Driving restrictions: Do they make drivers buy dirtier or cleaner cars?

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driving restrictions

driving restrictions are popular

- Driving restrictions —basically you cannot drive your car once a week— are increasingly popular for fighting congestion and (local) air pollution
- they come in different formats but all based on last digit of vehicles' license plates: some are permanent once-a-week restrictions, others work only in days of bad pollution or once a week but only during rush hours, etc.
- why so popular? they are politically visible and relatively easy to enforce
- Cities that have or had in place driving restriction policies (in its different formats): Santiago (1986), Mexico-City (1989), São Paulo (1996), Bogotá (1998), Medellín (2005), San José (2005), Beijing (2008), Tianjin (2008), Quito (2010).

some unfortunate evidence on how these restrictions work

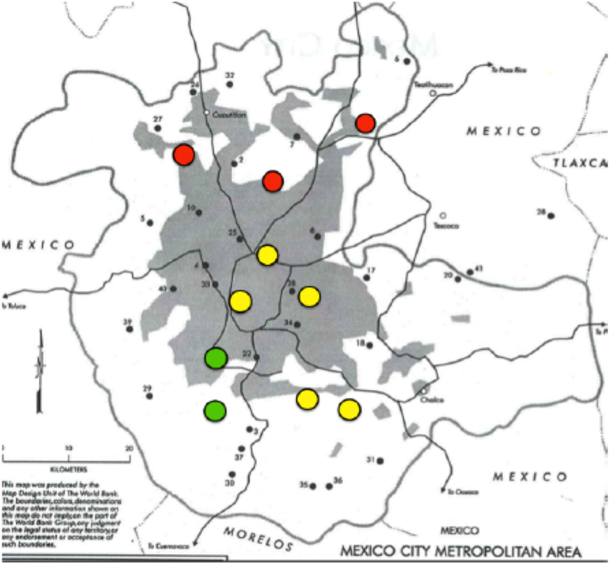
- A few papers looking at the Mexico-City restriction (Hoy-No-Circula) as implemented in 1989
- Davis (JPE 2008): applying RDD to hourly pollution data found no effect in the short run; and also more cars in the long run
- Gallego-Montero-Salas (JPubE 2013): looking at carbon monoxide during morning peak hours (90% comes from vehicles unlike other pollutants) found
  - a 10% reduction in the short run but a 13% increase in the long run (after a year) and
  - great disparity in policy responses among income groups

Table 5
Policy effects by monitoring station: HNC.

Station	Sector	Income per HH (relative to average income)	Short-run effect	Long-run effect	Difference LR–SR	Months of adaptation	R^2	Observations
Xalostoc	NE	0.55	0.1196	0.1760	0.0564	12.5**	0.635	1222
			(0.1044)	(0.1118)	(0.0903)	(6.06)		
Tlalnepantla	NW	0.50[a]	−0.2132*	0.0760	0.2208*	9***	0.646	
			(0.1172)	(0.1730)	(0.1240)	(3.1)		
I.M. del Petróleo	NW	0.53	−0.1781***	0.1598	0.3379***	14***	0.666	1209
			(0.0627)	(0.1244)	(0.0910)	(1.91)		
M. Insurgentes	CE	0.70	−0.2458***	0.1427	0.3885***	15***	0.599	1473
			(0.0727)	(0.1026)	(0.1023)	(2.33)		
Lagunilla	CE	0.71	−0.2821***	−0.0652	0.2169*	11***	0.620	1403
			(0.0906)	(0.1030)	(0.1145)	(1.78)		
Merced	CE	0.84	−0.1527*	0.0807	0.2334**	12***	0.543	1588
			(0.0802)	(0.1310)	(0.1057)	(1.52)		
Cerro Estrella	SE	0.54	−0.1781**	0.2037*	0.3818***	11.5***	0.333	1499
			(0.0857)	(0.1196)	(0.1001)	(1.51)		
Taqueña	SE	1.14	−0.0948	0.2255**	0.3203***	15***	0.326	1381
			(0.0618)	(0.1277)	(0.1011)	(2.41)		
Plateros	SW	1.99	−0.0331	−0.0331	0.0000	0	0.579	1355
			(0.0973)	(0.0973)				
Pedregal	SW	1.99	−0.0338	0.1378	0.1716**	10.5***	0.590	1708
			(0.0789)	(0.0789)	(0.0852)	(3.06)		

