Driving restrictions: What we know and lessons for climate policy

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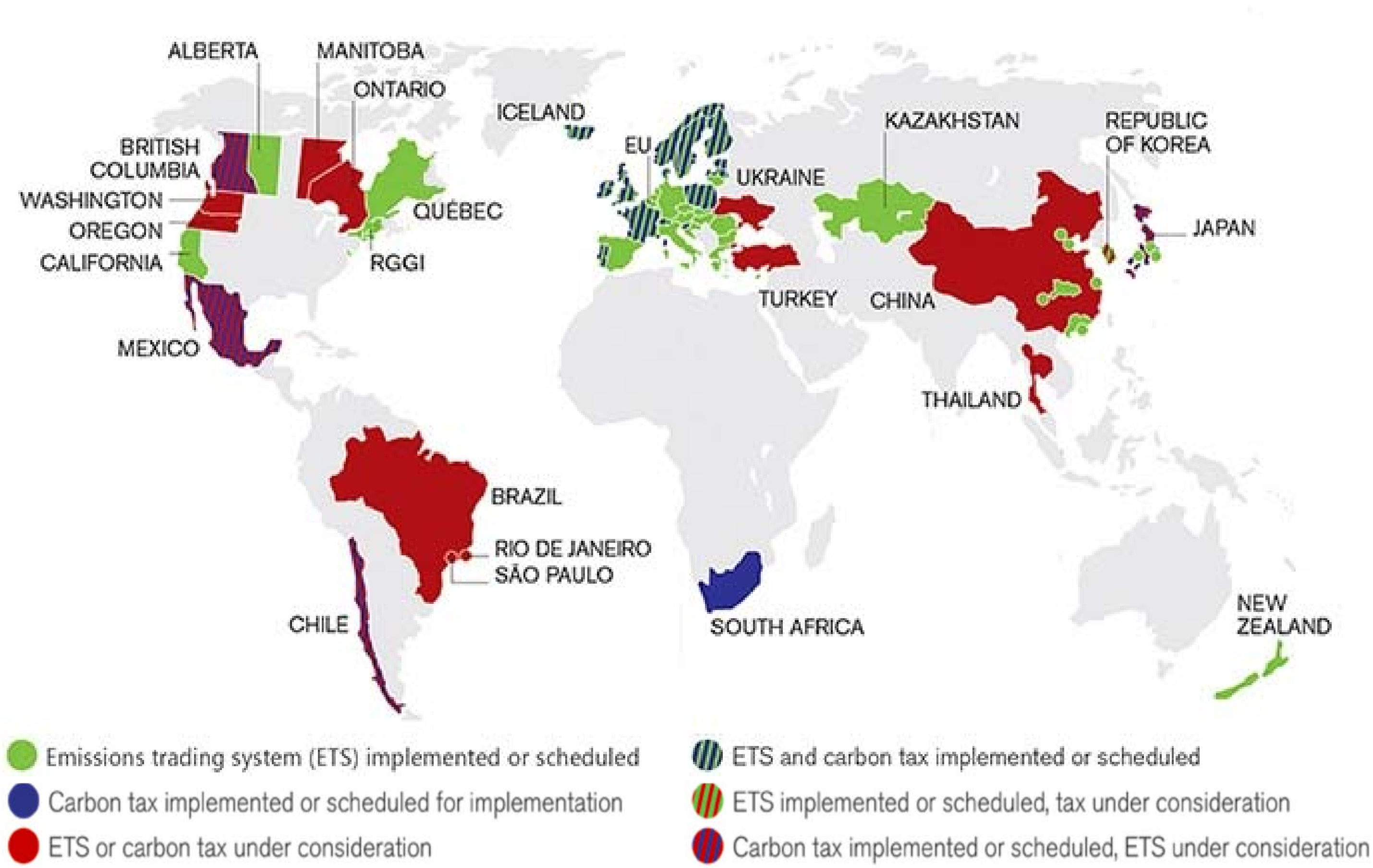
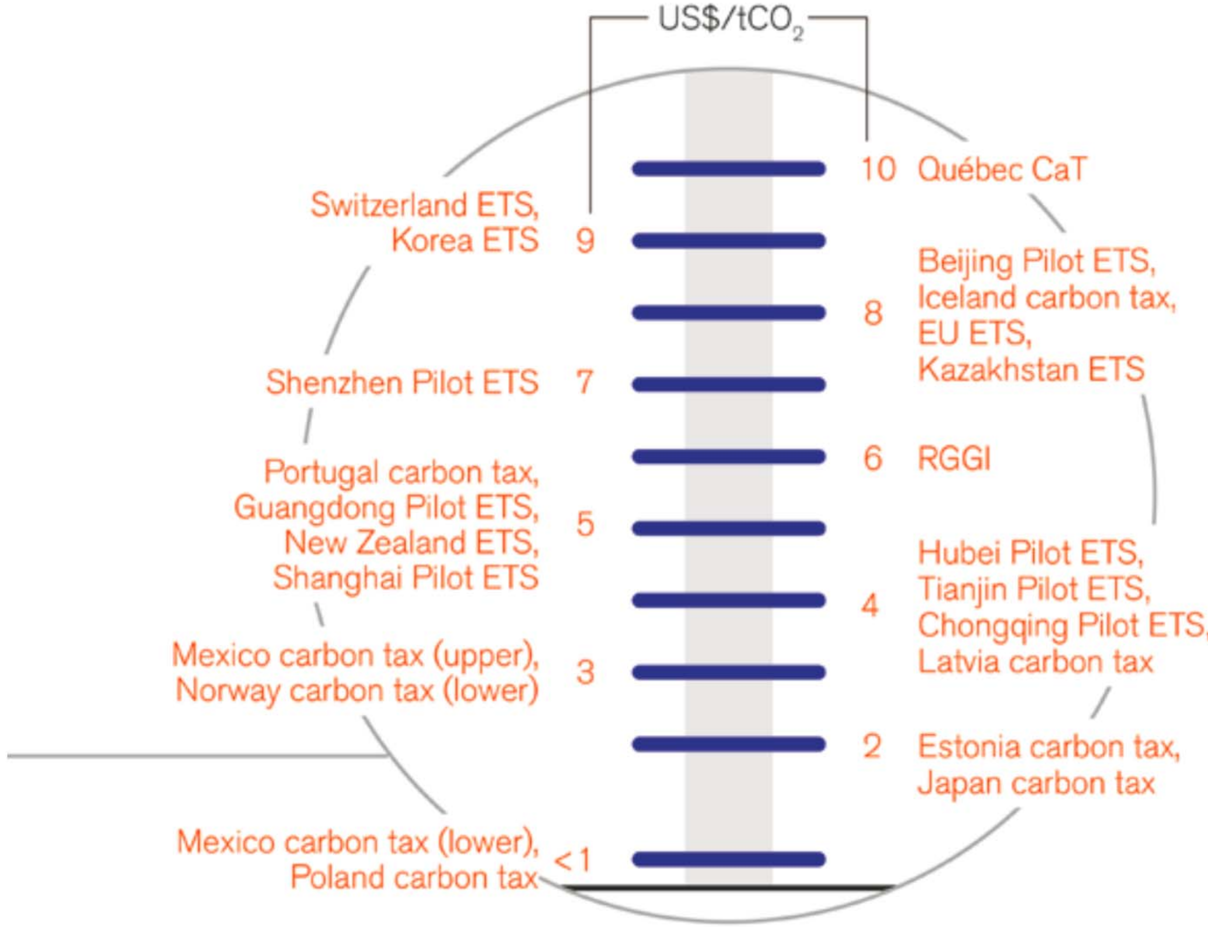
The World Bank's Carbon pricing map





