + \phi_2 f_2 (1 - s_1)\right)}_{>0}}_{\text{Rebound effect}} + \underbrace{\underbrace{\tilde{n}q\frac{\partial(s_1)}{\partial D}}_{>0}\underbrace{\left(\phi_1 f_1 - \phi_2 f_2\right)}_{<0}}_{\text{Efficiency effect<0}},$$

2. The empirical evidence (short panel): dieselization Vs. CO2 emissions? The efficiency Vs. rebound trade-off

CO2 emissions and dieselization: a DPD model

Estimated results of a DPD model using a short- and incomplete panel of data for main EU countries: pooled-OLS; fixed effect; GMM-approach

$$GCO2_{it} = \alpha_i + \lambda \cdot trend + \beta CO2_{it-1} + \delta_1 GY_{it} + \delta_2 Gq_{it} + \lambda GD_{it} + \varepsilon_{it}$$

Per capita CO2 emissions annual growth rate in passenger cars

Common trend: i.e., tech. improvement

Error, unobserved term

Control for scale and economic cycles (GDP) and the size of the fleet (stock of cars)

Constant term and potential fixed effect

Diezelization meassure (i.e.,)
1. Fuel diesel/Fuel gaso
2. Prices (incl. taxes)

Key: the sign of λ (capture the sum of efficiency and rebound)

Dynamic term control for initial CO2 technology of cars and conditional convergence

CO2 emissions and dieselization: a DPD model

Endogeneity problems (of CO2t-1, GDP and energy regressors) … use IV approach …

- Our (best) proposal: **system GMM** (Arellano & Bover; Blundell & Bond) … (GMM-dif is not appropriate when variables show strong inertia)

- **Take care about inference problems** (Roodman warning): i) use **panel-robust standard errors variance-covariance** matrix; ii) use **Windmeijer** (2005) small sample correction; iii) reduce the number of instruments ('collapse' the matrix of instruments or use principal components to reduce dimension, etc.)

- However, **system-GMM shows also problems** (inestability of estimation to the use of instruments and efficiency problems) … conservative strategy: show results using alternative econometrics (pooled OLS, FE and RE) and **check for robustness**

Estimation results

Unbalanced panel (max. 161 obs.): main EU countries (Aus, Bel, Den, Ger, Fra, Gre, Spa, Ita, Por, Fin, Swe, Nor, UK); time: 1998-2011

	OLS-pool		Fixed effect (within)		System GMM 2 stage, collapse instr.	
log co2(-1)	-0.0071	0.0022	-0.0731**	-0.1118***	-0.02974	-0.0165
	0.01617	0.01167	0.0321	0.0266	0.0672	0.2097
gy (GDP)	0.2061*	0.06912	0.2247*	0.08128	0.2354	-0.08368
	0.1122	0.1155	0.112	0.1256	0.2553	0.1511
gq (Fleet)	0.5267**	0.6641	0.5103*	0.3952	0.5352**	0.5163***
	0.2225	0.2139***	0.2905	0.2824	0.2671	0.1952
gpt (relative prices	0.1211***	--	0.1093**	--	0.1108*	--
	0.04029	--	0.0437	--	0.0638	--
gfuel (relative fuel)		0.1707***	--	0.1989***		0.2975***
		0.0506	--	0.0512		0.0802
trend (linear)	-0.00178**	-0.00288***	-0.001	-0.0024*	-0.0012	0.0036***
	0.0008	0.00095	0.0013	0.00127	0.0009	0.00096
r2	0.2966	0.3446	0.3082	0.3626		
obs	137	161	137	161		
num groups					13	14
num. instruments					14	14
Hansen (p-value)					0.377	0.452

Estimation results

Two further analysis (not shown):

1. Results remain when estimating the model in growth rates (exclude the log-co2 dynamic term)

2. The channel is through fuel consumption … including overall energy consumption into the model turns the coefficient of 'dieselization' non-significant in most cases or reduce the magnitude of their coefficients

3. A neoclassical dynamic model with gasoline and diesel cars: optimal fuel (gasoline-diesel) tax policy (no macro-theoretical papers about this issue)

Part 3. The model

Is the fuel (gasoline-diesel) tax policy favoring dieselization be optimal? We need a model (very preliminary).

- We build a neoclassical model with durable goods (diesel & gasoline cars) generating services for their use to households: diesel (j=1) and gasoline (j=2).
- Emissions are generated as a by product of fuel consumption.
- There is also a government that levies a variety of fiscal tools that affect the decision of cars ownership and utilization.

Part 3. The model

- Describe the economy: preferences, technology, resources
- Solve the competitive equilibrium allocation: the household, firms, car manufactures and refinery
- Solve the efficient allocation: the planner problem.
- Obtain Pigouvian taxation
- Calibrate the economy & simulate the s.s. (in progress)
- Simulate the transition under technological, fuel prices and fiscal policy shocks (Impulse Response Functions, IRF) (in progress)

Some Notation

The accumulation law of cars:

$$q'_j = x_j + (1 - \alpha_j)\, q_j$$

qj: the stock of vehicles (the fleet)
xj: the flow of new cars purchases

The cost of driving:

$$F_1 = f_1 \tilde{n}_1 q_1,$$
$$F_2 = f_2 \tilde{n}_2 q_2,$$
$$M = m_1 \tilde{n}_1 q_1 + m_2 \tilde{n}_2 q_2.$$

