The Effect of Transport Policies on Car Use: Theory and Evidence from Latin American Cities

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Motivation

- Air pollution and congestion remains serious problems in Latin American cities because of steady increase in car use (Economist Intelligence Unit, 2010).
- Two examples of drastic policy intervention:
  - Hoy-No-Circula (HNC) in Mexico-City:
    - driving restriction established in November 1989
    - most drivers cannot use their vehicles one day of the week
    - near universal compliance (Eskeland Feyzioglu, 1997; Davis, 2008)
  - TranSantiago (TS) in Santiago-Chile:
    - major public transportation reform in February 2007: reduction in the number of buses and a radical change in the design and number of routes: subway acting as the hub in a hub-and-spoke network.
    - major policy failure (Briones, 2009; Munoz et al, 2009) particularly at peak hours: persistent increase in travel time, uncertainty in service, acid test: sharp increase in price of taxi medallions.
    - The Economist (Feb 7th, 2008) referred to TS as "...a model of how not to reform public transport"

▸ Transantiago collapse ▸ Before and after TS ▸ Prices of taxi licenses

This paper

- What do we learn from these policy interventions on the way households decide between cars and public transport? (and hence on local pollution, congestion, and CO_2 emissions?)
- Interested in both:
  - short-run responses (e.g. Davis 2008, for HNC): how much flexibility is there in the short-run?
  - long-run responses (see Duranton and Turner (2011) for longer run): how long does it take for households to adjust their stock of vehicles? how much does it depend on income or location?
- Hard to construct a counterfactual for policy evaluation: transportation systems remarkably complex and dynamic (Small and Verhoef, 2007)
- Why HNC and TS?: drastic interventions like any other in the region; great income disparity within cities; interesting to contrast household responses of two different cities

Plan of the Talk

1. Look at the data
2. Results
3. Theory: making sense of these empirical results.
    1. A model of car ownership.
    2. Calibration and simulations.
    3. Welfare analysis
4. Conclusions.

Map of the Empirical Analysis

- Carbon monoxide (CO) analysis (for both HNC and TS):
  - results at the city-level
  - and by monitoring stations (i.e., neighborhood)
- Additional exercises (only for TS):
  - gasoline sales
  - car registration (car stock, trades of used cars, sales of new cars)
  - traffic flows

Quick look at the data

- main data set: hourly records of carbon monoxide (CO) from monitoring stations
- Mexico-City (HNC): 15 monitoring stations with hourly concentration records for 5 criteria pollutants and 4 weather variables
- Santiago (TS): 7 monitoring stations with hourly records for 5 criteria pollutants and 5 weather variables
- Vehicles are responsabile for most CO emissions (unlike other pollutants)
- Other papers using this high frequency pollution data: Davis (2008) for HNC.
- We compare CO levels before and after policy implementation (for different hours of the day and different days of the week) with a focus on a 4-year window around policy implementation
- Stations: ▸ Mexico ▸ Chile