Notes: Levels of significance are reported as ***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$.
[a] Authors' own estimate. Standard errors, in parentheses, are robust to heteroskedasticity and arbitrary correlation within 5-week groups.

the "Hoy-No-Circula" restriction at work: GMS (2013)



the new paper: driving restrictions may accelerate the introduction of cleaner cars

- there is an important long-run effect in some driving restrictions that has not been studied
- by only placing a restriction on old-polluting cars, they may help accelerate both the introduction of cleaner cars and the retirement of older cars
- the city of Santiago reformed its existing driving restriction policy in 1992 (Mexico-City in 1994) so that any new car was
  - required to be equipped with a catalytic converter (a device that reduces pollution considerably, specially lead)
  - and exempted from any driving restriction
- how did it work? not obvious for two reasons
  - there are two forces operating: some may bypass the restriction buying a new, cleaner car (sooner than otherwise), yet others may buy a second older car like in Hoy-No-Circula (which now can be even cheaper)
  - local vs global emissions (CO vs CO2)

abundant related literature on vehicle purchase/retirement decisions

- scrapping subsidies for the earlier retirement of old cars
  - Balladur and Juppé in France (Adda and Cooper, JPE 2000)
  - Cash for Clunkers program in the US in 1992 (Hahn, RAND 1995)
  - Cash for Clunkers program in the US in 2009 (Busse et al., NBER 2012; Mian and Sufi, QJE 2012)
- subsides on new/greener cars: the "Bonus/Malus" feebate program introduced in France in 2008 (D'Haultfoeuilley-Givordz-Boutin, 2012)
- scrappage decisions and gasoline policies (Jacobsen and van Benthem, NBER 2013)
- purchase of durable goods (Eberly, JPE 1994)

the Santiago 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 passed a new environmental standard (catalytic converter) would get a green sticker**
  - **new cars bought in 1993 and after without the green sticker couldn't drive in Santiago's Metropolitan Region and neighboring Regions V and VI (see map)**
  - **a car with a green sticker is exempt from any driving restriction**
- 1998: driving restriction (on 1992 and older models) becomes officially permanent
- 2003: restriction is extended to 40% of the fleet (4 digits every weekday are banned from circulation)

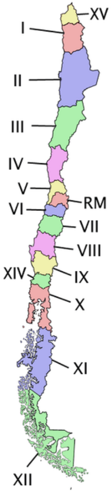


Figure: Chilean Map

Table: Some statistics of Chile and Santiago

	Chile	RM	Santiago
Population	16,926,084	6,891,011	5,015,070
Average income	$ 241,339	$ 292,498	$ 331,673
# of cars*	2,162,308	994,723	797,046
cars* *p.p.*	12.75%	14.44%	15.89%

(∗) counting only particular light cars

Figure: South America

our 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).