ñj: the mileage of a j-type vehicle (km/car)
fj: liters of fuel *j* per kilometer (fuel efficiency).
mj: maintenance & repair services per km.

fj and *mj* may depend on technology: improvements in energy efficiency may reduce *fj*, or cars improvements may reduce *mj (we assume exogenous)*

CO2 emissions

- Emissions is a by-product of fuel consumption, scaled by a factor ϕ1 and ϕ2 (CO2 emissions/liters of fuel)

$$E = \phi_1 f_1 \tilde{n}_1 q_1 + \phi_2 f_2 \tilde{n}_2 q_2$$

- The stock of pollution (CO2 particles) accumulates follows a standard process (δz is natural CO2 depreciation, absorption or capture):

$$Z' = (1 - \delta_z)\, Z + E.$$

RECALL: while f1<f2; ϕ1>ϕ2 … however, still: f1ϕ1<f2ϕ2

Preferences

The economy is inhabited by infinitely lived, representative households with preferences in terms of consumption, *c*, direct services from cars, *s*, and hours worked (negative), *h* in the sector of final goods.

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t, s_t, h_t) \right\}$$

The two type of vehicles (j=1,2) render unit services ($\chi j>0$) to their users: depends on qj and on their use, $\tilde{n}j$ (km-travelled/car)

$$s = \chi_1 q_1 \tilde{n}_1^{\varsigma} + \chi_2 q_2 \tilde{n}_2^{\varsigma}$$

where $0 < \zeta < 1$ shows that using cars too intensely has diminishing returns: it is better to use the fleet less intensely by having more cars.

Technology

3 types of goods are produced in the economy:

- Final good (y);
- Durable goods (cars: xj, j=1,2): the same factory produces both cars
- Fuel (diesel & gasoline, Fj, j=1,2): a refinery that uses crude oil to generate both gasoline and diesel

- All sectors live in a competitive framework, price-takers, maximize profits and households are their final owners (thus, they receive their possible profits)

Technology: final consumption good

$$y_t = A\ e^{-\varphi Z}\ \widetilde{h}^{\theta} k_y^{1-\theta}$$

$$\widetilde{h} = h^{\mu} s^{1-\mu}$$

$$s = \chi_1 q_1 \widetilde{n}_1^{\varsigma} + \chi_2 q_2 \widetilde{n}_2^{\varsigma}$$

2 Novelties:

1. Emissions deters the production possibility frontier (Golosov et al. 2012)

2. Labor in efficiency units: assumes certain degree of complementarity between durables consumption and labor supply (Fisher, 2007):
   - if μ=1 makes consumption of durables decrease in response to a positive shock to TFP, a prediction NOT supported by the data.
   - Instead, assuming μ<1 instead helps the model to reconcile with data.

Technology: the final good problem

$$\max_{(\widetilde{h},k)} \left[A\ e^{-\varphi Z}\ \widetilde{h}^{\theta} k_y^{1-\theta} - W\widetilde{h} - Rk_y\right]$$

Maximize profits: real prices equal to marginal productivity

$$\begin{aligned} W(\zeta) &= F_{\widetilde{h}} = A\theta\left(k/\overline{h}\right)^{1-\theta} = \theta y/\overline{h}, \\ R(\zeta) &= F_k = A(1-\theta)\left(\overline{h}/k\right)^{\theta} = (1-\theta)\, y/k. \end{aligned}$$

Profits are zero because of CRE in h & ky

Technology: Cars

Cars are produced in a **single factory** which manufactures a bundle of a **single model** of vehicle with 2 different engines: **diesel** and **gasoline** combustion

Only use technology and capital (the sector is strongly competitive)

$$\max_{(k_{x1},k_{x2})} \left[P_{x1}x_1 + P_{x2}x_2 - R\left(k_{x1}+k_{x2}\right)\right]$$

$$\begin{aligned} x_1 &= a_1 k_{x1}^{\theta_x}, \\ x_2 &= a_2 k_{x2}^{\theta_x}, \end{aligned}$$

Factor's demand functions:

$$\begin{aligned} P_{x1}a_1\theta_x k_{x1}^{\theta_x - 1} &= R \Leftrightarrow P_{x1} = R a_1^{-1}\theta_x^{-1}k_{x1}^{1-\theta_x} = R\frac{k_{x1}}{\theta_x x_1}, \\ P_{x2}a_2\theta_x k_{x2}^{\theta_x - 1} &= R \Leftrightarrow P_{x2} = R a_2^{-1}\theta_x^{-1}k_{x2}^{1-\theta_x} = R\frac{k_{x2}}{\theta_x x_2}, \end{aligned}$$

Technology: Cars

$$\frac{P_{x1}}{P_{x2}} = \frac{a_2}{a_1}\left(\frac{k_{x1}}{k_{x2}}\right)^{1-\theta_x} = \left(\frac{a_2}{a_1}\right)^{\frac{1}{\theta_x}}\left(\frac{x_1}{x_2}\right)^{\frac{1-\theta_x}{\theta_x}}$$

The supply elasticity is given by $(1-\theta_x)/\theta_x$ … for calibration, θx is prox. to 0 (supply is strongly elastic: generates volatile series of xj as observed)