Source: The World Bank, April 2015

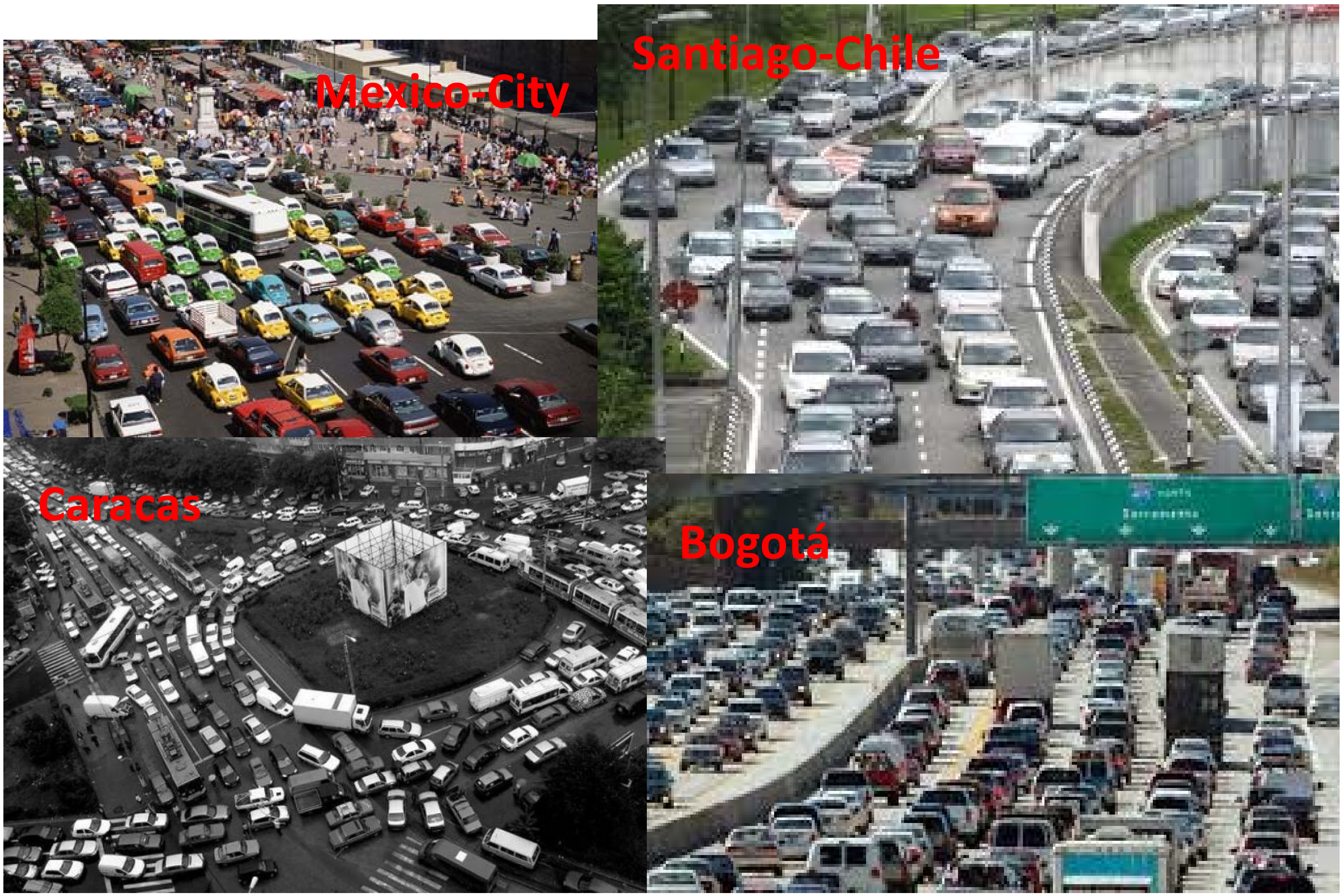
Chile's carbon tax and its political economy

- Approved in September 2014, it applies to power plants greater than 50 MW of thermal capacity starting in 2017
- Industry and transportation not affected
- This tax was approved only because it was a small part of a comprehensive tax reform package (increasing corporate taxes mainly)
- very unlikely these "green" taxes would have been pushed and approved in isolation
- (we had ETS discussion that didn't avance)
- (Mexico's CO_2 tax of 1-3 US$/ton, approved in Jan 2014, followed similar path, coverage smaller, 40%)

The carbon tax is not enough

- What to do with the transportation sector?
- the sector has its own political economy
- Gasoline taxes?...No, mentioned but immediately disregarded during the tax reform debate
- Scrappage subsidies?....No, too expensive
- Subsidies for EV and hybrids?....Virtually none
- Road pricing? No….it has been proposed for years but face strong opposition in Parliament
- What other policies have been tried in Latin America in the fight against vehicle congestion and local air pollution?
- Driving restrictions!

Vehicle congestion and local air pollution



…driving restrictions: what are they?

- they ban drivers from using their vehicles once a week on the basis of the last digit of the vehicle's license plate
- some restrictions have followed a drastic implementation: affecting almost all drivers in the city and permanently
- others are more gradual: in place only in days of unusually high pollution (e.g., Beijing); affecting only older vehicles
- some include provisions that exempt new, cleaner cars
- enforcement has been quite effective
- very popular in Latin America (now you also see them in large cities in China and even India tried them for a month last January; and Paris!)

Driving Restrictions: where?

Where do we see them?

- Athens (first introduced in 1982)
- Santiago-Chile (186): *restricción vehicular*,
- Mexico-City (1989): *Hoy-No-Circula*
- Sao Paulo-Brasil (1996): *Operacao Rodizio*
- Manila (1996)
- Bogotá-Colombia (1998) and Medellín-Colombia (2005): *Pico y Placa*
- San José-Costa Rica (2005): *Restricción vehicular*
- Beijing (2008), Hangzhou (2011), Chengdu (2012)
- Berlin, Frankfurt, Munich… (2008): Low-Emission zones
- Quito-Ecuador (2010): *Pico y Placa*
- Delhi (January 2016) : an odd-even experiment
- Paris (2014 and 2015): 1 day episodes

Have these restrictions worked?