Figure: CO observations for Mexico-City

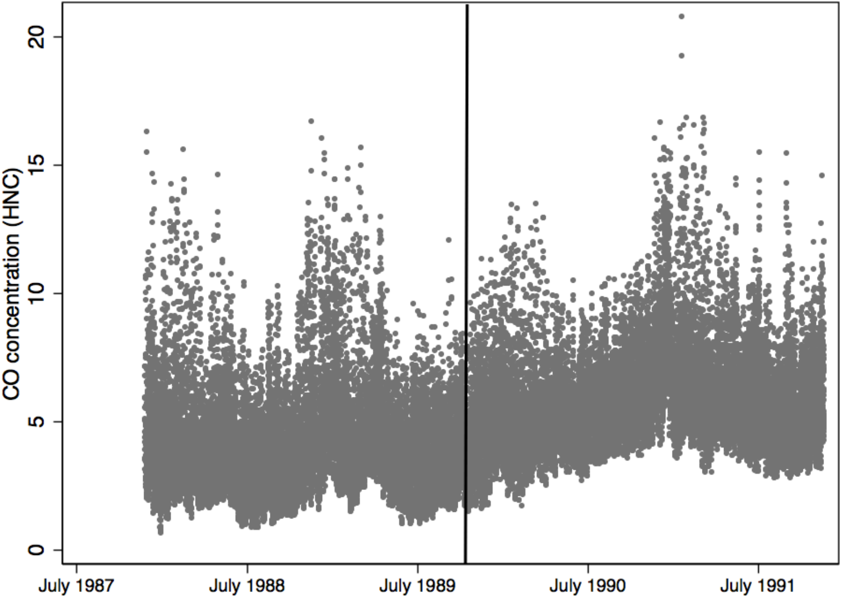


Figure: CO observations for Santiago

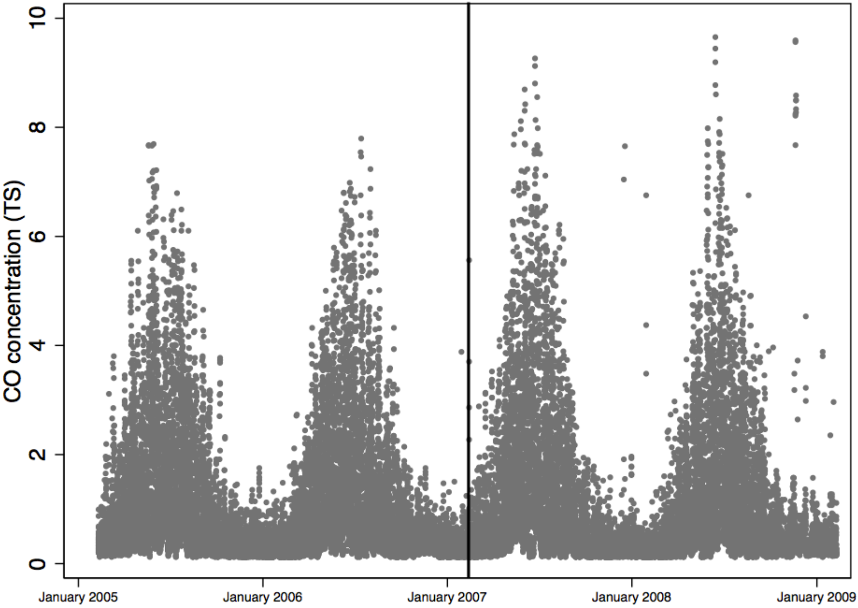


Figure: HNC Short Run

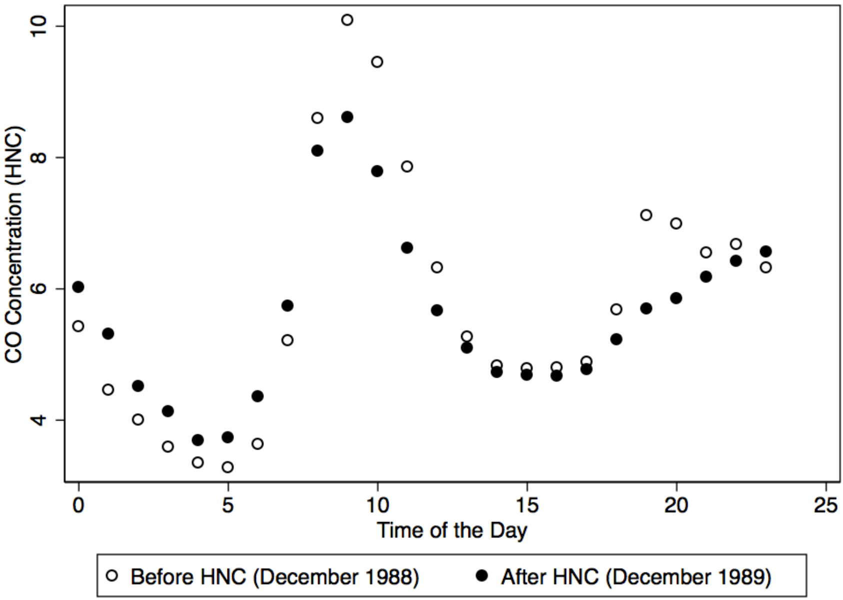


Figure: HNC Long Run

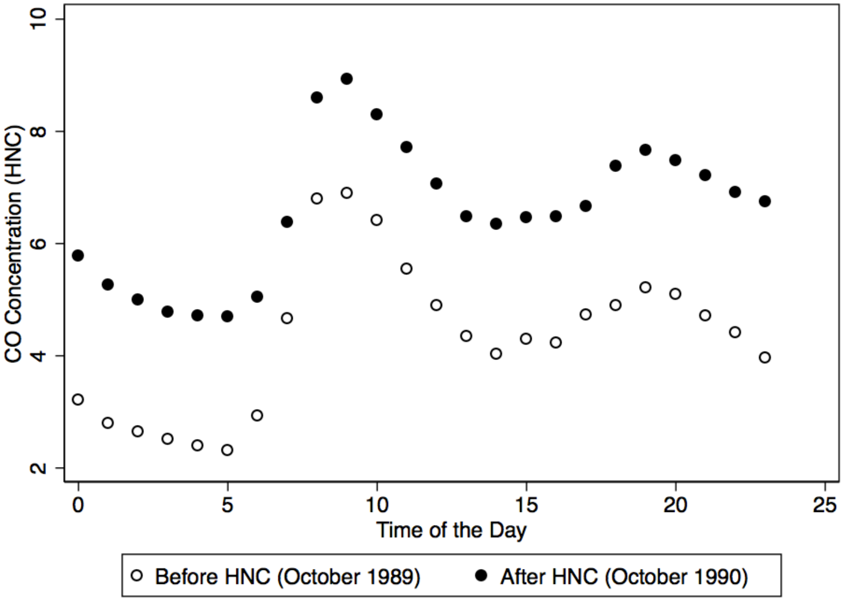


Figure: TS Short Run

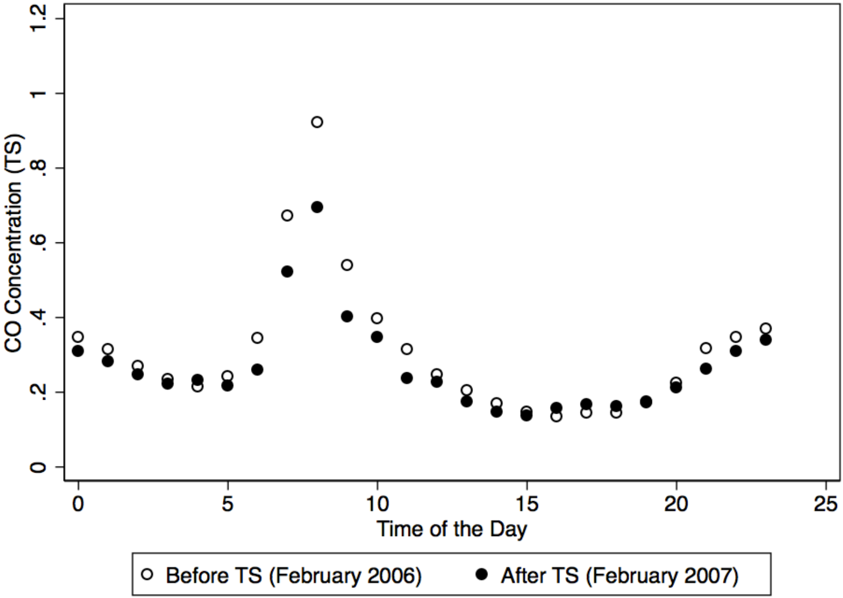
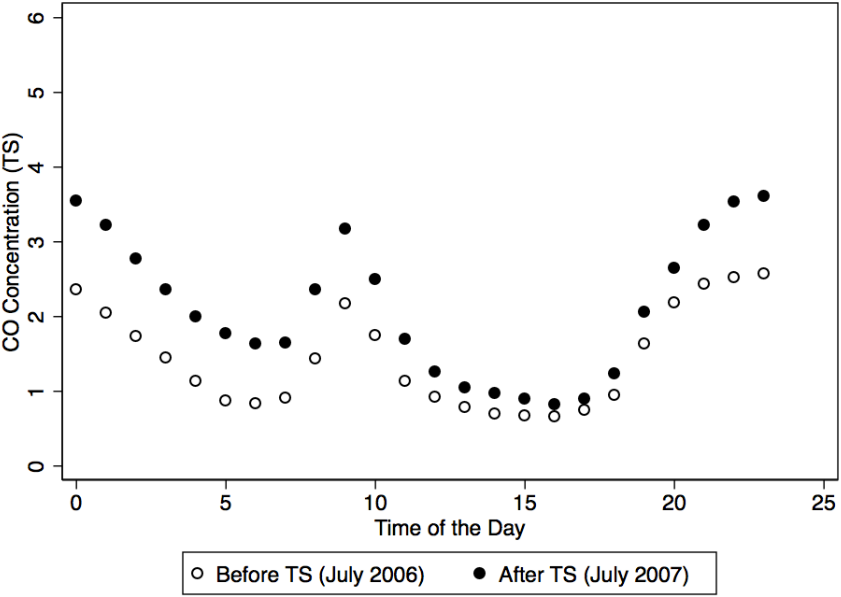


Figure: TS Long Run



Why CO?

- Mobile sources are responsible for 97% of CO in HNC (Molina and Molina, 2002) and 94% in TS (DICTUC, 2009).
- Contribution of light vehicles (passanger cars and commercial vehicles other than buses and trucks): 72% in HNC and 85% in TS.
- Only pollutant non-reactive on a time scale of 1 day (Schmitz, 2005).
- It has a relatively short residence time (more so under windier and warmer conditions).
- All these are important for identification because concentration can act as a good proxy for emissions.
- CO records are good at capturing simultaneously: more cars, older cars and more congestion.

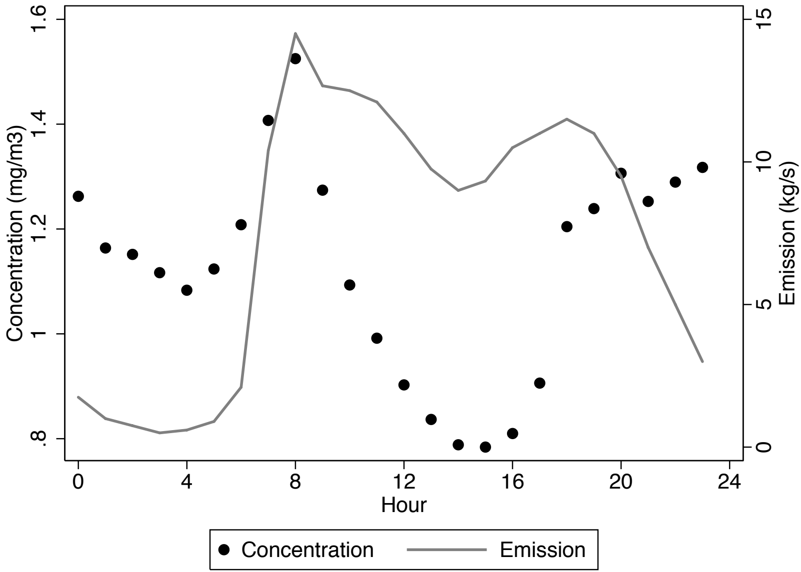
Empirical challenges

- pollutant data highly volatile (recall figures above) which makes an RDD (regression discontinuity design) approach for short-run responses less reliable (more on this later)
- our strategy is to estimate simultaneously short and long-run impacts
- our main results come from estimations at city and the station level and mainly at peak hours for weekdays
  - because of income disparity (model predicts quite different responses)
  - peak records are not contaminated, i.e., capture local activity (see figure)
- counterfactual for long-run impact? how we control for other time-varying factors (weather, economy, etc)?
  - different falsification exercises (policy starts year before, etc)
  - control group not affected by policy (city of Quillota close to Santiago but not affected by TS; none like it in Mexico-City)
  - how income affects policy response is quite consitent with model predictions

Table: Measuring CO volatility

$P(\|x_t - x_{t-1}\| > a \cdot x_{t-1})$	HNC	TS
$a = 0.01$	94.3%	97.8%
$a = 0.05$	75.9%	90.2%
$a = 0.10$	54.6%	78.3%
$a = 0.20$	26.6%	59.2%
$a = 0.30$	15.2%	43.6%
$a = 0.40$	9.6%	30.4%
$a = 0.50$	7.4%	22.7%
$a = 0.60$	6.6%	15.7%
$a = 0.70$	6.0%	11.4%
$a = 0.80$	5.8%	8.7%
$a = 0.90$	5.7%	7.5%
$a = 1.00$	5.5%	6.1%

Figure: Emissions vs concentration: weekday in Santiago, January 2002 (Schmitz, 2005)



Empirical Strategy

- 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

Summary of CO empirical results

	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

	Santiago (TS)		
	short-run	long-run	T(months)
peak-hours (7-8 am)	-5%	+28%	7
off-peak	?	?	?
sunday	?	?	?