Because of DRS, **this factory generates positive profits** which are returned to the ultimate owners of the factory (the households)

$$B = \sum_{j=1,2}\left(1-\theta_x\right)p_{xj}x_j$$

Technology: the Refinery

Fuels are produced in a competitive refinery which uses crude oil, *o*, and capital, KFj, under a CRS technology (zero profits generated)

$$\max_{(o_1,o_2,k_{F1},k_{F2})} \left[p_{F1}F_1 + p_{F2}F_2 - p_o\left(o_1+o_2\right) - R\left(K_{F1}+K_{F2}\right)\right]$$

$$F_1 \equiv b_1\ o_1^{\theta_F} K_{F1}^{1-\theta_F},$$

$$F_2 \equiv b_2\ o_2^{\theta_F} K_{F2}^{1-\theta_F}.$$

Demand functions for *KFj*:

$$p_o\left(\zeta\right) = p_{F1}\left(\zeta\right)\theta_F \frac{F_1}{o_1} = p_{F2}\left(\zeta\right)\theta_F \frac{F_2}{o_2},$$

$$R\left(\zeta\right) = p_{F1}\left(\zeta\right)\left(1-\theta_F\right)\frac{F_1}{K_{F1}} = p_{F2}\left(\zeta\right)\left(1-\theta_F\right)\frac{F_2}{K_{F2}}.$$

Variations in the price of crude oil (i.e., a shock) are transmitted to the final prices in exactly the same proportion (consistent with data, recall below).

Technology: the Refinery

$$\frac{p_{F1}\left(\zeta\right)}{p_{F2}\left(\zeta\right)} = \frac{b_2}{b_1}$$

Variations in the price of crude oil (i.e., a shock) are transmitted to final prices in exactly the same proportion (consistent with data).

The government & taxes

The government uses 4 taxes that might distort agents decisions:

1. Taxation on X_1; X_2 that affect the final price of new vehicles of type j

2. Taxation on fuel F_2; F_2 that affect the operation cost of cars

Government balances its budget period by period by using time-varying lump sum transfers , *TR*:

$$\sum_{j=1,2} \left[p_{xj} \tau_{xj} x_j + \tau_{fj} f_j \tilde{n}_j q_j \right] = TR.$$

The household's problem

Household solves a recursive problem (take W, R, TR, B, prices & taxes as given)

$$V(\zeta, k, q) = \max_{\{c,i,h,x_1,x_2,\tilde{n}_1,\tilde{n}_2,q_1',q_2',k'\}} u(c, s, h) + \beta \mathbb{E}\left[V(k', q')\right]$$

$$c + i + \sum_{j=1}^{2} \left[(1 + \tau_{x,j}) p_{xj} \cdot x_j + \overline{tc}_j q_j \right] = \widetilde{h} \cdot W + R \cdot k + TR + B$$

$$\overline{tc}_j \equiv \overline{mc}_j \tilde{n}_j + p_{TI}$$
$$\overline{mc}_j = (p_{F,j} + \tau_{F,j}) f_j + p_{MR} m_j$$

The total cost (*tcj*) of having a car is equal to a variant cost depending on its use (on ñj) + a fixed cost (tolls and insurance)

$$k' = i + (1 - \delta) k$$
$$q_1' = x_1 + (1 - \alpha_1) q_1$$
$$q_2' = x_2 + (1 - \alpha_2) q_2$$

The accumulation laws of state variables

Optimal conditions: a summary

Combining optimal conditions for i and k: '**optimal intertemporal** condition'

$$\begin{aligned} i &: \; u_c = \beta \mathbb{E}\left[V_k'\right], \\ k' &: \; V_k = R \cdot u_c + (1-\delta)\,\beta \mathbb{E}\left[V_k'\right] \end{aligned} \quad \longrightarrow \quad u_c = \beta \mathbb{E}\left[u_c'\left(R' + 1 - \delta\right)\right]$$

Combining conditions for h and i, we obtain the optimal intra-temporal conditions between h and c

$$W \cdot \mu \left(s/h\right)^{1-\mu} u_c + u_h = 0.$$

Optimal conditions: a summary

Optimal condition of **cars use** (mileage):

$$\overline{mc}_j u_c = \varsigma \chi_j \tilde{n}_j^{\varsigma - 1}\left[W\left(\zeta\right)\left(1-\mu\right)\frac{h^{\mu}}{s^{\mu}} u_c + u_s\right]$$

Marginal cost

Marginal benefits (include the productivity gains from using vehicles, due to its complementarity with labor).

And the relative mileage only depends on 2 ratios:

$$\frac{\tilde{n}_1}{\tilde{n}_2} = \left[\frac{\chi_1}{\chi_2}\frac{\overline{mc}_2}{\overline{mc}_1}\right]^{1/(1-\varsigma)} = \left[\frac{\chi_1}{\chi_2}\frac{\left(p_{F,2} + \tau_{F,2}\right) f_2 + p_{MR} m_2}{\left(p_{F,1} + \tau_{F,1}\right) f_1 + p_{MR} m_1}\right]^{1/(1-\varsigma)}$$

The elasticity of substitution between the mileage driven by diesel-gasoline cars (i.e., due to a differential shock in fuel taxes) (related to Rebound!):

$$ES = \frac{\partial\left(\tilde{n}_1/\tilde{n}_2\right)}{\partial\left(\overline{mc}_1/\overline{mc}_2\right)}\frac{\overline{mc}_1/\overline{mc}_2}{\tilde{n}_1/\tilde{n}_2} = -\frac{1}{1-\varsigma} < 0$$