- More importantly, can it be part of a climate policy package?
- It depends….two pieces of evidence with remarkably different messages
- Mexico-City's 1989 Hoy-no-Circula (restriction imposed upon all cars)
  - Eskeland and Feyzioglu (WBER 1997)
  - Davis (JPE 2008)
  - Gallego-Montero-Salas (JPubE 2013, EnergyEcon 2013)
- Santiago-Chile 1992 (cleaner cars exempted from restriction)
  - Barahona-Gallego-Montero (wp 2016)

Mexico-City 1989 (Hoy-no-circula)

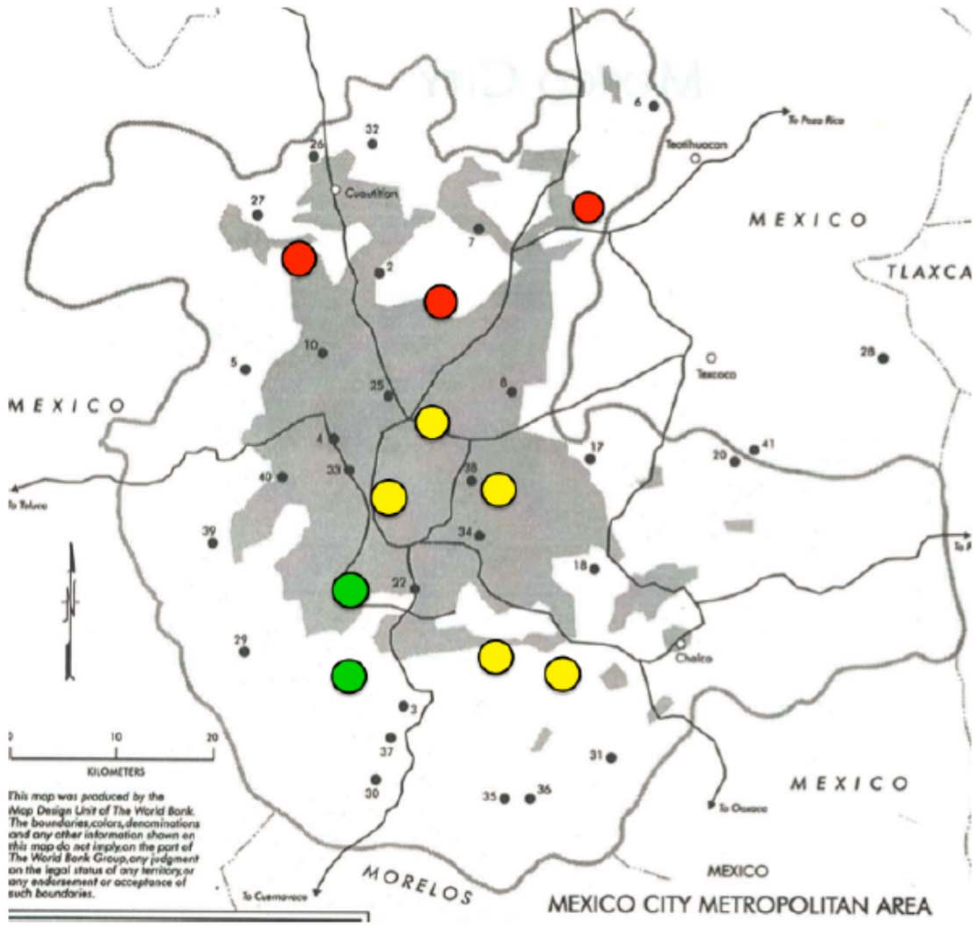
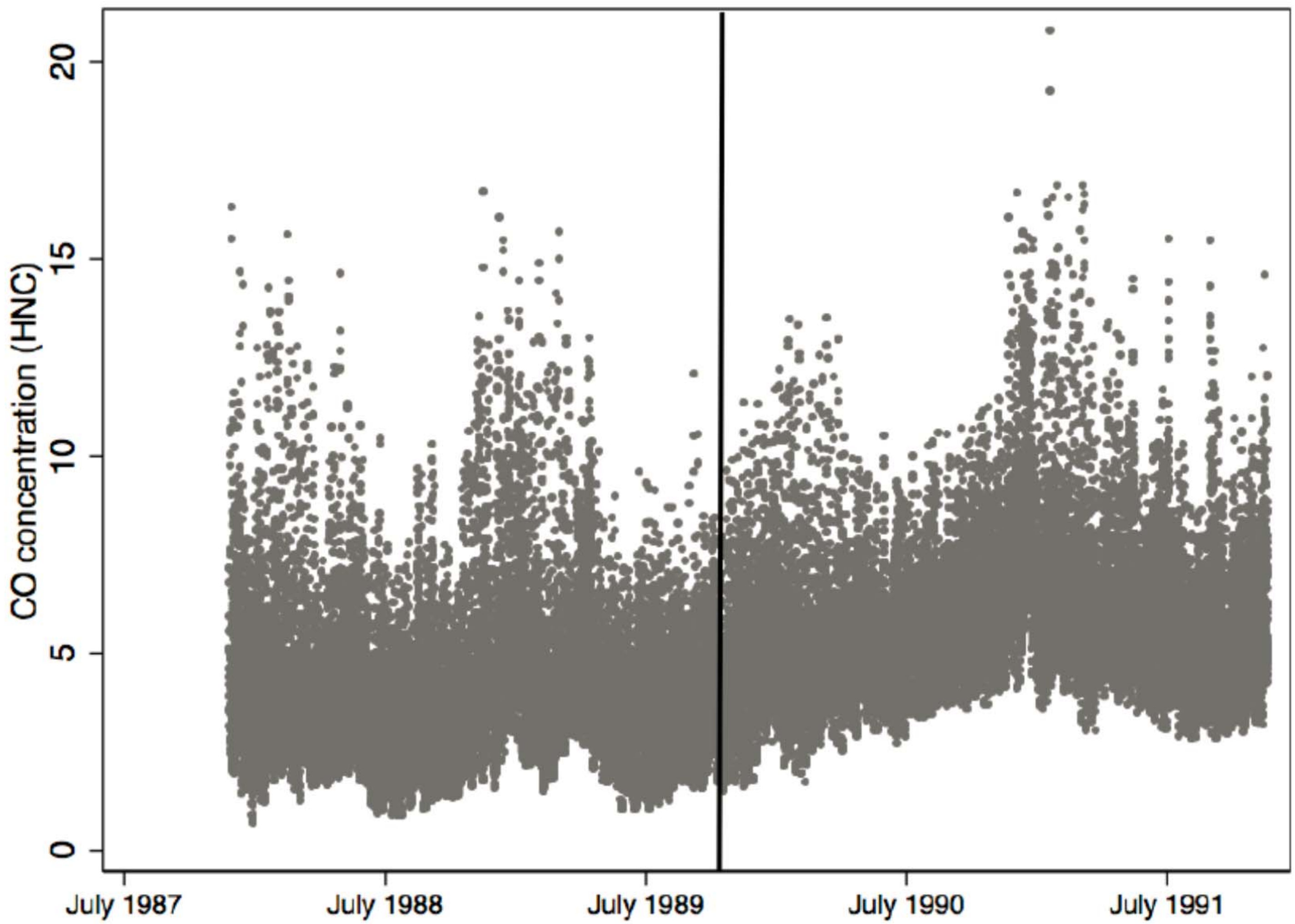