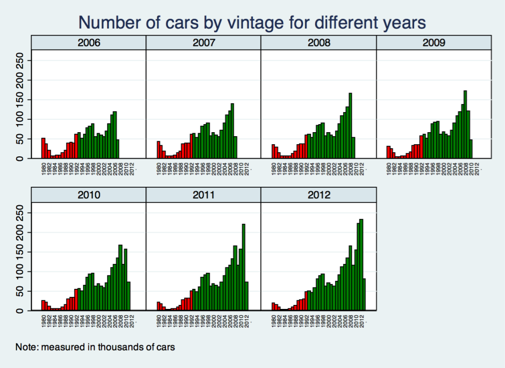


Figure: Evolution of the car fleet at the country level

Preliminary evidence: Santiago vs the rest of the country

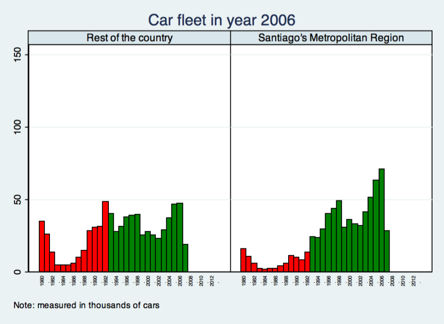


Figure: Fleet in 2006

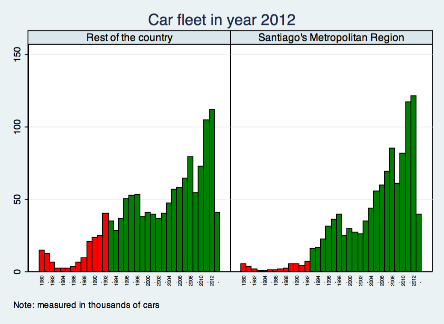


Figure: Fleet in 2012

- 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)

Preliminary evidence: Santiago vs the rest of the country

- normalizing every bar to 1 at a country level we can see a discontinuity around years 1992 and 1993.
- exploiting this discontinuity will be the main identification strategy

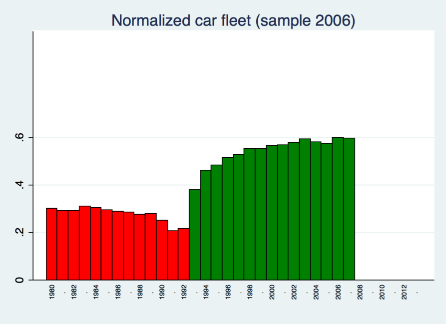


Figure: Metropolitan Region's normalized fleet in 2006

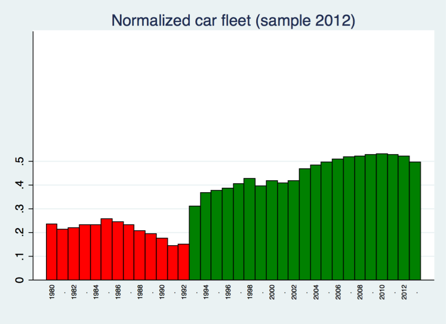


Figure: Metropolitan Region's normalized fleet in 2012

Santiago vs the rest of the country "controlling" for income

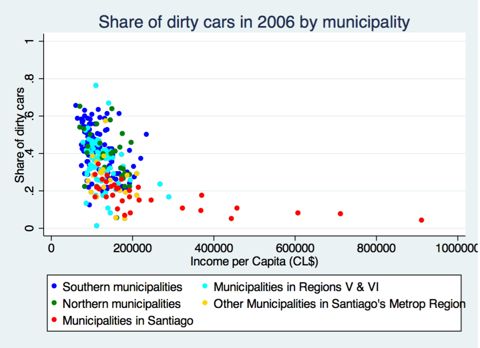


Figure: Red cars as function of income in 2006

- it seems that municipalities in Santiago (more than 30) have a smaller fraction of red cars (vintage 92 and older) in their fleets

controlling for income and used-car dynamics

- there may be different reasons behind the higher fleet turnover in Santiago
  - it could be the restriction policy
  - but also that a high turnover in high-income municipalites in Santiago results in a faster turnover in middle and low-income municipalities in the city (people get rid of a 92 car not because it is dirty but old)
- to test for this second possibility we look at the share of 92 and 93 cars, so let