Optimal conditions: a summary

The final set of conditions relates the optimal dynamics of the stock of vehicles, *qj*, with the purchase of new cars, *xj*

$$
\begin{aligned}
x_j &: \quad \beta \mathbb{E}\left[V'_{qj}\right] = (1+\tau_{x,j})\, p_{xj} u_c, \\
q'_j &: \quad V_{qj} = \chi_j \tilde{n}_j^{\varsigma}\left[u_s + u_c W (1-\mu)(h/s)^{\mu}\right] - u_c \overline{tc}_j + (1-\alpha_j)\beta \mathbb{E}\left[V'_{qj}\right]
\end{aligned}
$$

Combining: We obtain the optimal condition associated with the purchasing of new cars,

$$
\begin{aligned}
(1+\tau_{x,j})\, p_{Xj} u_c \quad = \quad & \beta \mathbb{E}\left\{\chi_j \left(\tilde{n}'_j\right)^{\varsigma}\left[u'_s + u'_c W' (1-\mu)(h'/s')^{\mu}\right]\right. \\
& \left. + \left[(1-\alpha_j)\left(1+\tau'_{x,j}\right) p'_{Xj} - \overline{tc}'_j\right] u'_c\right\}.
\end{aligned}
$$

Optimal conditions: a summary

Using a sequential notation, we can iterate forward:

$$
\begin{aligned}
(1+\tau_{xj,0})\, p_{Xj,0} \quad = \quad & \beta \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (1-\alpha_j)^t \left\{\chi_j \tilde{n}_{j,t+1}^{\varsigma}\left[\frac{u_{s,t+1}}{u_{c,0}} + (1-\mu) W_{t+1} \frac{h_{t+1}^{\mu}}{s_{t+1}^{\mu}} \frac{u_{c,t+1}}{u_{c,0}}\right]\right. \\
& \left. - \left(\overline{mc}_{j,t+1} \tilde{n}_{j,t+1} + p_{TI,t+1}\right) \frac{u_{c,t+1}}{u_{c,0}}\right\},
\end{aligned}
$$

A forward looking condition: the price of a new car of type *j* reflects the future stream of services minus the future stream of its opportunity cost, expressed in utility units

Optimal conditions: a summary

Finally, its ratio:

$$\frac{(1+\tau_{x1,0})\,p_{X1,0}}{(1+\tau_{x2,0})\,p_{X2,0}} = \frac{\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (1-\alpha_1)^t \left\{ \chi_1 \tilde{n}_{1,t+1}^{\varsigma} \left[u_{s,t+1} + (1-\mu)\, W_{t+1} \frac{h_{t+1}^{\mu}}{s_{t+1}^{\mu}} u_{c,t+1} \right] - \overline{tc}_{1,t+1} u_{c,t+1} \right\}}{\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (1-\alpha_2)^t \left\{ \chi_2 \tilde{n}_{2,t+1}^{\varsigma} \left[u_{s,t+1} + (1-\mu)\, W_{t+1}^{\mu} \frac{h_{t+1}^{\mu}}{s_{t+1}^{\mu}} u_{c,t+1} \right] - \overline{tc}_{2,t+1} u_{c,t+1} \right\}}$$

Following a decrease in the price (incl. taxes) of diesel vehicles (relative to the price of gasoline vehicles), household's optimal choice moves resources from the services of gasoline cars to those of diesel cars (**replacement effect**).

The competitive equilibrium

Given a government policy, $\{\tau_{x1}, \tau_{x2}, \tau_{F1}, \tau_{F2}, TR\}$, a recursive equilibrium is a set of decision rules,

$$\left\{ c, \left\{ x_j, \tilde{n}_j, q_j' \right\}_{j=1,2}, h, k' \right\},$$

and factor and other prices (fuel, new vehicles, maintenance and repairs, and tolls and cars insurances)

$$\{W, R, p_{x1}, p_{x2}, p_{F1}, p_{F2}, p_{MR}, p_{TI}\},$$

such that:

The competitive equilibrium

1. Given the government policy and factor prices, households follows their optimal rules
2. The final good, the cars factory and refinery solve their problems (i.e., factor prices are marginal productivities), $p_{MR} = \eta_{MR}$; $p_{TI} = \eta_{TI}$ (marginal costs, exogenous).
3. Benefits from the cars factory are returned to households: $B = \sum_{j=1,2} (1-\theta_x) p_{xj} x_j$
4. The government satisfies its budget constraint: $TR = \sum_{j=1,2} \{\tau_{fj} f_j \tilde{n}_j q_j + \tau_{xj} p_{xj} x_j\}$
5. Markets clear:

$$
\begin{aligned}
h^d &= h \\
k &= k_y + k_{x1} + k_{x2} \\
f_j \tilde{n}_j q_j &= F_j = b_j o_j \\
x_j &= a_j k_{xj}^{\theta_x}
\end{aligned}
$$

Walrash law

$$c + i + \sum_{j=1}^{2} [p_o o_j + \eta_{MR} m_j \tilde{n}_j q_j + \eta_{TI} q_j] = f(\widetilde{h}, k_y)$$