Figure: CO observations for Mexico-City



Our approach

- Flexible approach including monthly dummies for adaptation:

$$y_t = \alpha + \phi y_t^b + \beta T_t + \sum \delta_t d_t + \theta t + \gamma x_t + \epsilon_t$$

- Imposing adaptation process:

$$y_t = \alpha + \phi y_t^b + [a + b(t - t_T)]A_t + cT_t(1 - A_t) + \theta t + \gamma x_t + \epsilon_t$$

  - y_t^b: background pollution
  - x_t: includes fixed effects (day of week, month), weather variables, economic variables
  - d_t: dummies for transition months
  - $T_=1$ if $t > t_T$ (time of policy adoption) and zero otherwise.
  - $A_t = 1$ if $t_T < t \leq t_A$ (en of adjustment phase, endogenous using supF method of Quandt, 1960; Andrews, 1993; Hansen, 2000) and zero otherwise.
- Why linear trend θ? ▸ HNC ▸ TS

Our results for HNC

	Mexico-City (HNC)		
	short-run	long-run	T(months)
peak hours (8-9 am)	-11%	+13%	12.5
off-peak (12-2 pm)	-9%	+9%	8
sunday (8-10 am)	+2%	+19%	9.5

Table: Policy effects by station: HNC

Station	Sector	Income per HH (relative to average income)	Short-run effect	Long-run effect	Difference LR-SR effects	Months of adaptation
Xalostoc	NE	0.55	11.96%	17.60%	5.64%	12.5 (6.06)
Tlalnepantla	NW	0.50[a]	-21.32%*	0.76%	22.08%*	9 (3.10)
I.M. del Petróleo	NW	0.53	-17.81%***	15.98%	33.79%***	14 (1.91)
Lagunilla	CE	0.71	-28.21%***	-6.52%	21.69%*	11 (1.78)
Merced	CE	0.84	-15.27%*	8.07%	23.34%**	12 (1.52)
M. Insurgentes	CE	0.70	-24.58%***	14.27%	38.85%***	15 (2.33)
Cerro Estrella	SE	0.54	-17.81%**	20.37%*	38.18%***	11.5 (1.51)
Taqueña	SE	1.14	-9.48%	22.55%**	32.03%***	15 (2.41)
Plateros	SW	1.99	-3.31%	-3.31%	0.00%	0 –
Pedregal	SW	1.99	-3.38%	13.78%	17.16%	10.5 (3.06)

Santiago's driving restriction

- 1985: prohibition to the import of used cars into the country
- 1986: driving restriction is introduced in the city of Santiago; but only for days of unusually bad air quality
- 1990: the restriction becomes, for practical purposes, permanent from April to October; 20% of the fleet off the road during weekdays
- **1992: cars that complied with a new emissions standard (be equipped with a catalytic converter) would get a green sticker**
    - **new cars bought in 1993 and after without the green sticker not allowed to circulate in Santiago's Metropolitan Region**
    - **a car with a green sticker is exempt from any driving restriction**

Evidence #1:

The vehicle fleet in Santiago is cleaner than in the rest of the country because of the driving restriction

Fleet evolution: the data

- our main database consists of a panel of 323 counties/municipalities and 7 years (2006-2012) with detailed information on fleet evolution (number of cars per vintage).

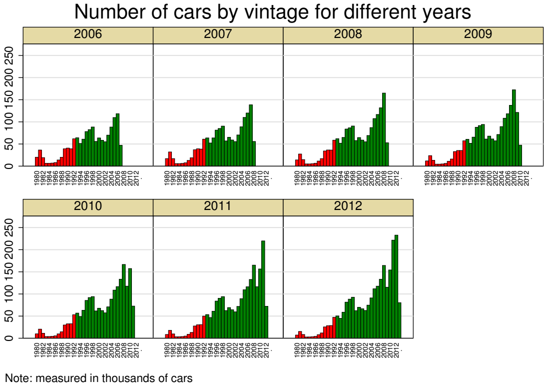


Figure: Evolution of the car fleet at the country level

Preliminary evidence: Santiago vs the rest of the country

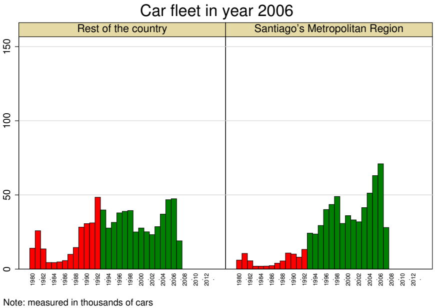


Figure: Fleet in 2006

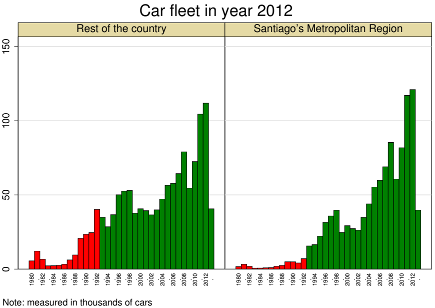


Figure: Fleet in 2012

- compelling evidence that the fleet in Santiago is cleaner than in the rest of the country
- but how much is explained by income? (Santiago is richer)

explaining the "Santiago effect" for 92/93

- of the total number of cars of vintage τ in the country in year $T \geq \tau$, how many go to municipality $i = 1, ..., 323$?

$$\begin{aligned} \log(c_{i\tau}) &= \beta_\tau Santiago_i + \alpha_\tau \log(Pop_i) + \gamma_\tau \log(Income_i) + ... \\ & ... + \delta_\tau + \psi X_i + \epsilon_{i\tau} \end{aligned}$$

where

- Pop_i: is the population in municipality i for that year sample
- $Income_i$: is the income per capita in county i
- $Santiago_i$: takes the value of 1 for municipalities in the city of Santiago
- δ_τ: vintage fixed effect
- other controls included (see table 1)

a few of observations...