$$92/93_{it} \equiv \frac{q_{1992}}{q_{1992} + q_{1993}}$$

be the 92/93 ratio in municipality i in sample year t

the 92/93 ratio: municipalities in Santiago vs the rest

- results supporting the policy effect look stronger now

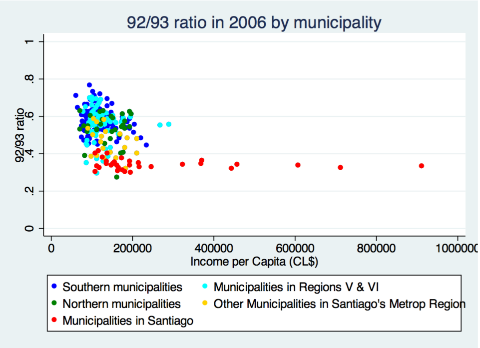


Figure: 92/93 ratio for sample 2006

92/93 ratio vs ratio for other adjacent vintages

- the "Santiago" effect only shows up for 92/93

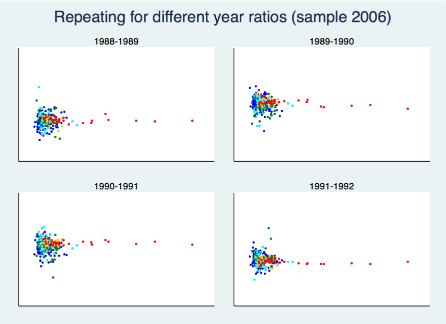


Figure: Vintages 88 to 92

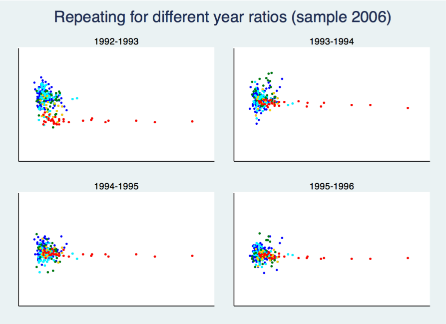


Figure: Vintages 92 to 96

more formally...

Table: OLS results for different adyacent-year ratios

	(1) 86-87	(2) 91-92	(3) 92-93	(4) 93-94	(5) 96-97
Santiago	-0.0322	-0.0133	-0.217***	-0.0195	-0.00156
	(0.054)	(0.027)	(0.023)	(0.024)	(0.016)
Population	-0.00982	-0.00399	-0.00858	-0.00607	-0.00319
	(0.011)	(0.005)	(0.005)	(0.005)	(0.003)
Income per Capita	-0.00795	0.00370	-0.000569	-0.00158	0.00230
	(0.014)	(0.007)	(0.006)	(0.006)	(0.004)
Income $*$ Santiago	0.0111	-0.00107	0.00215	0.000287	-0.00464
	(0.016)	(0.008)	(0.007)	(0.007)	(0.005)
Income variation	0.00970	0.00271	0.00832	0.00434	0.00658
	(0.014)	(0.007)	(0.006)	(0.006)	(0.004)
Distance to Santiago	-0.172**	-0.0242	0.0890***	0.0256	0.0156
	(0.062)	(0.030)	(0.027)	(0.027)	(0.019)
(Distance to Santiago)^2	0.0961**	-0.00990	-0.0693***	0.0283	0.00906
	(0.037)	(0.018)	(0.016)	(0.016)	(0.011)
North	0.0703*	0.0423**	0.00457	-0.0132	-0.0195*
	(0.029)	(0.014)	(0.012)	(0.013)	(0.009)
Urbanization	0.0540	0.0208	-0.0374**	-0.00974	-0.000775
	(0.034)	(0.016)	(0.014)	(0.015)	(0.010)
Constant	0.342***	0.360***	0.543***	0.527***	0.474***
	(0.034)	(0.017)	(0.015)	(0.015)	(0.010)
Observations	317	323	323	323	323
R^2	0.053	0.056	0.585	0.186	0.111

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Income per capita in hundreds of thousends of pesos.
Population in hundreds of thousends of persons.
Distance to Santiago in thousend of kilometers.

explaining the "Santiago effect" for 92/93

- the coefficient of Santiago in Table 1 for 92/93 accept two (not mutually exclusive) interpretations
  1. that there are fewer 92-vintage cars in Santiago (relative to the no-policy case) either because some were scrapped or displaced to other regions in the country (either way is good for local pollution)
  2. that are more 93-vintage cars than otherwise

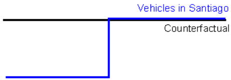


Figure: Case 1

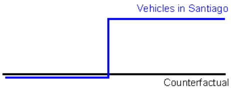


Figure: Case 2

- next challenge: see whether 1, 2 or both apply

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 $i = 1, ..., 323$?