Alternative RDD estimates

What we learn from these results

- The short-run response in HNC shows that driving restriction policies can be quite effective in the very short-run, that is, enforcement is possible (not in, e.g., Davis 2008 and Eskeland and Feyzioglu, 1997). This can help in the design of policies for tackling one-day episodes of high pollution.
- The short-run response in TS is consistent with negligible short-run cross elasticities of Litman (2004), but also with canceling forces: less congestion from fewer buses and more cars on the street.
- The long-run response in both cases indicate that households adjust rather quickly, quicker than that suggested by the earlier literature on consumption of durable goods (e.g., Caballero, 1990) but closer to the more recent literature (e.g., Chah et al., 1995; Gallego et al., 2001).
- There are also additional results showing how responses vary with income (more later)

HNC Results: City Average and by Stations

Table: HNC effect on CO concentration (flexible approach)

	Peak			Off-Peak				Sunday		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HNC	0.129	0.122	0.289***	0.084*	0.046	0.092*	0.161**	0.143**	0.125*	0.173
	(0.087)	(0.091)	(0.093)	(0.044)	(0.055)	(0.052)	(0.067)	(0.068)	(0.070)	(0.139)
Month 1	-0.199***	-0.173***	-0.350***	-0.161***	-0.118***	-0.187***	-0.269***	-0.109	-0.091	-0.260**
	(0.067)	(0.063)	(0.067)	(0.040)	(0.043)	(0.041)	(0.048)	(0.074)	(0.079)	(0.109)
Month 2	-0.214***	-0.180***	-0.278***	-0.131***	-0.095**	-0.152***	-0.207***	-0.106**	-0.109**	-0.225***
	(0.052)	(0.052)	(0.050)	(0.034)	(0.036)	(0.031)	(0.036)	(0.046)	(0.045)	(0.077)
Month 3	-0.151***	-0.114**	-0.289***	-0.122***	-0.096***	-0.129***	-0.218***	-0.074	-0.065	-0.220***
	(0.046)	(0.048)	(0.050)	(0.033)	(0.031)	(0.032)	(0.032)	(0.046)	(0.044)	(0.073)
Month 4	-0.092*	-0.064	-0.159**	-0.126***	-0.096***	-0.120***	-0.161***	-0.059	-0.024	-0.115
	(0.047)	(0.051)	(0.060)	(0.035)	(0.033)	(0.030)	(0.033)	(0.049)	(0.046)	(0.080)
Month 5	-0.197***	-0.184***	-0.244***	-0.086***	-0.049	-0.126***	-0.160***	-0.101	-0.104	-0.181**
	(0.049)	(0.051)	(0.065)	(0.029)	(0.036)	(0.039)	(0.044)	(0.079)	(0.074)	(0.085)
Month 6	-0.151***	-0.077*	-0.071	-0.031	0.069	0.035	0.033	-0.034	-0.012	-0.045
	(0.039)	(0.040)	(0.052)	(0.038)	(0.046)	(0.051)	(0.059)	(0.054)	(0.052)	(0.109)
Month 7	-0.245***	-0.171***	-0.120**	-0.027	0.062*	0.008	0.036	-0.098**	-0.064	-0.051
	(0.037)	(0.035)	(0.054)	(0.027)	(0.034)	(0.033)	(0.041)	(0.041)	(0.040)	(0.077)
Month 8	-0.166***	-0.104***	-0.027	0.013	0.077**	0.037	0.070*	0.048	0.059	0.110
	(0.039)	(0.036)	(0.040)	(0.030)	(0.032)	(0.032)	(0.036)	(0.044)	(0.042)	(0.075)
Month 9	-0.114***	-0.077**	0.023	0.013	0.108***	0.090**	0.139***	0.054	0.087**	0.204***
	(0.040)	(0.037)	(0.038)	(0.031)	(0.034)	(0.036)	(0.036)	(0.042)	(0.040)	(0.064)
Month 10	-0.064	-0.039	0.062	-0.070*	0.006	-0.005	0.052	0.029	0.046	0.210**
	(0.044)	(0.042)	(0.044)	(0.038)	(0.038)	(0.044)	(0.044)	(0.051)	(0.049)	(0.080)
Month 11	0.021	0.010	0.118**	0.018	0.072*	0.081	0.139***	0.084*	0.082*	0.259***
	(0.050)	(0.048)	(0.056)	(0.044)	(0.042)	(0.049)	(0.048)	(0.044)	(0.044)	(0.070)
Month 12	0.061	-0.046	0.036	0.077	0.010	-0.006	0.034	0.061	0.016	0.128
	(0.075)	(0.053)	(0.082)	(0.058)	(0.041)	(0.054)	(0.068)	(0.044)	(0.040)	(0.076)
Y_{night}	0.339***	0.374***		0.058	0.054	0.173***		0.526***	0.535***	
	(0.052)	(0.050)		(0.038)	(0.042)	(0.049)		(0.033)	(0.034)	
SO_2	0.258***			0.289***				0.100**		
	(0.046)			(0.025)				(0.038)		
Y_{peak}				0.294***	0.356***					
				(0.035)	(0.040)					

Table: HNC effect on CO concentration (estimation with structure)

	Peak	**Off-Peak**	**Sunday**
	(1)	(2)	(3)
Immediate impact	-0.130**	-0.094***	0.022
	(0.051)	(0.029)	(0.037)
Adaptation trend	3.29e-05***	3.40e-05***	2.75e-05***
	(0.935e-05)	(5.83e-06)	(8.59e-06)
Impact after adaptation	0.113	0.092**	0.189***
	(0.081)	(0.041)	(0.043)
Trend	-9.13e-06*	2.83e-06	-7.60e-07
	(4.65e-06)	(2.85e-06)	(3.39e-06)
Real exchange rate	-0.646**	-0.512*	-0.065
	(0.279)	(0.291)	(0.318)
Y_{night}	0.313***	0.061	0.532***
	(0.050)	(0.038)	(0.031)
Y_{peak}		0.294***	
		(0.036)	
SO_2	0.236***	0.281***	0.092**
	(0.046)	(0.025)	(0.036)
Months of adaptation	12.5	8	9.5
	(1.74)	(0.92)	(1.68)
After - Immediate impact (p-value)	0.000	0.000	0.000

Within city estimates

- Estimates for different stations in both cities (only possible at peak hours: contamination across stations at other times).
- Why?
  - Heterogeneity in income, car stock (before policy) in HNC and in the case of TS: heterogeneity in intensity of policy.
  - Policy evaluation.
- Similar empirical approach and control for factors at the station level.

