"Abatement Strategies and the Cost of Environmental Regulation: Emission Standards on the European Car Market"

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Introduction

- EU regulation on emission standard for passenger cars was announced in 2007 and became full binding in 2015.
- The paper studies firms' response to the emission standard and its welfare effects;

Background:EU Emission Standard

- The regulation sets a sales average of 130 g CO_2/km each calendar year. The target also depends on the vehicle weight.

$$\frac{\sum_{j \in fleet} q_j (e_j - f(w_j))}{\sum_{j \in fleet} q_j} \leq 130 \tag{1}$$

$$f(w_j) = a(w_j - w_0) \tag{2}$$

- Producers have to pay premiums for excess emissions: 5 euro per unit sold for he first excess g/km and increases to 95 euro per unit above 134 g/km.
- In 2007, average 146g/km, 1280 euro per vehicle.
- The official CO_2 emissions is determined by the New European Driving Cycle. (Official: lab test v.s. Actual: on road)

Background: Firms' Strategy

1. Mix-shifting: change pricing to shift the sales mix to vehicles with CO_2 emissions below the target;
2. Downsizing: releasing more fuel efficient vehicles;
3. Technology adoption: improving the fuel-efficiency of the vehicle fleet;
4. Gaming: improving the emissions as measured in official ratings without improving the actual emission on the road;

Research Overview

The paper:

- studies which strategies that automobile firms applies in response to the regulation using reduced-form regression.

  After the policy announcement, official emission reduce by 14%, 70% of which is explained by gaming. Technology adoption only explains 30%.

- quantifies the welfare effect of the policy through a structural model;

  The regulation decreases consumer surplus and profits: increases in costs from technology adoption beyond the willingness to pay for fuel consumption.

  The policy has small positive impacts when take indirect welfare effects into account.

- analyzes how the design of the regulation induced firms to choose these strategies;

Data

- Resource: JATO ANALYTICS, a market research firm
- Time period: 1998-2001
- Country: Belgium, France, Germany, Italy, Great Britian, The Netherlands, Spain
- The data set contains sales and product characteristics for each passenger car: brand (e.g. BMW)-body (e.g. SUV)-engine (fuel type and engine performance) *(called "model engine variants" in the paper)*
- Product characteristics contain: vehicle size, engine performance and fuel consumption (liters per 100 km and CO_2 emissions per km)

Emission Reduction

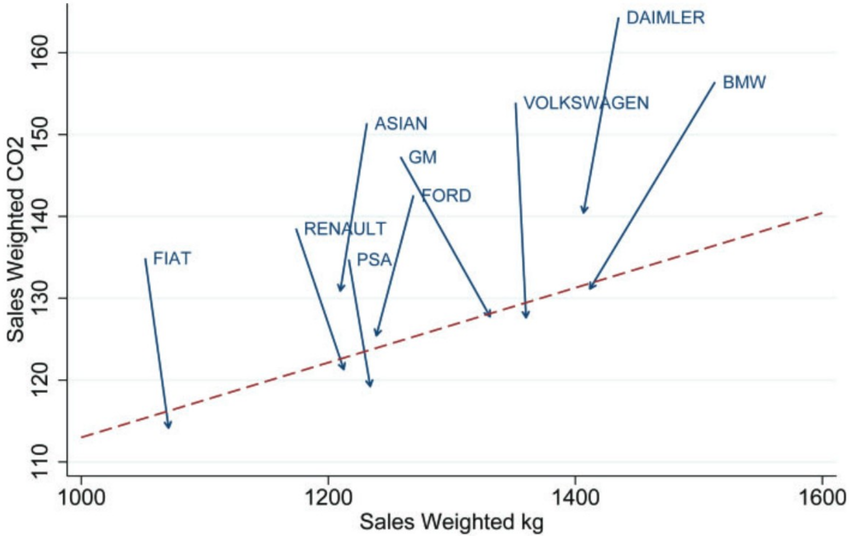

Figure 1: Compliance of firms in 2007 and 2011

Evidence: Technology Adoption

- Baseline Regression:

$$\log(e_{jy}) = \zeta_y + \log(x_{jy})\eta + \epsilon_{jy} \tag{3}$$

- ζ_y shows the technology level: if firms choose to implement technology, shifts in ζ_y. (residuals after controlling product characteristics)
- IF firms choose to alter the sales mix or to downsize, then the part of the emissions explained by characteristics, x_{jy}, should decrease over time.
- Allow firm-specific trend in technology (Model 2) and replace the official emission for on-road emissions with a smaller sample (Model 4 and 5).