The efficienct allocation problem

$$V(\zeta, k, q) = \max_{i_{xj}, i_y, i_{Fj}, h, \tilde{n}_j, o_j, q_j', k_{xj}', k_y', k_{Fj}'} u(c, s, h) + \beta \mathbb{E}\left[V\left(\zeta', k', q'\right)\right]$$

$$c = f(\widetilde{h}, k_y) - i - \sum_{j=1,2} (p_{ot} o_{jt} + \eta_{MRt} m_j q_{jt} \tilde{n}_{jt} + \eta_{TI} q_{jt})$$

$$k = k_y + k_{x1} + k_{x2} + k_{F1} + k_{F2}$$

$$f_j \tilde{n}_j q_j = b_j o_{jt}^{\theta_F} k_{Fj}^{1-\theta_F}$$

$$q_j' = a_j k_{xj}^{\theta_x} + (1-\alpha_j) q_j,\ j = 1, 2$$

$$k' = i + (1-\delta) k$$

$$Z' = (1-\delta_z) Z + E$$

$$E = \phi_1 f_1 \tilde{n}_1 q_1 + \phi_2 f_2 \tilde{n}_2 q_2$$

$$i = i_y + i_{x1} + i_{x2} + i_{F1} + i_{F2}$$

The efficienct allocation problem

Basically, we have 6 optimal conditions: i) optimal intertemporal (ct Vs. ct+1); ii) h vs. c; iii) ñ1 vs. ñ2; iv) o1 Vs. o2; v) x1 vs. x2; vi) the resource constraint

It is easy to show that i), ii) and vi) coincide with CE (for any tax) …. However, it is unclear for iii), iv) and v)

We next compare, for CE and efficient allocation, those optimal conditions related with iii), iv) and v)

Piguvian taxes

First: ñ1 Vs ñ2

1. The CE:

$$\left(\frac{p_o}{b_j} + \tau_{F,j}\right) f_j \tilde{n}_j u_c + m_j \eta_{MR} \tilde{n}_j u_c = \varsigma \chi_j \tilde{n}_j^{\varsigma} \left[u_s + (1-\mu)\,\theta \frac{y}{s} u_c\right]$$

2. The Efficient:

$$u_c p_o \frac{f_j}{b_j} \tilde{n}_j - \beta \phi_j f_j \tilde{n}_j \mathbb{E}\left[V_Z'\right] + m_j \eta_{MR} \tilde{n}_j u_c = \varsigma \chi_j \tilde{n}_j^{\varsigma} \left[u_s + (1-\mu)\,\theta \frac{y}{s} u_c\right]$$

Therefore, the piguvian tax rate must satisfy:

$$\left(\frac{p_o}{b_j} + \tau_{F,j}\right) f_j \tilde{n}_j u_c \quad = \quad u_c p_o \frac{f_j}{b_j} \tilde{n}_j - \beta \phi_j f_j \tilde{n}_j \mathbb{E}\left[V_Z'\right]$$

Piguvian taxes

$$\tau_{F,j} = -\frac{\beta\phi_j \mathbb{E}\left[V_Z'\right]}{u_c}$$

Setting Piguvian taxes, Cars owners must pay for the social damage of burning fossil fuels of type j (externality) (Notice: E(V')<0)

Piguvian taxes

Using the expression for emissions damage (optimal condition from the planner), Vz,

$$V_Z = -\varphi A e^{-\varphi z}\tilde{h}^{\theta} k_y^{1-\theta} u_c + \beta(1-\delta_z)V_Z'$$

we can rewrite the optimal tax rate … and in steady-state:

$$\tau_{Fj,t} = \frac{\phi_j \varphi}{1-\delta_g}\, \mathbb{E}_t \sum_{n=1}^{\infty} \beta^n \left(1-\delta_g\right)^n \frac{u_{C,t+n}}{u_{C,t}} Y_{t+n}. \qquad \tau_{Fj,ss} = \phi_j \frac{\beta\varphi}{1-\beta\left(1-\delta_g\right)} Y_{ss}$$

The marginal social damage and the optimal tax are higher:

i) the higher the scale of emissions from fossil fuel combustion by cars j: $\phi j \cdot \varphi$

ii) the higher the residence time of CO2 in the atmosphere (the smaller δ_z);

iii) the higher is β (care more about the future)

iv) factors affecting s.s. of pc income

v) it does not depend on energy efficiency, fj !!!!!

Piguvian taxes

Moreover, its ratio is:

$$\frac{\tau_{F1}}{\tau_{F2}} = \frac{\phi_1}{\phi_2}$$

It does not depend on $f1/f2$ … that this ratio is lower than one was a motivation of the *dieselization* policy …

Moreover, although $f1<f2$, $\phi 1>\phi 2$ … hence, **the optimal ratio is totally the opposite we observe in reality**

Initially, we would expect something like $\phi 1 f1/\phi 2 f2$, which is indeed lower than one (though higher than $f1/f2$) … at least the direction of what we observe in reality is the correct one …

Indeed, we can prove that this would be the optimal ratio if is applied over mobility ($\tilde{n}jqj$) instead of over fuel consumption … but this is not what is being done!

Piguvian taxes

Compare conditions for qj and xj to obtain the optimal txj

The planner:

$$V_{qj} = \chi_j \tilde{n}_j^{\varsigma}\left[u_s + u_c\theta(1-\mu)\tfrac{y}{s}\right] - u_c\left(p_o\tfrac{f_j}{b_j}\tilde{n}_j + \eta_{MR}m_j\tilde{n}_j + \eta_{TI}\right) + (1-\alpha_j)\left[V_k - (1-\delta)u_c\right]\left(a_j\theta_x k_{xj}^{\theta_x - 1}\right)^{-1}$$
$$\beta f_j \phi_j \tilde{n}_j \mathbb{E}\left[V_Z'\right].$$

The CE:

$$V_{qj} = \chi_j \tilde{n}_j^{\varsigma}\left[u_s + u_c W(1-\mu)(h/s)^{\mu}\right] - u_c\left(\left(\tfrac{p_o}{b_j} + \tau_{F,j}\right) f_j\tilde{n}_j + \eta_{MR}m_j\tilde{n}_j + \eta_{TI}\right) +$$
$$(1-\alpha_j)(1+\tau_{x,j})p_{xj}u_c$$

Equalize and, after tedious substitutions and setting optimal τFj, we lead to τxj=0 !!!