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)

TS Results: City Average and by Stations

Table: TS effect on CO concentration (flexible approach)

	(1)	(2)	(3)	(4)
TranSantiago	0.321***	0.312***	0.278**	0.357***
	(0.075)	(0.078)	(0.103)	(0.121)
Month 1	-0.322***	-0.284**	-0.087	-0.237**
	(0.100)	(0.105)	(0.100)	(0.114)
Month 2	-0.311***	-0.309***	-0.275***	-0.450***
	(0.073)	(0.078)	(0.087)	(0.096)
Month 3	0.020	0.021	0.051	0.141*
	(0.052)	(0.055)	(0.066)	(0.082)
Month 4	-0.220***	-0.202***	-0.143*	0.081
	(0.053)	(0.055)	(0.081)	(0.093)
Month 5	0.012	0.029	0.035	0.101
	(0.064)	(0.064)	(0.079)	(0.116)
Month 6	-0.137	-0.148	-0.174*	-0.040
	(0.087)	(0.095)	(0.100)	(0.108)
Month 7	-0.032	-0.043	-0.104	-0.097
	(0.094)	(0.127)	(0.114)	(0.197)
Month 8	-0.466***	-0.459***	-0.647***	-0.782***
	(0.067)	(0.062)	(0.077)	(0.121)
Month 9	0.087	0.149*	0.010	-0.239*
	(0.095)	(0.082)	(0.095)	(0.141)
Month 10	-0.022	0.119*	-0.036	-0.264***
	(0.060)	(0.063)	(0.072)	(0.083)
Y_{night}	0.414***	0.395***	0.494***	
	(0.026)	(0.024)	(0.027)	
SO_2	0.503***	0.497***		
	(0.085)	(0.086)		

Table: TS effect on CO concentration (estimation with structure)

	(1)	(2)
Immediate impact	-0.059	-0.052
	(0.098)	(0.091)
Adaptation trend	8.38e-05***	9.36e-05***
	(2.50e-05)	(2.59e-05)
Impact after adaptation	0.268***	0.283***
	(0.071)	(0.072)
Trend	1.12e-05***	1.02e-5***
	(2.80e-06)	(3.07e-06)
Real exchange rate	-0.493	-0.428
	(0.309)	(0.334)
Y_{night}	0.431***	0.408***
	(0.026)	(0.023)
$S0_2$	0.541***	0.537***
	(0.085)	(0.087)
Months of adaptation	7	6
	(0.86)	(0.73)
After - Immediate impact (p-value)	0.008	0.003

Table: Policy effects by station: TS

Station	Sector	Income per HH (relative to average income)	Ratio of buses to total flows at peak hours (before-TS)	Percentage change in bus availability (after-TS)	Short-run effect	Long-run effect	Months of adaptation
El Bosque	S	0.53	10.8%	-34.6%	-12.46%	20.20%**	5.5 (1.52)
Cerro Navia	W	0.54	13.0%	-28.1%	-6.99%	39.79%***	7 (1.25)
Pudahuel	W	0.65	11.2%	-26.7%	-5.68%	34.65%***	7 (1.71)
Cerrillos	SW	0.81	10.5%	-29.3%	-7.15%	35.80%**	9 (2.33)
Independencia	N	0.93	6.2%	-30.2%	-2.88%	29.15%***	7 (1.53)
La Florida	SE	1.06	7.6%	-29.5%	0.13%	32.28%***	5 (0.73)
Las Condes	NE	2.45	2.2%	-31.9%	-4.31%	16.63%**	4.5 (1.11)

Table: CO Correlation Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Santiago:															
1. La Paz	1														
2. La Florida	0.819	1													
3. Las Condes	0.420	0.584	1												
4. Parque O'Higgins	0.788	0.757	0.169	1											
5. Pudahuel	0.836	0.842	0.394	0.905	1										
6. Cerrillos	0.693	0.771	0.323	0.826	0.888	1									
7. El Bosque	0.854	0.883	0.358	0.890	0.922	0.812	1								
8. Cerro Navia	0.735	0.701	0.170	0.887	0.942	0.860	0.846	1							
Regions:															
9. Temuco	0.111	0.308	0.151	0.003	0.145	0.120	0.108	0.121	1						
10. Con Con	-0.128	0.011	-0.222	-0.144	-0.161	-0.130	-0.065	-0.193	0.222	1					
11. Iquique 1	0.118	0.273	0.121	0.060	0.046	0.110	0.152	-0.013	0.028	0.220	1				
12. Iquique 2	0.246	0.110	0.082	0.041	0.123	0.256	0.106	0.147	-0.255	-0.509	0.013	1			
13. Quillota	0.533	0.724	0.405	0.481	0.619	0.584	0.656	0.521	0.313	0.310	0.336	-0.094	1		
14. Rancagua	0.205	0.146	0.020	0.269	0.267	0.129	0.189	0.329	0.360	-0.101	-0.459	-0.244	-0.133	1	
15. Viña del Mar	-0.262	-0.118	0.180	-0.410	-0.415	-0.421	-0.291	-0.572	-0.087	0.251	0.009	-0.160	-0.136	-0.095	1

Table: Falsification exercise and diff-in-diff using a different control group

	Falsification		Diff-in-diff	
	(1)	(2)	(3)	(4)
TranSantiago	0.048		0.256*	
	(0.173)		(0.133)	
Immediate impact		-0.013		0.092
		(0.140)		(0.164)
Adaptation trend		-2.64e-05		3.30e-05
		(3.50e-05)		(3.51e-05)
Impact after adaptation		0.078		0.264**
		(0.148)		(0.119)
Trend	-3.94e-06	-4.82e-06	-7.11e-06	-6.26e-06
	(6.83e-06)	(6.08e-06)	(6.20e-06)	(6.21e-06)
Y_{night}	0.885***	0.919***		
	(0.076)	(0.078)		
ΔY_{night}			0.576***	0.585***
			(0.047)	(0.048)
SO_2	-0.033	-0.019		
	(0.021)	(0.022)		
ΔSO_2			0.022	0.031
			(0.025)	(0.023)

Additional Results for TS: Gasoline sales

- Our approach: Diff-in-diff regressions of monthly sales (including region-specific trends).
  - Increase in per-capita sales by between 4.8 and 5.8 log points ▸ TS effect on gasoline sales.
  - Size consistent with CO effects: simple regression of CO concentration on gasoline sales (for Santiago) implies an elasticity of 4.
- HNC? We do not have data to estimate the same type of regressions but Eskeland and Feyzioglu (1997) and Davis (2008) find no evidence of reduction in gasoline sales and Eskeland and Feyzioglu (1997) find evidence of an increase of about 7%.

Additional Results for TS: Car registrations

- Three margins: total cars registered (annual data), sales of new cars (monthly data), trades of used cars (monthly data).
- Our approach: Diff-in-diff regressions (including region-specific trends).
  - Increase of car stock of between 3.8% and 11.9% TS effect on car registrations
  - ...Mostly ($\sim 2/3$) related to new cars and big impact on first year on car trades TS effect on trades and sales
- HNC? We do not have data to estimate the same type of regressions but both Eskeland and Feyzioglu (1997) and Davis (2008) find evidence of a significant increase in the car stock mostly related to imports of used cars from other Mexican regions.

Additional Results for TS: Traffic flows

- Natural candidate por policy evaluation: hourly records of vehicle traffic from traffic control stations scattered across the city but some problems...
    1. just data for Santiago
    2. cover just part of the city
    3. general equilibrium and displacement effects
    4. not easy to disentangle between private vehicles and buses
- Use data for 29 counting stations, aggregate them into two groups: (i) high income stations and (ii) middle-low income stations, and subtract estimates of changes in bus flows (two scenarios).

Table: TS Effects on traffic flows

Final	Peak hours	Off-peak hours
	Scenario 1: decrease of bus flows by 30%	
High-income stations flows	0.00	-0.05
	(0.08)	(0.05)
Low-income stations flows	0.14**	0.05
	(0.07)	(0.04)
	Scenario 2: decrease of bus flows by 20%	
High-income stations flows	0.00	-0.05
	(0.22)	(0.04)
Low-income stations flows	0.13**	0.05
	(0.06)	(0.03)

Summary of additional exercises

- Gasoline sales: TS effect about 5%.
- Stock of cars: TS effect of between 4-10%.
- Traffic flows: TS effect bigger in middle/low income areas, close to 0 in high-income areas, and slightly bigger at peak hours.