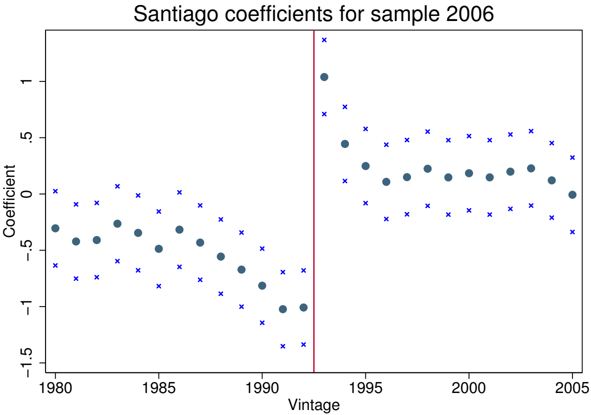


Figure: Sample 2006 corrected

Evidence #2:

The driving restriction has created a price differential between 5 and 18% for otherwise similar cars (this is also indication that the restriction is well enforced)

- evident discontinuity in used-car prices between vintages 1992 and 1993

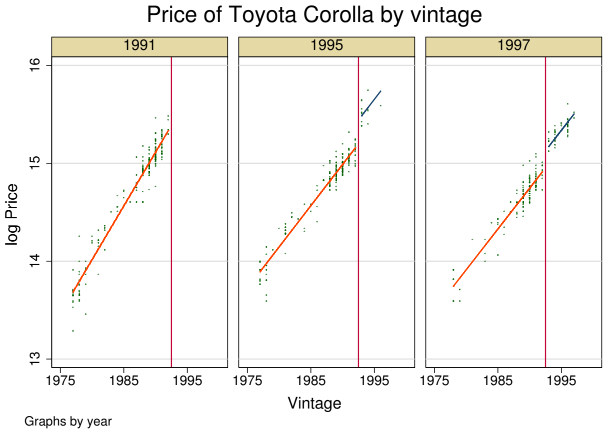


Figure: Price of used car Toyota Corolla by vintage

Table 3: Effect of driving restriction on prices (1993-2000)

	Fiat Uno	Honda Accord	Honda Civic	Mazda 323	Peugeot 205	Peugeot 505	Toyota Corolla
Catalytic	0.0458***	0.162***	0.0633***	0.0459***	0.0378***	0.149***	0.180***
	(0.006)	(0.008)	(0.007)	(0.006)	(0.007)	(0.008)	(0.009)
Age f.e.	yes	yes	yes	yes	yes	yes	yes
Offer date f.e.	yes	yes	yes	yes	yes	yes	yes
Observations	4136	5980	5530	5796	3396	6788	5764
R^2	0.930	0.966	0.924	0.950	0.937	0.934	0.941

Notes: OLS regressions with age and date fixed effects. Standard errors clustered by offer date in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

prices in the used-car market

- another test: some ads reported some Honda Accord models prior to 1993 having catalytic converters
- the effect only shows up for cars made before 1993

	(1991)	(1992)	(1993)	(1994)
Catalytic	0.223***	0.189***	0.0206	-0.00487
	(0.059)	(0.040)	(0.036)	(0.026)
Constant	15.60***	15.68***	15.96***	16.40***
	(0.031)	(0.026)	(0.023)	(0.009)
Observations	47	53	58	49
R^2	0.245	0.309	0.006	0.001

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

- cars with a carburetor engine couldn't be equipped with a catalytic converter

Evidence #3:

The clean-car exemption has eliminated the incentives to bypass the restriction with old high emitting cars

- using data from household-level surveys we look at whether households in Santiago are more likely to own more than one car

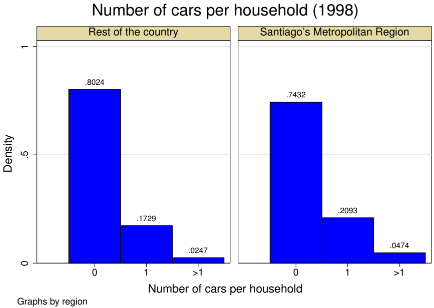


Figure: Number of cars (1998)

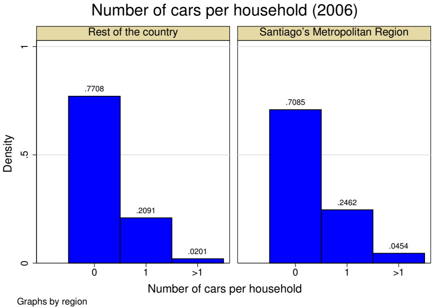


Figure: Number of cars (2006)

Buying a second car?

- controlling for different household's characteristics we estimate the effect of living in Santiago on having more than one car

	(1998)			(2006)		
Panel A: marginal effects on probability of having two cars conditional on having at least one						
OLS	0.0018			0.00999		
	(0.006)			(0.0144)		
probit	-0.00076			0.0031		
	(0.001)			(0.0107)		
Panel B: marginal effects on probability of having an extra car						
	$\frac{\delta P[y=0]}{\delta x}$	$\frac{\delta P[y=1]}{\delta x}$	$\frac{\delta P[y\geq 2]}{\delta x}$	$\frac{\delta P[y=0]}{\delta x}$	$\frac{\delta P[y=1]}{\delta x}$	$\frac{\delta P[y\geq 2]}{\delta x}$
ordered logit	0.0279***	-0.0258***	-0.0021***	0.0206*	-0.0192*	-0.0014*
	(0.01)	(0.009)	(0.0007)	(0.011)	(0.0104)	(0.0007)
ordered probit	0.0318***	-0.0299***	-0.002***	0.0212*	-0.01998*	-0.00126*
	(0.01)	(.0103)	(0.0007)	(0.012)	(0.0112)	(0.00067)
Panel C: marginal effects on having an extra car using count data models						
poisson	-0.0185***			-0.0181***		
	(0.0058)			(0.0065)		
hurdle poisson-logit	0.062			-0.01216		
	(0.081)			(0.0968)		

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A model of car ownership and use

- There are three agents in this model: **car producers**, **car dealers** and **drivers**.
- The cost of producing a new car is c (price at which producers sell new cars to car dealers).
- The (annual) rental price at which a car of vintage $\tau = \{1, 2, 3, ...\}$ is rented to drivers is denoted by p_τ.
- the probability that a vintage-τ car is still in the market for the next period as a vintage-$(\tau + 1)$ car is $\gamma_\tau \in (0, 1)$.
- A car can be scrapped at any time, getting a value of v for its parts.