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

where

- Pop_i: is the population of municipality i in year T (sample year, say, 2006)
- $Income_i$: is the income per capita in county i in year T
- $Santiago_i$: takes the value of 1 for municipalities in the city of Santiago
- δ_τ: vintage fixed effect.
- other controls included (see table 1)

plotting "Income" coefficients

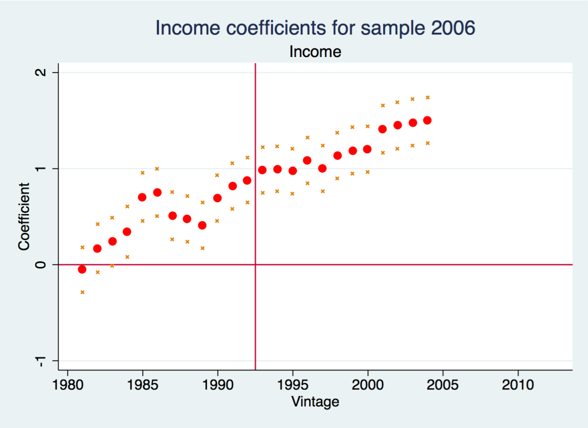


Figure: Sample 2006

the coefficient of Santiago for different vintages

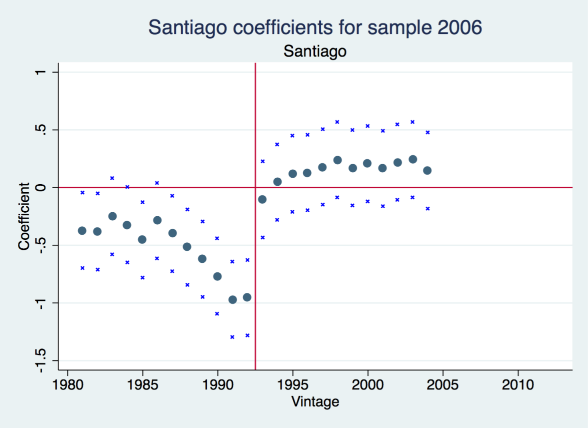


Figure: Sample 2006

a few of observations...

- the plot with the **Income** coefficients moves to the right as we move from the 2006 to the 2012 sample, making no distinction whether cars are "green" (93 and after) or "red" (92 and before)
- as for the **Santiago** coefficient, we have a significant discontinuity in the coefficients around the 92 and 93 vintages
- note that the coefficient for **Santiago** in 1993 is zero
- does this mean that the 92/93 is mostly explained by the exodus of 92 cars from Santiago to the rest of the country?
- notice also the drop of the **Santiago** coefficient as we approach 92 from the left

what we have learned so far

- two results
  1. fewer red cars in the city of Santiago relative to the rest of the country
  2. and indication of more green cars
- explaining results
  - (a) red vehicles that were retired from the national fleet
  - (b) red vehicles that were displaced from Santiago to rest of the country
- if (a) applies; regions act as a good control group (we should find differences in used car prices in Santiago and regions)
- but if (b) applies, counterfactual not as clean and two things may be happening (we should find used-car markets to be linked).
  1. national fleet remain unchanged....a larger fraction of the new cars go to Santiago and regions receive a larger fraction of used cars from Santiago
  2. national fleet expands with new cars...both because regions keep buying as before but Santiago buys more

some evidence from prices of used cars in Chile

- There is also some evidence of a discontinuity in used car prices between vintages 1992 and 1993