Evidence: Technology Adoption

TABLE 2
Technological progress estimates

	Model 1		Model 2		Model 3		Model 4		Model 5	
			Official ratings					Actual ratings		
	Coef.	St.E.	Coef.	St.E.	Coef.	St.E.	Coef.	St.E.	Coef.	St.E.
1999	−0.5	0.8	−1.4	0.1	−1.7	1.4	−0.9	0.5	−1.2	0.1
2000	1.9	0.6	2.4	0.1	1.7	0.9	−1.5	0.2	−1.5	0.1
2001	−1.5	0.4	−2.2	0.2	−1.4	0.9	−1.2	0.2	−1.7	0.1
2002	−1.3	0.4	−1.5	0.2	−1.5	0.6	−0.9	0.3	−0.8	0.1
2003	−1.5	0.3	−1.9	0.2	−0.8	0.3	−0.5	0.2	−0.5	0.1
2004	−1.8	0.5	−2.1	0.2	−1.4	0.7	−0.7	0.3	−0.9	0.2
2005	−1.5	0.3	−1.9	0.2	−0.9	0.2	−0.2	0.2	−0.1	0.1
2006	−1.3	0.3	−1.7	0.1	−1.1	0.5	−0.4	0.2	−0.4	0.1
2007	−1.4	0.6	−2.2	0.1	−0.9	0.9	−0.2	0.5	−0.5	0.1
2008	−2.7	0.4	−3.1	0.1	−2.2	0.8	−0.9	0.4	−0.9	0.0
2009	−3.0	0.6	−3.6	0.1	−3.2	1.0	−1.4	0.5	−1.4	0.1
2010	−4.3	0.7	−4.7	0.1	−5.5	1.6	−2.5	0.5	−1.8	0.0
2011	−3.3	0.4	−4.5	0.1	−3.2	1.1	−1.3	0.6	−1.9	0.1
	Difference in technology growth 2011–2007 and 2007–1998									
Difference	2.3	0.5	2.42	0.07	2.6	0.9	0.8	0.3	0.65	0.08

Decomposition of Emissions

- Predict emissions, $\hat{e}_{jy}$, as the fitted values of regression (3) with Model 2;
- Predict $\overline{e}_{jy}$ using regression (3) but fixing the technology level at $\zeta_y = \zeta_{2007}$: the effect of mix-shifting and downsizing.
- The difference between two time series for each j shows the effect of technology adoption.

Decomposition of Emissions

		All vehicles	
		No Tech.	Tech.
	True	$\bar{e}_{jy}$	$\widehat{e}_{jy}$
1998	169	156	172
1999	168	156	170
2000	169	155	171
2001	167	154	169
2002	164	154	166
2003	161	153	162
2004	158	152	159
2005	156	152	157
2006	154	152	155
2007	151	152	152
2008	147	152	147
2009	142	152	143
2010	135	152	136
2011	130	152	130

- After 2007, $\overline{e}_{jy}$ remain constant: mix-shifting or downsizing cannot explain the decline in official emissions;
- After 2007, $\hat{e}_{jy}$ are decreasing rapidly: technology adoption is fully responsible for the observed drop in the official emissions.

Summary

- The reduction in official emission after policy announcement is due to technology adoption and gaming;
- 70% reduction in official emissions comes from gaming, while 20% comes from actual technology improvements. (extra reduction in official emissions due to technology adoption after policy is 2.4% while 0.7% for actual emissions)

Utility

Consumer i's indirect utility for product j in market my (country-year) is

$$u_{ijmy} = x_{jmy}\beta_i^x - \beta_i^e d_{jmy} e_{jmy} k_j - \alpha p_{jmy} + \xi_{jmy} + \varepsilon_{ijmy} \tag{4}$$

- x_{jmy}: a vector of observed product characteristics;
- fuel cost (per km): fuel prices, d_{jmy}, times emissions (per km), e_{jmy}, times a fuel type specific factors k_j. (assumption: fuel prices follow random walk)
- p_{jmy}: vehicle price
- β_i^k: individual valuation for characteristics k, $\beta_i^k = \beta^k + \sigma^k v_i^k$, v_i^k is drawn from $\mathcal{N}(0,1)$

Demand

- Each consumer i in market my chooses j that maximized her utility.
- The market share of vehicle j in market my, s_{jmy}: the probability that producer j has the higher utility:

$$s_{jmy}(\delta_{jmy}, \sigma) = \int \frac{exp(\delta_{jmy} + \mu_{jmy}(\sigma, v))}{1 + \sum_{l=1}^{J} exp(\delta_{lmy} + \mu_{lmy}(\sigma, v))} d\mathbf{P}_v(v) \tag{5}$$

  - δ_{jmy}: the mean utility, which collects all terms in consumers' utility that do not vary across individuals;
  - μ_{jmy}: individual idiosyncratic deviations, $\mu_{jmy} = \sum_k \sigma^k v_i^k x_{jmy}^k$;
- Consumers in each market is A_{my}: $s_{jmy} = q_{jmy}/A_{my}$