- There is a continum of drivers of mass 1 that vary in their willingness to pay for the quality of the car (they consider at most one car; see empirical result 3).
- A consumer that rents a vintage-τ car obtains utility:

$$u(\tau, x, \theta) = \frac{\alpha}{\alpha - 1}\theta s_\tau x^{1-\frac{1}{\alpha}} - \psi x - p_\tau$$

where θ is the consumer's type, s_τ is the quality of the car, x is a measure of car use during the period, ψ is unit cost of using the car (e.g., parking, gasoline, etc), $\alpha > 1$ is a parameter that captures decreasing returns in car use, and p_τ is the rental price including insurance, inspections, and any other fixed cost.

household's use and ownership decisions

- Since a consumer θ that rents an age τ car anticipates that she will drive
$$x(\theta) = \left(\frac{\theta s_\tau}{\psi}\right)^\alpha \tag{1}$$
her utility from renting a vintage-τ car reduces to
$$u(\tau, x(\theta), \theta) = k\,(\theta s_\tau)^\alpha - p_\tau \tag{2}$$
where $k = [(\alpha - 1)\psi^{\alpha-1}]^{-1}$.
- Our formulation captures with a single parameter two empirical regularities:
  - people that value quality more tend to drive newer cars and
  - newer cars are, on average, run more often.

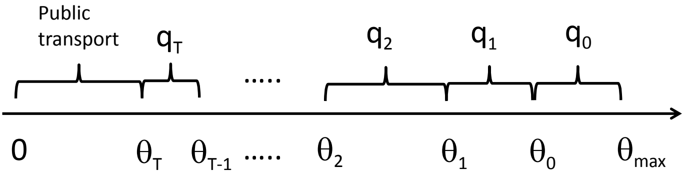
a model of...

- Consumers are distributed according to the cdf $F(\theta)$ over the interval $[\underline{\theta}, \bar{\theta}]$.
- A consumer that doesn't rent a car gets its outside utility u_0 (e.g., utility from using public transport).
- The quality of a car falls with age (higher maintenance costs, more likely to break down, etc), according to

$$s_{\tau+1} = \beta s_\tau$$

with $\beta \in (0, 1)$. The quality of a new car is denoted by s_0.

- All agents discount the future at $\delta \in (0, 1)$.



HOUSEHOLDS RENTING DIFFERENT VINTAGE CARS

the market equilibrium

- At the beginning of any given year t there will be some stock of used cars $Q^t = \{q_1^t, q_2^t, ...\}$.
- As a function of that stock, the market equilibrium for the year t must satisfy several conditions.
- First, it must be true that in equilibrium consumers of higher types rent newer cars. There will be a series of cutoff levels $\{\theta_0^t, \theta_1^t, ...\}$ that precisely determines which consumers are renting which cars.
- Denote by θ_τ^t the consumer that is indifferent between renting a car of vintage τ at price p_τ^t and one of vintage $\tau + 1$ at a lower price $p_{\tau+1}^t$, that is

$$k\left(\theta_\tau s_\tau\right)^\alpha - p_\tau = k\left(\theta_\tau s_{\tau+1}\right)^\alpha - p_{\tau+1}$$

for all $\tau = 0, 1, ..., T - 1$, where T is the age of the oldest car that is rented.

- The series of cutoff levels must be also consistent with the population of drivers and the existing stock of used cars Q^t and the new cars coming to the market this year (q_0^t).

$$
\begin{aligned}
q_0 &= 1 - F(\theta_0) \\
q_\tau &= F(\theta_{\tau-1}) - F(\theta_\tau)
\end{aligned}
$$

- Car dealers have always the option to scrap an old car and receive v. Denoting by T^t the age at which cars are being scrapped, in equilibrium dealers must be indifferent between renting an age T vehicle today (and scrap it tomorrow, if the vehicle still exits) and scrapping it today.

$$p_T + \delta\gamma v = v$$

the market equilibrium

- In general, only a fraction of age T vehicles will be scrapped in equilibrium, so
$$F(\theta_{T-1}) - F(\theta_T) \leq \gamma q_{T-1}$$

- Note that because quality drops discretely with age, it can happen that in equilibrium all vintage-($\tau - 1$) are rented but all vintage-τ are scrapped. Then the relevant scrapping condition is:
$$p_{T-1} + \delta\gamma v > v > p_T + \delta\gamma v$$

the market equilibrium

- In addition, in equilibrium (competitive) car dealers must break even, so today's and future's rental prices must satisfy

$$c = \sum_{i=0}^{T} (\gamma\delta)^i p_i + (\gamma\delta)^{T+1} v$$

  where T is the age at which a car bought today, i.e., at t, is expected to be retired from the rental market.

- One last condition that must hold in equilibrium is that the lowest-valuation consumer to rent a car today, θ_T , obtains no surplus, i.e., it gets the surplus from using public transport, which we normalize to zero.

$$k\left(\theta_T s_T\right)^{\alpha} - p_T = u_0$$

- Suppose that cars emit pollutants at a rate e per mile, so that $e_{\tau+1} > e_\tau$. Denote by h the harm from pollution, so the cost to society of a vintage-τ car running for x miles is $e_\tau xh$.
- The social planner can restore the social optimum by levying a Pigouvian tax equal to h on each unit of pollution and so change consumer's driving decision to

$$x^*(\theta) = \left(\frac{\theta s_\tau}{\psi + e_\tau h}\right)^\alpha$$

and its utility to

$$u(\tau, x^*(\theta), \theta) = k_\tau \left(\theta s_\tau\right)^\alpha - p_\tau$$

where $k_\tau = [(\alpha - 1)(\psi + e_\tau h)^{\alpha-1}]^{-1}$.

real-world policy interventions

- Since Piguouvian taxation is not feasible, policy makers must rely on alternative and imperfect policy instruments:
    - scrapping subsidies
    - driving restrictions, etc.
- The way a scrapping subsidy enters into our model is by simply increasing v.
- Driving restriction is captured by the parameter $R_\tau < 1$, which tells you that vintage-τ cars can only be used a fraction R of the time, so that

$$x(\theta) = R_\tau \left(\frac{\theta s_\tau}{\psi} \right)^\alpha$$

and driver's utility

$$u(\tau, x(\theta), \theta, R_\tau) = R_\tau k \left(\theta s_\tau \right)^\alpha - p_\tau$$

obtaining relevant parameter values to feed the model

- We use the 2006 car fleet sample
- We aggregate our fleet data from the county level (320) to the electoral district level (60).
- We group vintages in four-year groups
- Given that the used-car market between Santiago and the rest of the country is well arbitrated, the equilibrium equations to be estimated are

$$R_{i\tau} k\left(\left(\theta_{i\tau}+\varepsilon_{i\tau}\right) s_\tau\right)^\alpha - p_\tau = R_{i\tau+1} k\left(\left(\theta_{i\tau}+\varepsilon_{i\tau+1}\right) s_{\tau+1}\right)^\alpha - p_{\tau+1}$$

$$q_{i\tau} = F_i(\theta_{i\tau-1}) - F_i(\theta_{i\tau})$$

where $R_{i\tau}$ indicates whether a car of vintage-group τ in district i faces a restriction ($R < 1$) or not ($R = 1$), p_τ is the rental price, $q_{i\tau}$ is the number of cars per capita, and $\varepsilon_{i\tau}$ is an county-vintage specific shock in preferences.