Important conclusion: τFj is enough to correct inefficiencies in the economy. Moreover, it does not generate any distortion in the Car's sector

Piguvian taxes

Equalize and, after tedious substitutions and setting optimal τFj, we lead to τxj=0!!!

Important conclusion: τFj is enough to correct inefficiencies in the economy.

Moreover, it does not generate any distortion in the Car's sector.

Piguvian taxes

An interesting exercise: suppose fuel taxes differ from optimal … hence:

$$\tau_{Xj} = \frac{1}{p_{Xj}}\left(\tau_{Fj} - \tau^{*}_{Fj}\right)\frac{1}{1-\beta(1-\alpha_j)} f_j \tilde{n}_j$$
$$p_{Xj} = R\frac{k_{x2}}{\theta_x x_2}$$

The only way to correct externality in emissions is setting fuel taxes at their optimal levels

When fuel taxes are not set at the optimal level, taxes on cars must react accordingly subsidizing when fuel taxes are low and viceversa

$$\tau_{Fj} > \tau^{*}_{Fj} \Rightarrow \tau_{Xj} > 0$$
$$\tau_{Fj} < \tau^{*}_{Fj} \Rightarrow \tau_{Xj} < 0$$

Dieselization, emissions, efficiency, replacement and rebound

Starting from the definition of total emissions:

$$E = \phi_1 f_1 \tilde{n}_1 q_1 + \phi_2 f_2 \tilde{n}_2 q_2$$

We can rewrite in terms of the share of diesel cars and the share of diesel miles drive per car (Sñ1; Sq1)

$$\frac{E}{\tilde{n}q} = \phi_2 f_2 \left(1 - S_{q1}\right) + \phi_2 f_2 S_{q1} S_{\tilde{n}1} + \left(\phi_1 f_1 S_{q1} - \phi_2 f_2\right) S_{\tilde{n}1}$$

A dieselization measure increases $S_{\tilde{n}1}$ and S_{q1}. Hence, we have that emissions per total Km driven changes due to:

1. $\phi_2 f_2 \left(1 - S_{q1}\right) < 0$: replacement effect, good for emissions
2. $\phi_2 f_2 S_{q1} S_{\tilde{n}1} > 0$: rebound effect, bad for emissions
3. $\left(\phi_1 f_1 S_{q1} - \phi_2 f_2\right) S_{\tilde{n}1} < 0$: efficiency effect, good for emissions

CE Calibration

$$u(c,s,h) = \ln(c) + \psi_s \ln(s) - \psi_h \frac{h^{1+1/\nu}}{1+1/\nu}$$

Use s.s. equilibrium conditions + several data matching with variables/parameters of the model: recover parameter values (details in the paper)

Table 1: Targets and parameters

National accounts			Prices and taxes		
Interest rate (yearly)		0,040	Diesel price	p_{F1}	0,522
Labor income share	θ	0,667	Gasoline price	p_{F2}	0,483
Fraction of hour worked	H	0,310	Price of maintenance and repairs	p_{MR}	1,000
Stationary output	Y	1,000	Diesel tax	τ_{F1}	0,435
Consumption ratio	C/Y	0,700	Gasoline tax	τ_{F2}	0,550
Investment ratio	I/Y	0,200	Sale tax on new diesel cars	τ_{X1}	0,200
Fuel consumption ratio		0,030	Sale tax on new gasoline cars	τ_{X2}	0,200
Insurances and tolls ratio		0,005			
Frisch elasticity of labor supply	ν	0,72			
Fischer complementarity hours-cars	μ	0,98			
Vehicles fleet			**Other vehicles' properties**		
Stock of diesel cars (%)	Q_1	0,455	Relative efficiency (GPM)	f_1/f_2	0,831
Stock of gasoline cars (%)	Q_2	0,545	Fraction of fuel within opperating costs		[0.6, 0,7]
Relative mileage (diesel/gasoline)	$\tilde{n}_1/\tilde{n}_2$	1,416	Relative utility (diesel/gasoline)	χ_1/χ_2	0,913

CE Calibration

Table 2: Summary of calibrated values

Definition	Parameter	Value
Time discount rate	β	0,9615
Labor income share	θ	0,6667
Depreciation rate	δ	0,06
Willingness to work	ψ_H	15,315
Willingness to drive	ψ_S	0,1364
Substituibility diesel-gasoline mileage	ς	0,5098
Gallons per miles (diesel cars)	f_1	0,0459
Gallons per miles (gasoline cars)	f_2	0,0553
Maintenance need (diesel cars)	m_1	0,0188
Maintenance need (gasoline cars)	m_2	0,0245
Depreciation rate of diesel cars	α_1	0,0649
Depreciation rate of gasoline cars	α_2	0,0649
Capital-to-GDP	K/Y	3,3333
Maintenance and repairs expenditures	M/Y	0,0255
New cars investment expenditures		0,0395
New diesel cars purchases	X_1	0,0295
New gasoline cars purchases	X_2	0,0354
Price of insurances and tolls	p_{TI}	0,005
Price of new diesel cars	p_{X1}	0,6398
Price of new gasoline cars	p_{X2}	0,5836
Lump sum transfers	TR	0,0373