Theory: making sense of these empirical results

- Household's problem: allocation of existing vehicle capacity to competing uses (peak vs off-peak hours) and decision to adjust capacity in response to a policy shock.
- Short and long-run effects on car travel for peak and off-peak hours can be different.
- Same model can accomodate for both HNC and TS policies.
- Simple model: we (partially) borrow from the non-linear pricing (or bundling) literature (e.g. McAfee et al 1989; Armstrong and Vickers 2010).

A model of car ownership I

Households

- Choice: polluting cars vs pollution-free outside option (buses) for travel during peak (h) and off-peak (l) hours (for a weekday).
- Heterogeneity in preferences:
    - Horizontal differentiation: two-dimensional Hotelling model: $(x^h, x^l) \in [0,1] \times [0,1]$, where x^h and x^l are the household's distance to the car option for peak and for off-peak hours, respectively. Product differentiation (or transport cost) parameters are t^h and t^l.
    - Vertical differentiation: inelastic travel demands $(q^h, q^l) \in [0,1] \times [0,1]$, where q^h and q^l are travel quantities.
- Household can own $s \in [0, 1, 2]$ vehicles. Cars come with a capacity restriction depending on s:
    - if $s = 1$, capacity is $k < 1$.
    - is $s = 2$, no capacity constraints.

- Public transportation has no capacity restriction.
- Unit costs:
  - unit cost of using the car is p_c^i for $i = h, l$; and of taking the bus is p_b^i.
  - assume them as exogenously given: $\Delta p^i \equiv p_b^i - p_c^i$.
- Utility depends on the stock of vehicles and whether capacity is binding or not, e.g.

$$u(\cdot|s) = v - p_c^h q^h - p_b^l q^l - t^h x^h - t^l(1 - x^l)$$

- (Long-run) stock choice:

$$s^* = \arg\max_s [u(\cdot|s) - rs]$$

where r is the cost of buying a car (if $r < \min\{t^h, t^l\}$, households with strong preferences for cars, say $x^h = 0$ or $x^l = 0$, buy a car even if $q^h = q^l \approx 0$).

- The structure of the model allows us to sequence the analysis from vertical to horizontal preferences:
    - first, segment households on the likelihood of buying one or two cars from looking at q^h and q^l.
    - then, which of these households will buy and use the car(s) from looking at x^h and x^l.
- Two comparative static exercises:
    - increase in Δp^h by some small and permanent amount ε (TS)
    - decrease in k by some small and permanent amount ε (HNC)

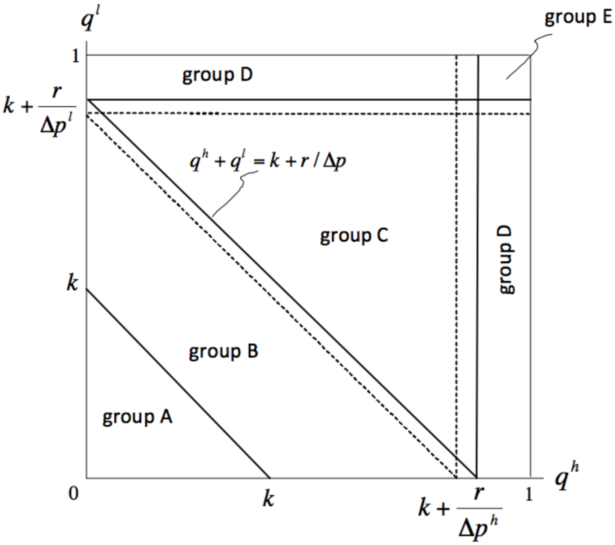


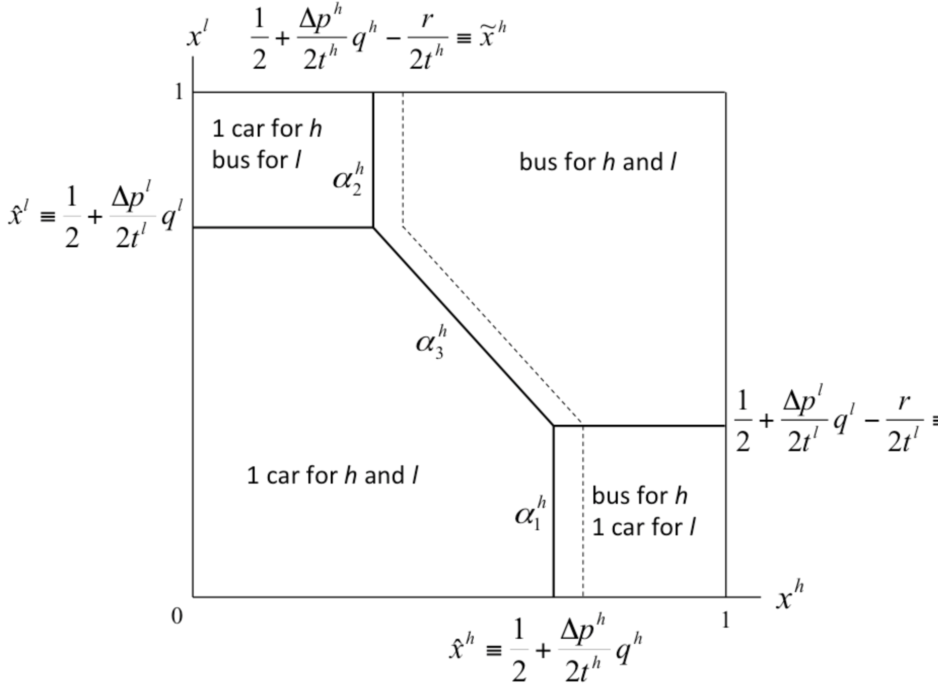
Figure 2.1. Decision to o n a vehicle based on vertical preferences

More Figures

Exercise 1: Effect of a TS-type policy

- Effect of TS ($\uparrow \Delta p^h$) upon group A: $q^h + q^l \leq k$ and $s \in \{0, 1\}$.
- Short run impact: unlike households that buy (and use) the car-bundle, households that only use the car for l-travel (the "two-stop shoppers") have spare car-capacity that is ready to be used for h-travel.

  $\longrightarrow$ there is an immediate (i.e., short run) increase in car trips (and pollution) during $h(\alpha_1^h)$.
- Long-run impact: extra increase in car travel (and pollution) from additional car purchases (α_2^h and α_3^h).

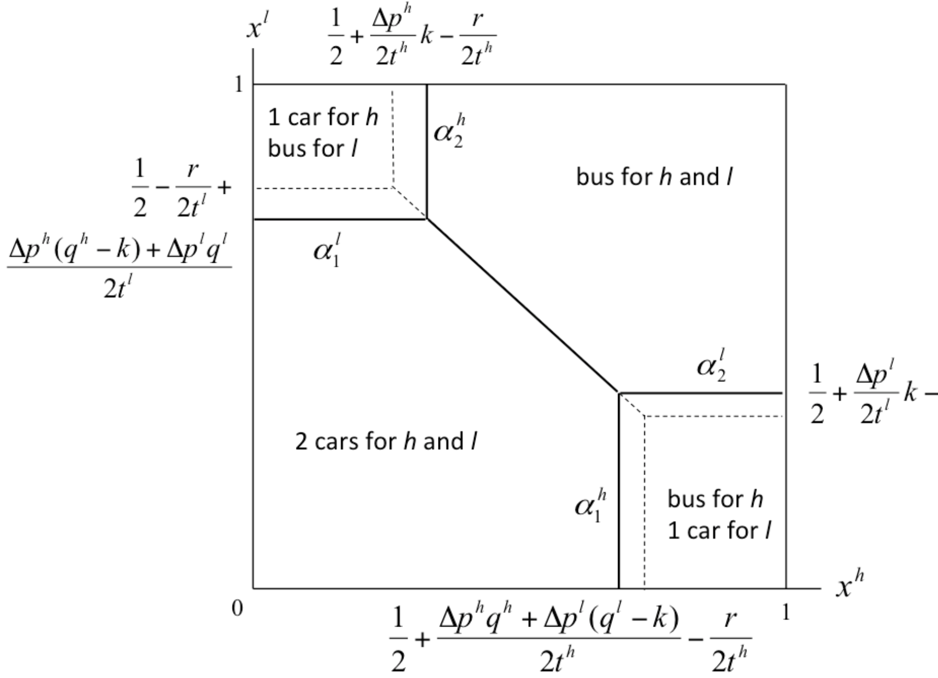

x^l
$\frac{1}{2}+\frac{\Delta p^h}{2t^h}q^h-\frac{r}{2t^h}\equiv\tilde{x}^h$
1
1 car for h
bus for l
α_2^h
bus for h and l
$\hat{x}^l\equiv\frac{1}{2}+\frac{\Delta p^l}{2t^l}q^l$
α_3^h
$\frac{1}{2}+\frac{\Delta p^l}{2t^l}q^l-\frac{r}{2t^l}$
1 car for h and l
α_1^h
bus for h
1 car for l
0
1
x^h
$\hat{x}^h\equiv\frac{1}{2}+\frac{\Delta p^h}{2t^h}q^h$