obtaining parameter values

- To obtain values for p_τ we collected data of used-car prices from newspaper ads between years 1988 and 2000
- We used a fixed effects regression model to predict the price of a standard car in every year of the panel.
- The difference of the predicted net present values of the cars in a 4 year period was assumed to be the rental price p_τ.
- $F_i(\theta|\mathbf{x}_i)$ is the distribution function of θ which is approximated by a cubic function (bounded between 0 and 1) captured by the vector $\mathbf{x}_i = (a_i, b_i, c_i, d_i)$, where each parameter depends on the district's characteristics:

$$x_i = \phi_x^1 + \phi_x^2 Income_i + \phi_x^3 Urb_i + \phi_x^4 Distance_i + \eta_i$$

obtaining parameter values

- We then imposed that the correlation between $(\varepsilon_{i\tau} - \varepsilon_{i\tau+1})$ and the distrcit's observable variables is zero:
    - a dummy that taked the value of 1 if the district is located in Santiago and three variables corresponding to the average income of the district, its distance to Santiago and its urbanization ratio.
- Parameter values obtained:

$$\{R = 0.9666; \beta = 0.8911; \alpha = 2.1014; \psi = 0.36822\}$$

obtaining parameter values

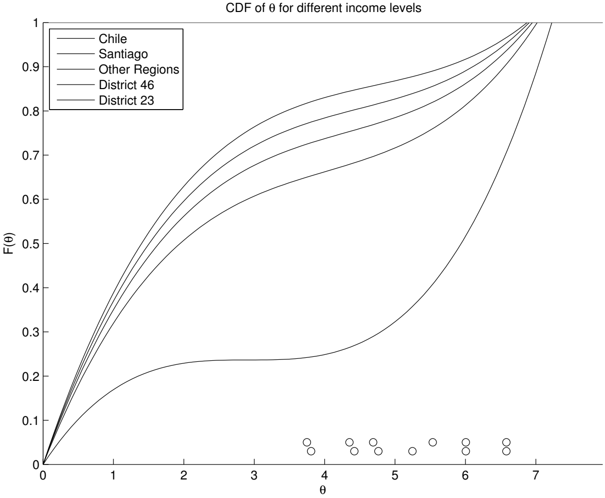


Figure: Distribution function $F_i(\theta|x_i)$ for different districts

other parameter values: survival rate

- γ, the survival rate of cars of different vintages, was computed directly by looking at how many of the vintage-τ cars in year t where still around in year $t+1$.
- We did this for many years and vintages to obtain:

Survival ratio of cars					
vintage group	1-4	5-8	9-12	13-16	17-20
γ	0.9966	0.9966	0.9966	0.9434	0.8267
vintage group	21-24	25-28	29-32	33-36	
γ	0.7226	0.5828	0.5242	0.5242	

- To estimate the pollution damage from a τ-vintage car we relied on two different source.
- Following Parry and Strand (2012), we assume that the damage of local tailpipe emissions is US$0.06 per mile in Santiago and US$0.007 outside Santiago.
- We assume a passanger car runs about 12,000 miles per year (NHTSA, 2006)
- We take Mexico's values from Molina and Molina (2002) for the relation between emissions contribution and vintages

Car vintage	Fleet Percent Share	Emissions Contribution
1993-2001	60%	15%
1985-1992	28%	30%
1980-1985	7%	25%
1979 & older	5%	30%

other parameter values: pollution damages

- In our model, average damage generated by a vintage-τ car is given by

$$\frac{\int_{\theta_\tau}^{\theta_{\tau-1}} \left(\frac{\theta s_\tau}{\psi}\right)^\alpha e_\tau h f(\theta) d\theta}{\int_{\theta_\tau}^{\theta_{\tau-1}} f(\theta) d\theta}$$

  where $f(.)$ is the pdf of parameter θ.

- We assume the following emission rate function e_τ:

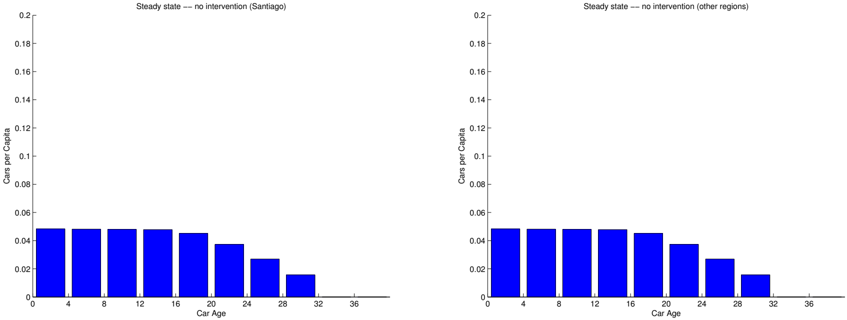
$$\begin{aligned} e_0 &= 0 \\ e_\tau &= (1+\omega)e_{\tau-1} + \omega \end{aligned}$$

- Running an OLS we estimate ω and h, so that $\omega = 1.52$ and $h = 0.012$ for cars in Santiago and $h = 0.001$ for cars outside Santiago.

other parameter values: cost, scrap value and discount factor

- we let $c = \$16,000$, as it was the average price of new cars used in the rental price estimations
- for the scrap value we use initially $v = \$600$.
- for the discount value we use $\delta = 0.656$, a value that corresponds to a 4 years period discount value of 0.9.

- we now split the country into two different regions, Santiago and the rest of the country.