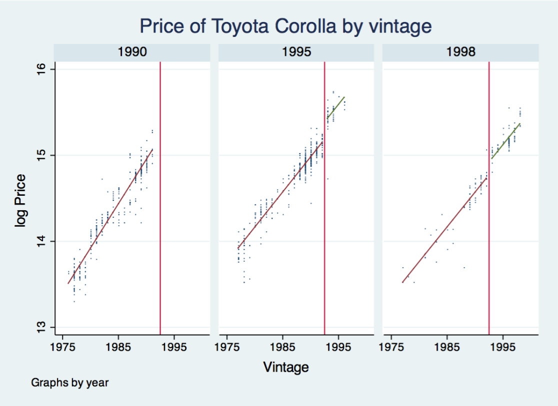


Figure: Price of used car Toyota Corolla by vintage

some evidence from prices of used cars in Chile

- Running the following OLS regression we find that cathalytic converter cars are in average between 15% and 20% more expensive.

$$p_{i\tau} = \alpha\tau + \beta Post_{\tau}^{1992} + \varepsilon_{i\tau}$$

	(1990)	(1995)	(1998)
Panel A: Linear control			
Vintage	-0.103***	-0.0816***	-0.0806***
	(0.001)	(0.001)	(0.003)
Post 1992		0.203***	0.151***
		(0.017)	(0.027)
Observations	486	623	169
R^2	0.937	0.932	0.941
Panel B: Non lineal control (2 degree polynomials)			
Post 1992		0.224***	0.210***
		(0.044)	(0.049)
Observations	486	623	169

Standard errors in parentheses

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

some evidence from prices of used cars in Chile

- For Honda Accord, for example, we can also find some cars that reported having a catalytic converter prior to 1993.
- Running a regression where the independant variable is a dummy when a car reported to have a catalytic converter for different car vintages we found a signifant difference in prices only 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

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

a model of fleet turnover

- There are three agents: **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 in the next period is $\gamma \in (0, 1)$.
- A car can be scrapped at any time for a residual value of v.

a model of fleet turnover

- There is a continuum of drivers of mass 1 that vary in their willingness to pay for the quality.
  A consumer that rents a vintage-τ car gets:

$$u(\tau, \theta) = \theta s_\tau - p_\tau$$

  where θ represents willingness to pay for quality, s_τ is the quality of the car (service that car provides) and p_τ is its rental price (including insurance, gasoline expenditure, etc).

- Consumers are distributed according to the cdf $F(\theta)$ over the interval $[\underline{\theta}, \overline{\theta}]$.

- A consumer that doesn't rent a car gets its outside utility (e.g., surplus from using public transport).

a model of fleet turnover

- 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 $\delta \in (0, 1)$.

the market equilibrium

- At the beginning of any given year t there will be some stock of used cars $\mathbf{Q}^t = \{q_1^t, q_2^t, ...\}$.
- 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 and one of vintage $\tau + 1$ at a lower price $p_{\tau+1}$

$$\theta_\tau s_\tau - p_\tau = \theta_\tau s_{\tau+1} - p_{\tau+1}$$

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

the market equilibrium

- It is possible to express the rental price of any used car ($\tau \geq 1$) at any point in time as a function of the rental price of a new car (p_0) and the series of cut-off levels as follows

$$p_\tau = p_0 - (1-\beta)s_0 \sum_{i=0}^{\tau} \beta^i \theta_i$$

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

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

the market equilibrium

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

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

- 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 (price taking) car dealers must break even, so today's and tomorrow's rental prices must be such that

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

where R is the age at which a car bought today, i.e., at t, is expected to be retired from the rental market (in steady state $R = T$)

- One last condition that must hold in equilibrium is that the lowest-valuation consumer to rent, θ_T , obtains her outside option, i.e., surplus from using public transport, which we normalize to zero

$$\theta_T s_T - p_T = 0$$

some preliminary insights from the model

- We can characterize the steady state for a set of parameter values (we are still working on computing the transition path)
- For now let (in the future these values are to be obtained from the data)

$$
\begin{aligned}
\theta &\sim U[0,1] \\
\beta &= 0.9 \\
\gamma &= 0.85 \\
\delta &= 0.9 \\
c &= 1 \\
v &= 0.25
\end{aligned}
$$

some preliminary insights from the model

- Let also the pollution damage associated to a vintage τ vehicle be given by

$$D_{\tau+1} = (\alpha + 1)D_\tau + \alpha, \qquad D_0 = 0$$

  increasing and convex in τ, with $\alpha = 0.1$.