Firm Behavior

- Firms have three strategies: price setting (mix-shifting); technology adoption, and gaming;
- Assumption: the vehicle fleet of firms is exogenous. (no downsizing);
- Profit maximizing by choosing price (p_{jm}), technology adoption (t_{jm}) and gaming (g_{jm}) with the emission standard constraint:

$$\max_{p_{jm},t_{jm},g_{jm}} \sum_{m} \sum_{j \in F_f} [(p_{jm} - c_{jm})q_{jm}] \tag{6}$$

$$\text{s.t.} \quad \frac{\sum_m \sum_{j \in F_f} q_{jm}((1 - t_j - g_i)e_j - f(w_j))}{\sum_m \sum_{j \in F_f} q_{jm}} \leq \kappa \tag{7}$$

- Lagrange:

$$\mathcal{L} = \sum_{m} \sum_{j \in F_f} [(p_{jm} - c_{jm}(t_j) - \lambda L_j(t_j, g_j))s_{jm}(p_{jm}, t_{jm}, g_{jm})A_m] \tag{8}$$

where $L_j = (1 - t_j - g_j)e_j - f(w_j) - \kappa$. ($L_j \leq 0$, $\lambda \geq 0$)

Firm Behavior

- FOC: price

$$\frac{\partial \mathcal{L}}{\partial p} = \mathbf{q} + \Phi \circ \Delta_{\mathbf{p}}(\mathbf{p} - \mathbf{c} - \lambda \circ \mathbf{L}) \tag{9}$$

  Increases in mark up and losses from reduced scales;

- FOC: technology adoption

$$\frac{\partial \mathcal{L}}{\partial t} = (-\mathbf{c}_t' + \lambda \circ \mathbf{e}) \circ \mathbf{q} + \Phi \circ \Delta_{\mathbf{t}}(\mathbf{p} - \mathbf{c} - \lambda \circ \mathbf{L}) \tag{10}$$

  Increase in marginal cost and the benefit of increased market share;

- FOC: gaming

$$\frac{\partial \mathcal{L}}{\partial g} = \lambda \circ \mathbf{e} \circ \mathbf{q} + \Phi \circ \Delta_{\mathbf{g}}(\mathbf{p} - \mathbf{c} - \lambda \circ \mathbf{L}) \tag{11}$$

Estimation

- Three sets of parameters from the demand side: $\beta_i^e, \beta_i^x, \alpha$ and marginal cost, c_{jm}.
- Estimation method: GMM and OLS

Solution and Computation Methods

- Simplifications in solution:
    1. FOC w.r.t gaming does not satisfy. Assume every 0.3 units of t imply 0.7 units of g: $g = \frac{3}{7}t$
    2. Firms implement the same amount of technology across product j among its vehicle fleet.
- Compare the initial equilibrium without policy and the new equilibrium with policy; (equilibrium: p, t, λ)
- Direct welfare effects: consumer surplus, profits and gains from reducing CO_2;
- Indirect welfare effects: other externalities related to automobile market size, for instant, congestion, accident risks; behavioral biases of consumers (undervalue future fuel savings)

Welfare Effects

	I	II	III
	Opt.	Tech	Mix shift
Solve for:	p,t,λ	$p,t,(\lambda=0)$	$p,f,(t=0)$
Gaming:	70%	70%	-
Consumer Soph.:	Yes	Yes	Yes
Total sales (%)	−1.08	−1.30	−7.34
	[−3.11,0.19]	[−3.41,0.02]	[−8.74,−3.67]
Emissions (%)	−4.85	−4.31	−19.16
	[−6.53,−3.63]	[−5.98,−3.33]	[−21.66,−12.92]
			Direct
Consumer surplus	−2.57	−2.51	−19.10
	[−6.17,−0.22]	[−6.12,−0.16]	[−20.74,−15.44]
Profits	−0.60	−0.65	−2.58
	[−1.71,0.05]	[−1.77,0.03]	[−3.60,−0.12]
CO_2 value	0.34	0.30	1.32
	[0.21,0.44]	[0.21,0.41]	[0.62,1.60]
Total	−2.83	−2.86	−20.36
	[−7.45,0.12]	[−7.49,0.12]	[−22.83,−15.01]
Implied value CO_2	265	297	458
	[104,711]	[114,821]	[334,546]
			Indirect
Other Ext.	2.19	2.65	14.94
	[−0.20,6.42]	[0.16,7.02]	[5.19,18.13]
Undervaluation	1.52	1.28	6.75
	[1.21,2.02]	[1.07,1.79]	[3.89,8.03]
Total:	0.88	1.07	1.33
	[0.57,1.53]	[0.90,1.84]	[−5.78,4.71]

- I and II: firms choose technology adoption and gaming in response to policy.
- II and III: the abatement technology chosen by firms is crucial for the market outcomes.
- EU standard decreases both consumer surplus and profits: technology adoption increases marginal cost and then price.
- When considering two indirect effects, EU standard increases welfare.

References

Reynaert, M. (2021). Abatement strategies and the cost of environmental regulation: Emission standards on the european car market. *The Review of Economic Studies*, 88(1):454–488.