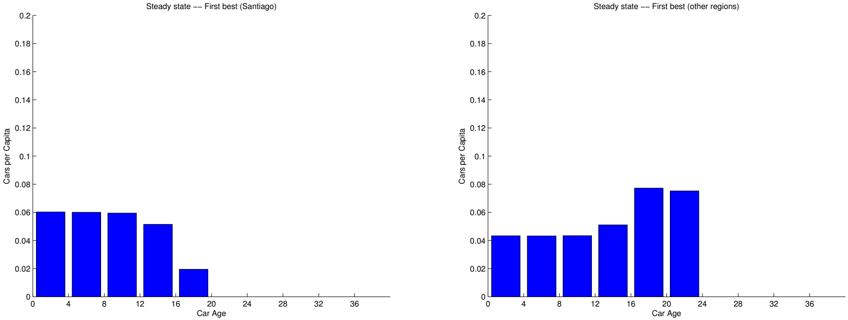


(a) Santiago (b) Rest of country

Figure: Car fleet with no intervention

a two-city model: first best

- it is first best that older cars go to the rest of the country where pollution is less of a problem

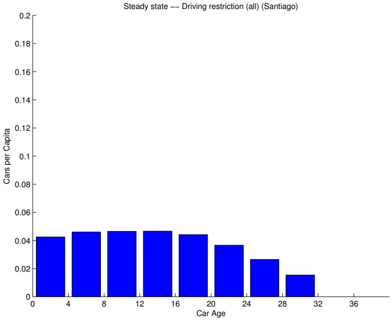


(a) Santiago (b) Rest of country

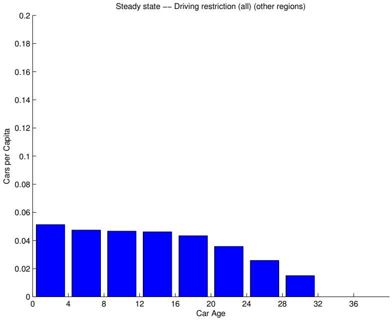
Figure: Car fleet under Pigouvian taxes

- let us again normalize welfare gains under the first best to 100.

- when a restriction is applied to all cars in Santiago, this latter's fleet gets even older.



(a) Santiago



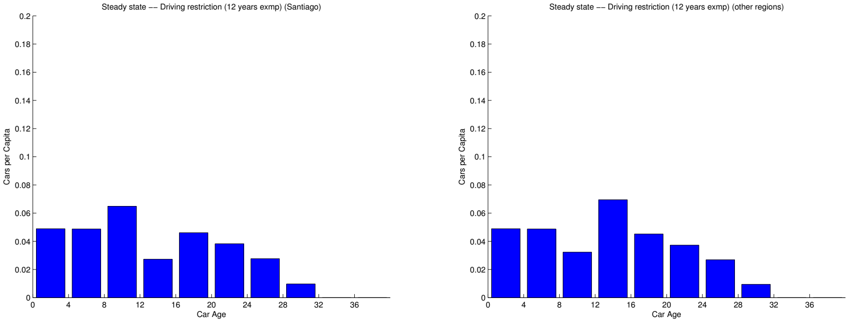
(b) Rest of country

Figure: Fleet under driving restriction to all vehicles

- in this case, welfare gains amount to -20.7.

a two-city model: driving restriction

- exempting cleaner cars improve things substantially



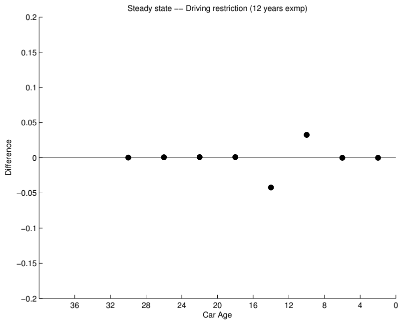
(a) Santiago (b) Rest of country

Figure: Fleet under driving restriction upon older vehicles only

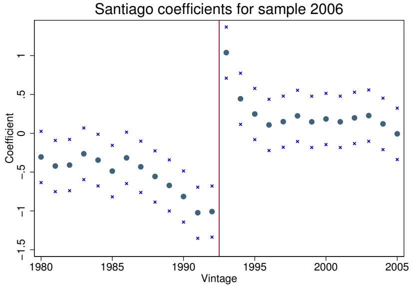
- in this case, welfare gains get to 12.6.

a two-city model: driving restriction

- we can also compare the model's prediction to the coefficients estimated in the empirical part.



(a) Model prediction

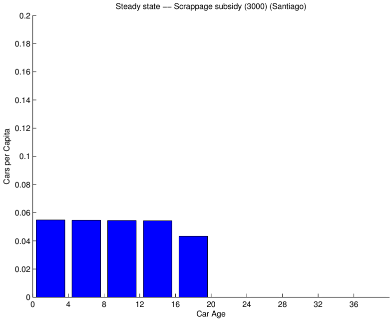


(b) Emprical estimation

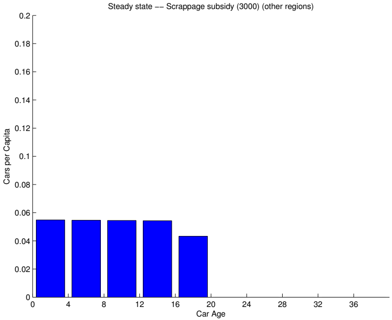
Figure: Model prediction and empirical estimation when cleaner cars are exempted

a two-city model: optimal scrappage subsidy

- we can then calculate welfare under an optimal scrappage subsidy of \$2,980.



(a) Santiago

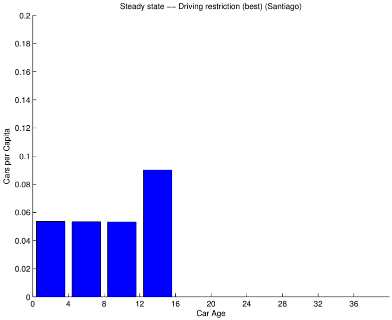


(b) Rest of country

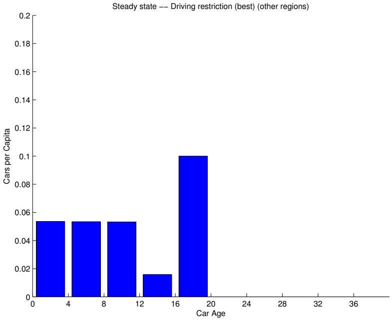
Figure: Car fleet under an optimal scrappage subsidy

- in this case, welfare gains amount to 68.6.

- or the optimal driving restriction where old cars are forbidden in Santiago.



(a) Santiago



(b) Rest of country

Figure: Car fleet under an optimal driving restriction

- in this case, welfare gains amount to 90.2.

summarizing..

- now driving restrictions behave even better than subsidies, as they can be focused on a particular city.
- they get very close to the first best.

Table: Welfare calculations in a two cities model

Contrafactual	Welfare (US$)	Rel. welfare
No intervention	7697	0
First best	9028	100
Subsidy US$2980	8610	68.6
Driving restriction $R = 0.966\ \forall\tau$	7421	-20.7
Driving restriction $R = 0.966,\ \tau > 3$	7866	12.7
Driving restriction $R = 0,\ \tau > 4$	8898	90.2

Conclusions

- we find a great impact on the evolution of the car fleet as a result of the driving restriction policy implemented in Santiago.
- older cars were exported from Santiago to the rest of the country, where local pollution is less of a problem (what about global pollution?).
- we also find no evidence of people bypassing the policy by purchasing a second (older) car.
- we built a model to better understand how different driving restrictions (and other policies) work and how close they can take us to the first best.
- well designed driving restrictions can work reasonably well (for fighting air pollution not congestion)