S.S. simulation

A change in taxes

A change in crude oil taxes

An improvement in technology

… To be completed …

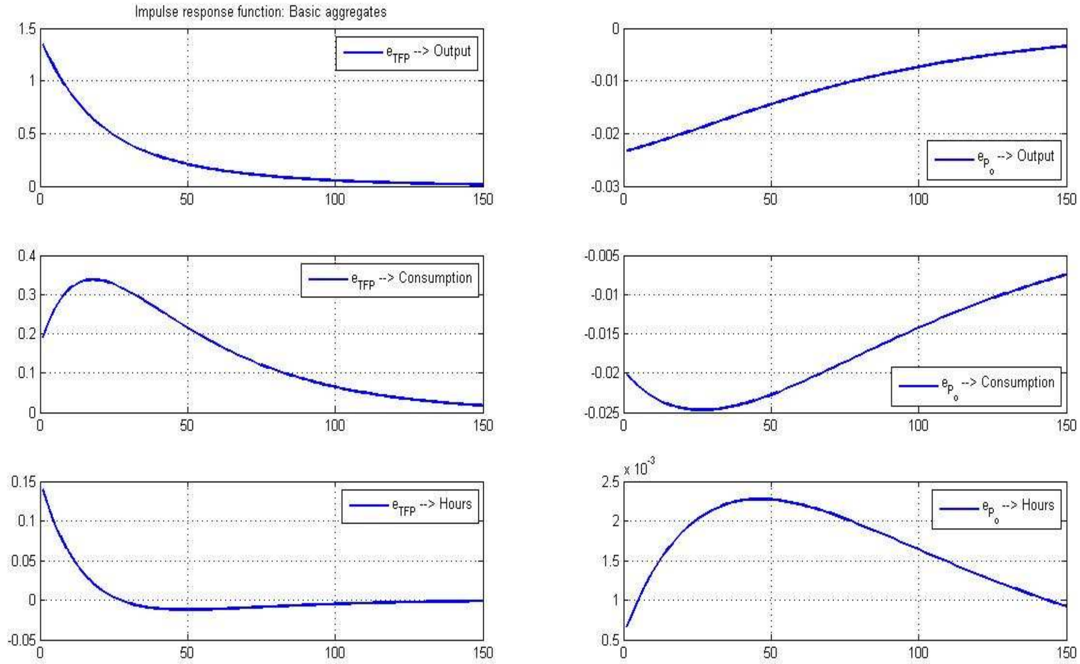
Some Impulse Response exercise

TFP positive Shock **Po positive shock**

Y

C

h



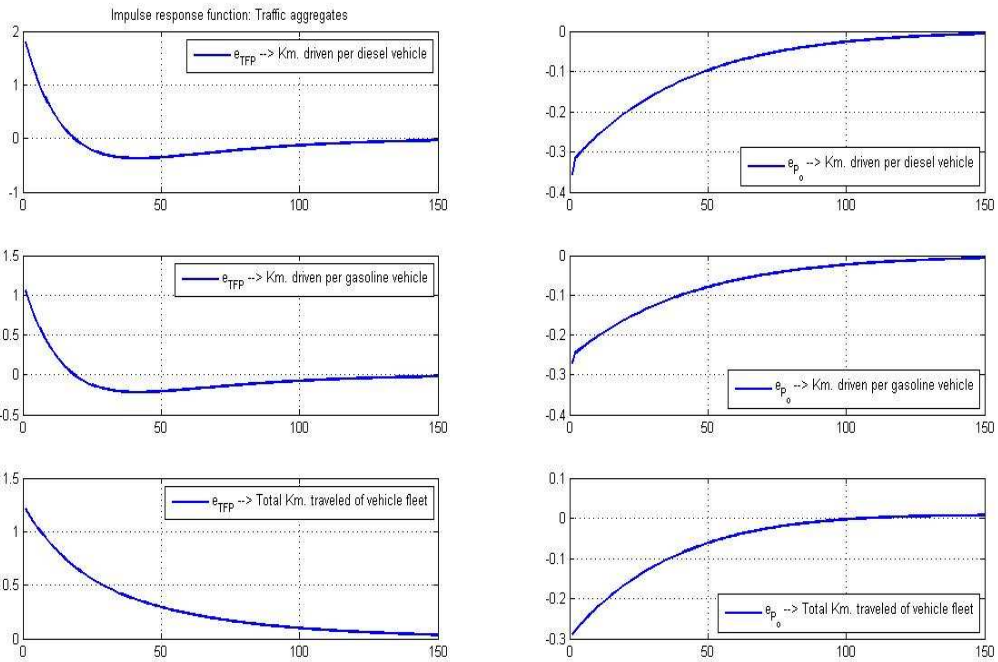
Some Impulse Response exercise

TFP positive Shock **Po positive shock**

ñ1

ñ2

ñ1q1 + ñ2q2



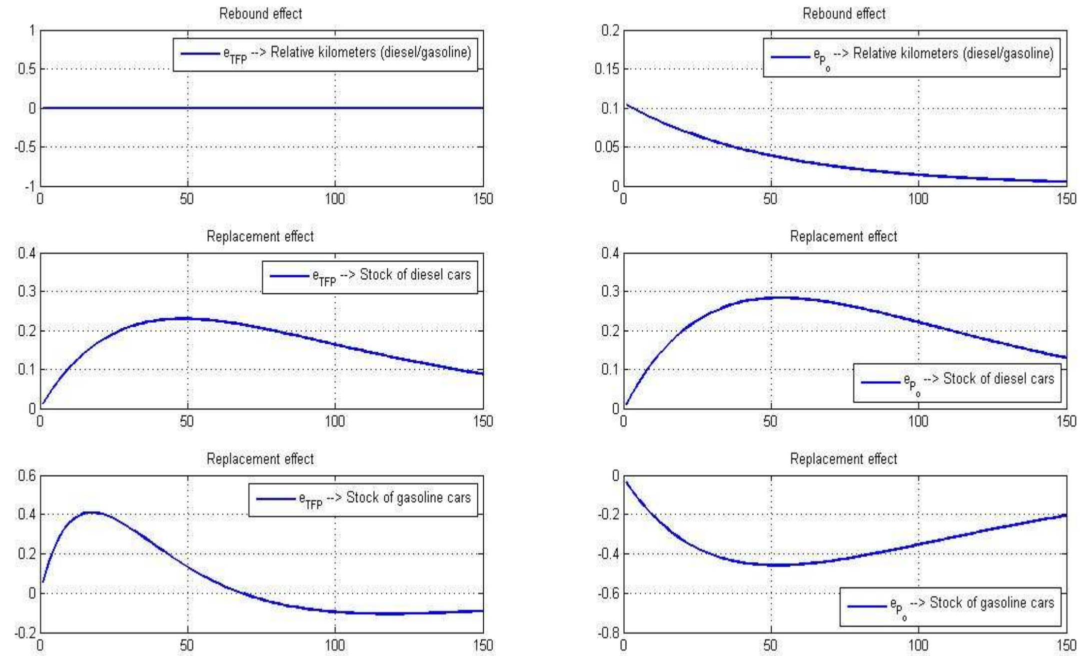
Some Impulse Response exercise

TFP positive Shock **Po positive shock**

ñ1/ñ2

q1

q2

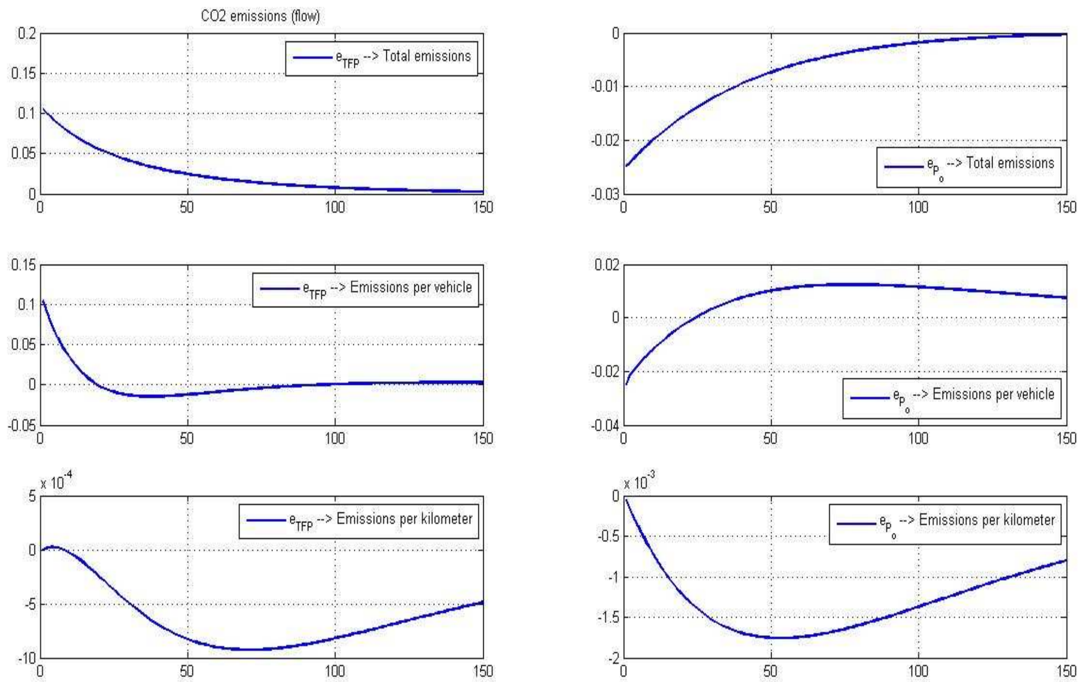


Some Impulse Response exercise

Co2

Co2/ cars

Co2/ km



Conclusions

- A major component of the European strategy for reducing fuel use and CO_2 emissions from the light duty vehicle sector has been a shift to diesel technology
- Europe has been moving towards a majority diesel fleet since the European Commission encouraged lower taxes on diesel fuel. This is because diesel engines are more fuel efficient and burning less CO_2.
- The taxes have kept final diesel prices below gasoline in Europe. As a result, in the majority of countries: the percentage of diesel passenger cars has risen, diesel sales and diesel consumption shares have increased
- A European phenomenon: "Dieselization" … Environmental consequences?
- We must consider not only the initial efficiency effect, but also the replacement and the rebound impact
- Using a econometrics and a theretical model with durable goods (cars) and emissions, we find the dieselization policy has been highly inefficient