- We can use the model to simulate how the fleet evolves in response to different policies including driving restrictions of different kinds, scrapping subsidies and also to Pigouvian taxes

Steady state without any intervention

- In equilibrium and without intervention we would get the following fleet

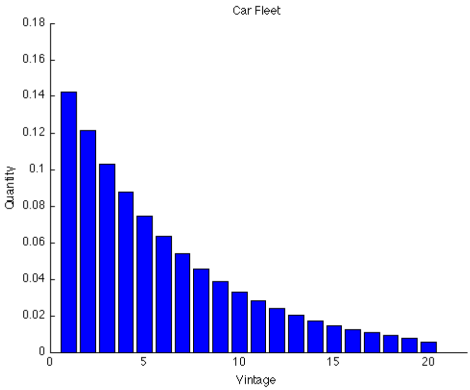


Figure: Car fleet without intervention

First Best

- Charging a Pigouvian tax we could reach the first best, which looks very different from the previous distribution

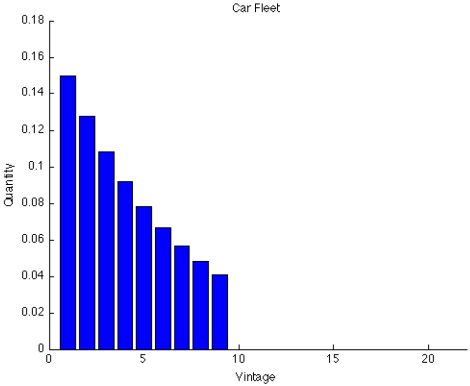


Figure: Car fleet with pigouvian taxes

France scrappage subsidy (1994)

- The french government offered a 5.000 franc subsidy for scrapping old cars. We can model it by increasing v in 0.08 units.

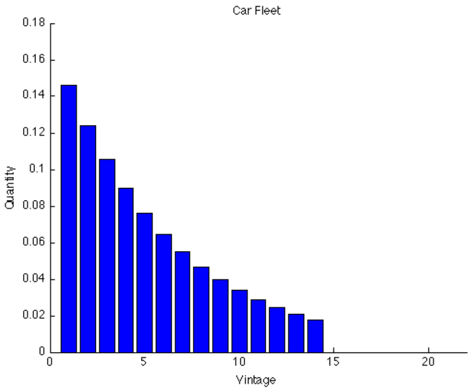


Figure: Car fleet with France scrappage subsidy program

France scrappage subsidy (1994)

- We could think, however, on a larger subsidy of 0.28 units that gets closer to the first best.

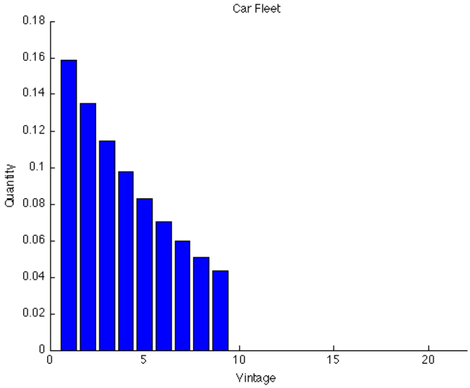


Figure: Car fleet with a greater subsidy

Driving restrictions (HNC)

- Another possible intervention is to forbid cars from driving one day on every week. In our model this is done by lowering the value of car quality s_T.

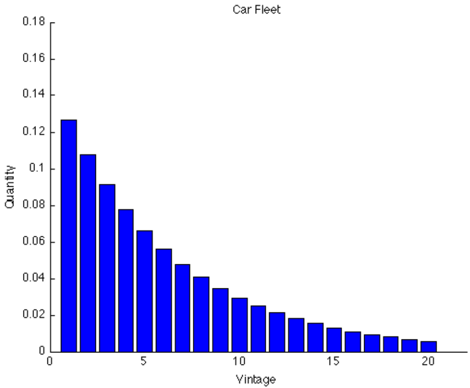


Figure: Car fleet under driving restrictions to all cars (HNC 1989, Stgo 1986)

- One could improve this policy by exempting new cars from the restriction. In Mexico restriction applies on average to cars older than 6 years.