Exercise 2: Effect of HNC-type policy

- Effect of HNC ($\downarrow k$) upon group C: $q^h, q^l > k$ and $s \in \{0, 1, 2\}$.
- Short-run effect: drop by the amount ε of car trips from the two-stop shoppers.
- Long-run effects
  - some would like to sell their cars if resale price were r (α_2^h and α_2^l) like in Eskeland and Feyzioglu (1997). But what ig transaction/lemon costs (Eberly, 1994)?
  - some buy a second car; not only by-passing the driving restriction for their i trips but now also using the car for all of their j trips (α_1^h and α_1^l). This is by far the most adverse effect of a driving restriction.

$\longrightarrow$ non-trivial movement of people to buy and sell cars.

$\longrightarrow$ effects on both h and l need not be the same.



x^l
$\frac{1}{2}+\frac{\Delta p^h}{2t^h}k-\frac{r}{2t^h}$
1
1 car for h
bus for l
α_2^h
bus for h and l
$\frac{1}{2}-\frac{r}{2t^l}+$
$\frac{\Delta p^h(q^h-k)+\Delta p^l q^l}{2t^l}$
α_1^l
α_2^l
$\frac{1}{2}+\frac{\Delta p^l}{2t^l}k-$
2 cars for h and l
α_1^h
bus for h
1 car for l
x^h
0
1
$\frac{1}{2}+\frac{\Delta p^h q^h+\Delta p^l(q^l-k)}{2t^h}-\frac{r}{2t^h}$

Numerical exercises

- **HNC-type policy shock**: capacity falls from k_0 to $k_1 < k_0$.
  - preferences from uniform distributions, i.e., $f(x^h, x^l) = g(q^h, q^l) \equiv 1$.
- SR: impact right after implementation
- LR: impact after households have adjusted their stocks
- **TS-type policy shock**: prices move (increase) from Δp_0^i to Δp_1^i for one or both $i = h, l$.
  - preferences from uniform distribution, i.e., $f(x^h, x^l) = g(q^h, q^l) \equiv 1$
- SR: impact right after implementation
- LR: impact after shock adjustment

Table:

Targets	HNC	TS	Parameters	HNC	TS
$s = 0$	0.71	0.62	Δp^h	0.91	0.91
$s = 1$	0.23	0.30	Δp^l	1.01	1.23
$s = 2$	0.06	0.08	t^h	0.95	1.22
q^h_{car}/q^h	0.16	0.31	t^l	0.90	1.20
q^ℓ_{car}/q^ℓ	0.16	0.32	k	0.29	0.40
q^h_{car}/q^ℓ_{car}	0.98	0.85	r	0.98	0.95

Table: HNC

exercise	ΔC^h_{SR}	ΔC^ℓ_{SR}	ΔC^h_{LR}	ΔC^ℓ_{LR}	Δ stock
k down 20%	-8.2%	-8.1%	-5.5%	-5.6%	-5.7%
+ transaction costs	-8.2%	-8.1%	-1.2%	-1.2%	2.8%
+ older vehicles	-8.2%	-8.1%	12.7%	12.4%	2.8%
high-income	-1.1%	-1.1%	3.3%	3.7%	2.0%
low-income	-13.5%	-13.7%	3.4%	4.2%	1.6%

Table: TS

exercise	ΔC^h_{SR}	ΔC^ℓ_{SR}	ΔC^h_{LR}	ΔC^ℓ_{LR}	Δ stock
both Δp up 24%	0.0%	0.3%	33.2%	32.2%	21.8%
Δp^h up 75% & Δp^ℓ down 61%	5.1%	-5.2%	32.9%	0.0%	13.4%
Δp^h up 15% & Δp^ℓ unchanged	0.4%	-0.3%	11.2%	5.7%	5.4%
+ congestion & older vehicles	0.4%	-0.3%	31.0%	7.2%	5.4%
high-income	2.0%	0.0%	13.5%	0.3%	1.6%
low-income	0.4%	-0.3%	45.3%	10.2%	9.4%
Dictuc (2009) prediction	-0.6%	0.4%	-15.2%	-8.5%	-7.9%

Welfare Analysis

- What are the welfare costs of these policies? How do they compare among them? How do short-run and long-run compare?
- Use the model and notice initial calibration are very similar in the two cities.

Table: Transport costs inflicted by HNC and TS

Costs	HNC	TS	ratio TS/HNC
Short-run	3.62%	9.02%	2.5
Short-run (corrected)	3.62%	14.30%	4.0
Long-run	3.54%	8.84%	2.5
Long-run (corrected)	3.54%	14.03%	4.0
Long-run (w/car return)	3.28%	14.03%	4.3

Table: Transport costs as a function of income

Neighborhood	HNC (SR)	HNC (LR)	TS (SR)	TS (LR)
Low-income	1.52%	1.51%	11.39%	11.30%
Middle-income	3.62%	3.54%	9.02%	8.84%
High-income	2.08%	1.84%	3.38%	3.25%

TS effect on taxi license prices

Conclusions & Some Policy Implications I

- Empirical results show:
  1. Non-trivial adaptation period.
  2. Differentiated effects over peak and off -peak hours.
  3. Differentiated effects across income groups.
- People adjust rather quickly: little time to react.
- Welfare evaluation suggests TS has bigger welfare costs and in both policies the adaptation period does not reduce welfare costs in a significant way.
- Policy implications:
  - Mexico-City driving restriction (HNC) didn't include, unlike others, incentives for a faster and cleaner fleet turnover.
  - TS: big change without small-scale experimentation and a bunch of (contract) constraints to implement adjustments.

Conclusions & Some Policy Implications II

- Policy design: more market-base oriented either working as substitute or complements (see London Congestion Charge and Singapur's vehicle quota market).
- More on policy instruments for vehicle pollution: Feng et al (2005), Fullerton and Gan (2005).

Figure: TranSantiago: the day after...

Back to motivation

Table: Before and after TS

Indicator	Before TS	After TS		
		0-6 months	12-18 months	2010
Total number of buses[a]	7,472	5,444	6,396	6,649
% of people waiting at least 10 minutes in bus stop[b]		21.0	7.1	
Waiting time per connection[b]		6.08	3.65	3.49
Travel time to work (both ways; min.)[c]	76.8	89.7		
Travel time by transportation mode (both ways; min.)[c]				
Public transportation	102.4	133.3		
Private car	65.4	63.4		
Taxi	35.1	33.9		

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Figure: Prices of taxi licenses in Santiago (sub-sample of license ads)

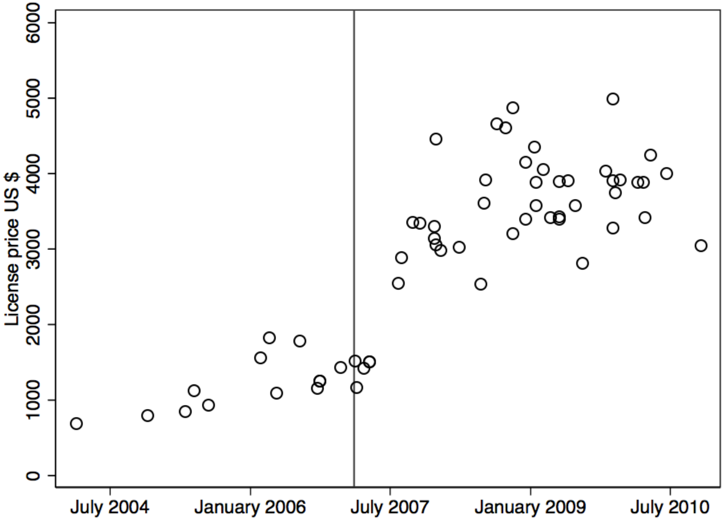

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Table: TS effect on gasoline sales