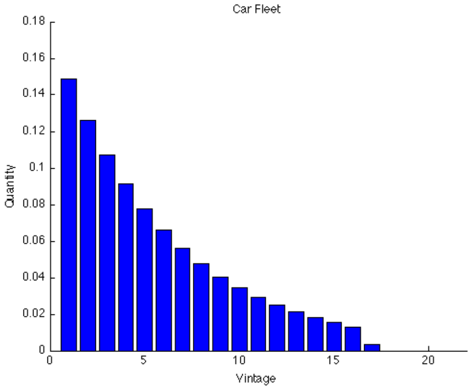


Figure: Car fleet under driving restrictions to older cars (HNC 1994)

Driving restrictions (HNC)

- This can also be improved in our model by lowering the expemtion to 4 years and decreasing the quality of cars 60% instead of 20%.

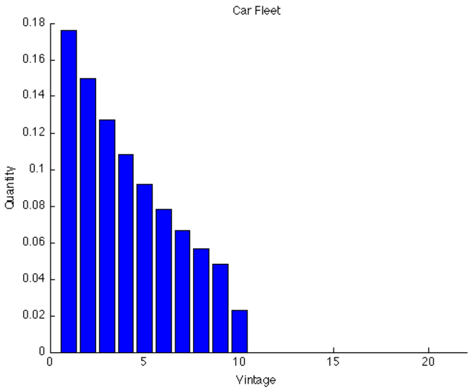


Figure: Car fleet under a stronger driving restrictions system

transition to the steady state

- The model also allows us to characterize the transition to the steady state.
- We simulated an economy where cars last 3 periods, starting without any cars, and implementing a scrappage subsidy in $t = 9$

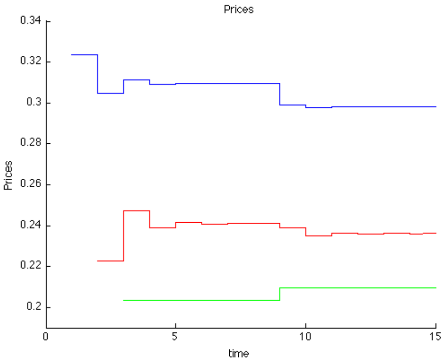


Figure: Evolution of prices p_{τ}^{t}

transition to the steady state

- The indifferent individuals in every period are given by the following graph

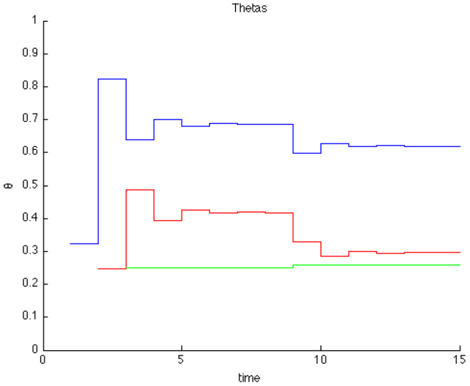


Figure: Evolution of θ_τ^t

Final remarks

- Driving restrictions are very popular in the developing world
- Across the board driving restrictions (e.g., the Mexico-City restriction in 1989) may lead to some pollution reduction in the short run (first month or so)
- but over the longer run, they are likely to lead to higher emissions as drivers buy a second and older car to by pass the restriction
- Driving restriction policies that exempt new and cleaner cars from the restriction (e.g., the Santiago restriction as reformed in 1992) accelarate the fleet turnover towards cleaner cars
- Since new cars eventually become old, this latter exemption should be for a limited number of years (following the Mexico-City reform of 1994)
- Well designed driving restrictions (e.g., exemptions for a limited number of years, banning the import of old cars, etc) can be an effective instrument for fighting pollution (clearly not for fighting congestion).