	(1)	(2)
TS	0.058***	0.048**
	(0.018)	(0.016)
GDP growth	0.054	-0.013
	(0.246)	(0.200)
F-test joint significance Log($P_{\text{Gasoline}}/P_{\text{Diesel}}$)		
$\times$ Region Dummies (p-value)	0.00	0.00
Observations	936	611
R^2	0.945	0.957

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Table: Registered vehicles

	(1)	(2)
TS	120,068***	38,622***
	(4,376)	(10,507)
Region fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Region-year fixed effects	No	Yes
Observations	52	52

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Table: TS effect on car trades and sales

	Trades			Sales		
	(1)	(2)	(3)	(4)	(5)	(6)
TS	2,406.6***	1,028.5	-272.6	3,078.6***	2,201.2**	2,421.2**
	(503.1)	(1,035.5)	(1,230.7)	(474.0)	(969.5)	(1,037.2)
Month 1			1,889.8***			2,989.1***
			(674.6)			(568.4)
Month 2			2,594.7***			-316.3
			(647.6)			(540.9)
Month 3			1,032.5			-1,644.3***
			(622.3)			(515.8)
Month 4			2,778.7***			-560.5
			(598.8)			(493.3)
Month 5			1,438.1**			-1,212.0**
			(577.4)			(474.0)
Month 6			-702.1			-1,876.9***
			(558.3)			(458.1)
Regional linear trends	No	Yes	Yes	No	Yes	Yes

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Figure: Residuals HNC

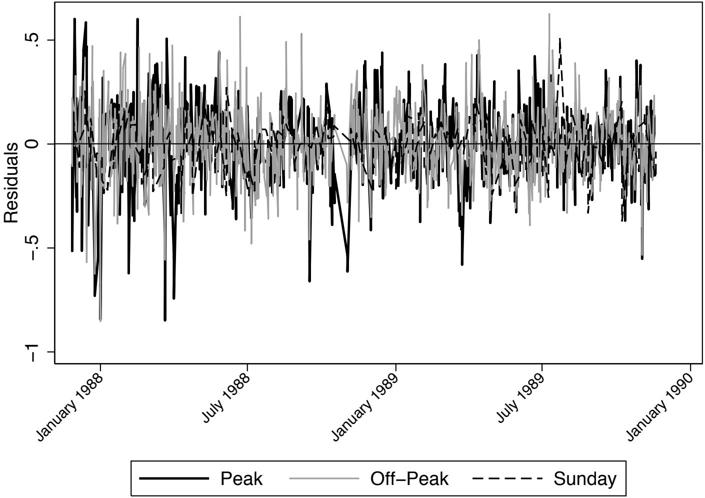

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Figure: Residuals TS

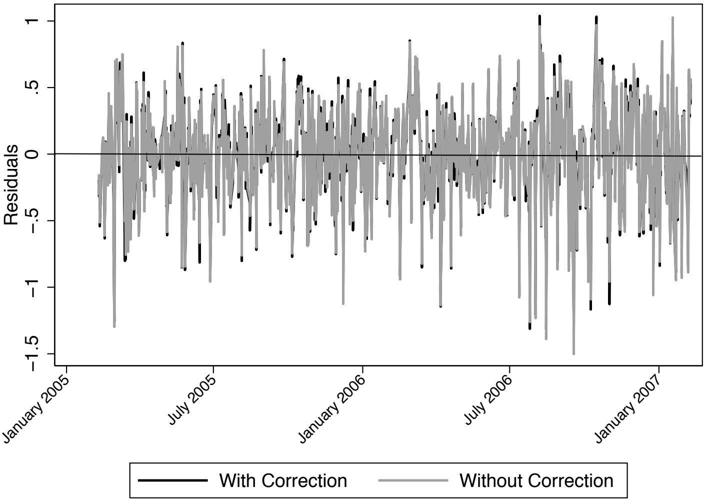

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Table: TS effect on taxi license prices

	Dependent variable: taxi license price							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TS	0.709***	0.561***	0.620***	0.483***	0.572***	0.547***	0.509*	0.730***
	(0.041)	(0.064)	(0.190)	(0.070)	(0.072)	(0.096)	(0.279)	(0.102)
Log(licenses/population)		-0.910***	0.197	-0.632**	-0.859**	-1.118**	-0.130	-2.941***
		(0.288)	(0.649)	(0.309)	(0.356)	(0.464)	(0.915)	(0.458)
Trends	Yes	No	Yes	No	No	No	Yes	No
Year fixed effects	No	No	No	Yes	No	Yes	Yes	No
Model fixed effects	No	No	No	No	Yes	Yes	Yes	No
Sample	All	All	All	All	All	All	All	lic. ads
Observations	430	430	430	430	430	430	430	60
R^2	0.422	0.437	0.466	0.493	0.546	0.719	0.741	0.738

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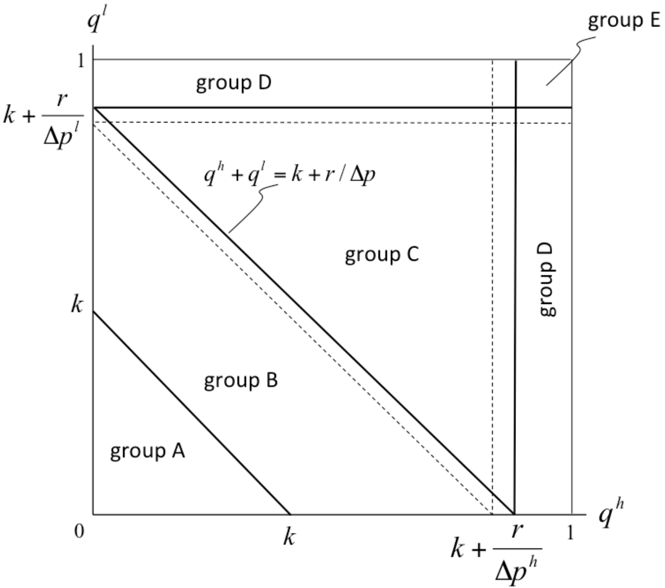

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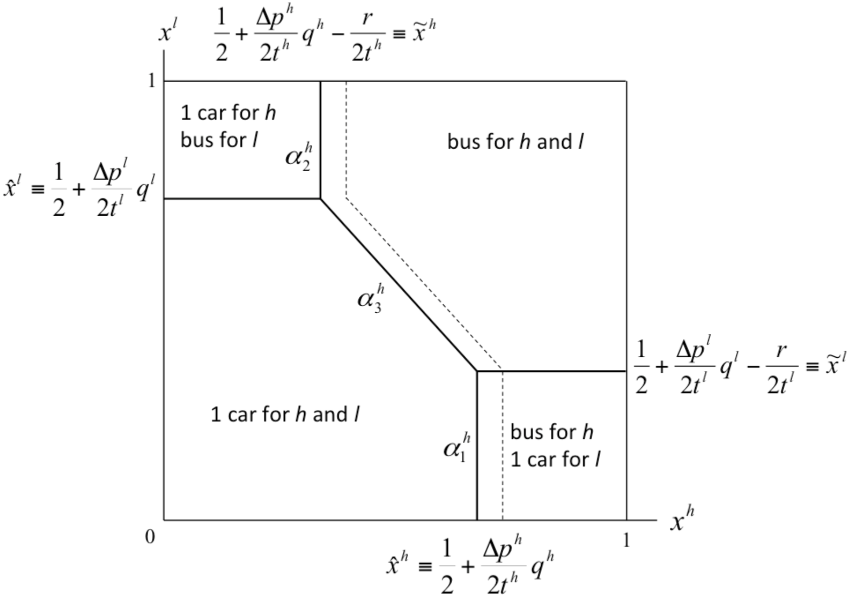

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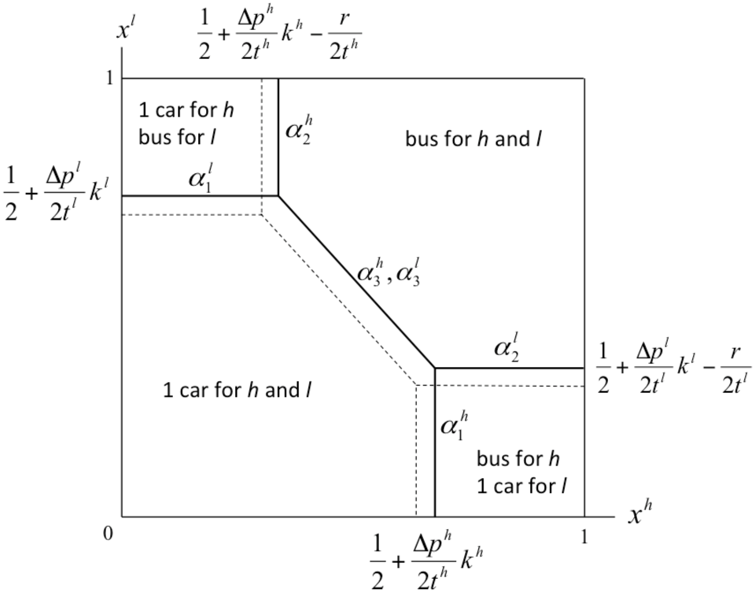

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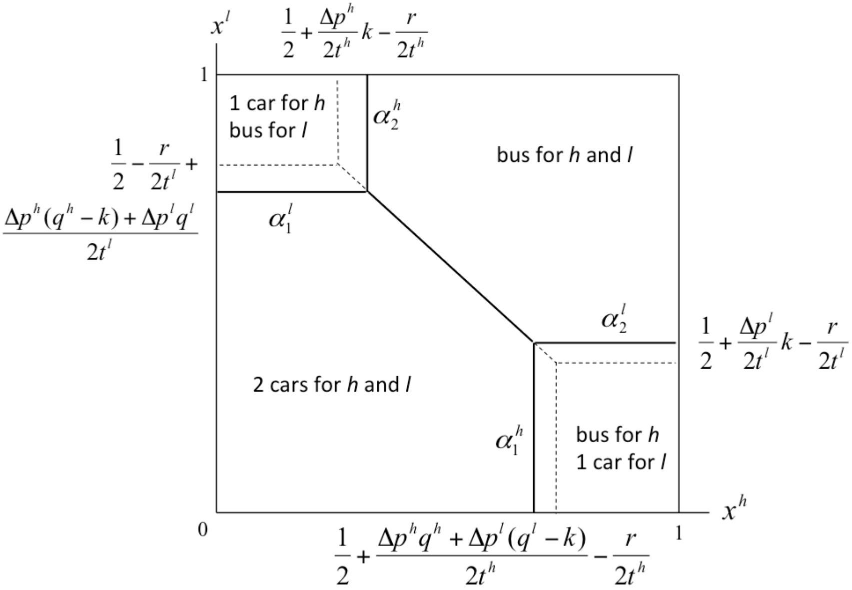

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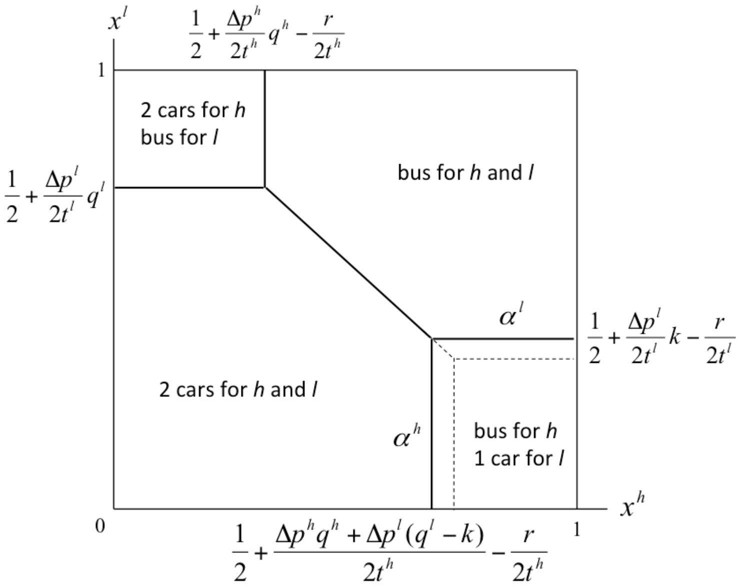

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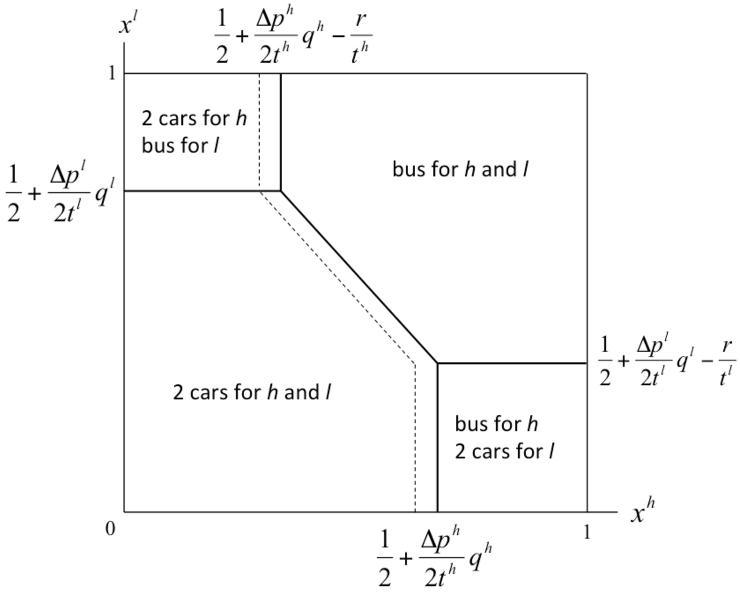

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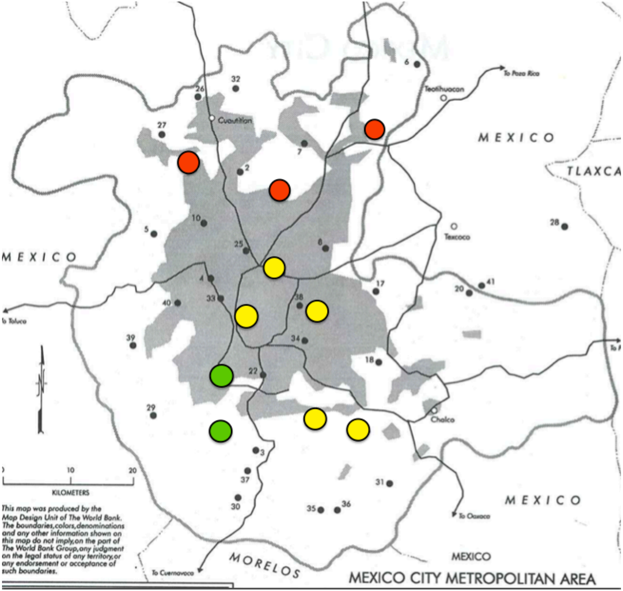
Alternative short-run impact estimation: RDD

- RDD estimations using Imbens and Kalyanaraman (2012) with optimal bandwith

	monthly	weekly	daily
HNC peak	-0.057***	-0.250***	-0.640***
	(0.012)	(0.017)	(0.170)
TS peak	-0.0002	-0.550***	-0.270
	(0.031)	(0.100)	(0.450)

- Daily or weekly pollution data too noisy (lots of idiosyncratic volatility).

Back to Summary of CO results



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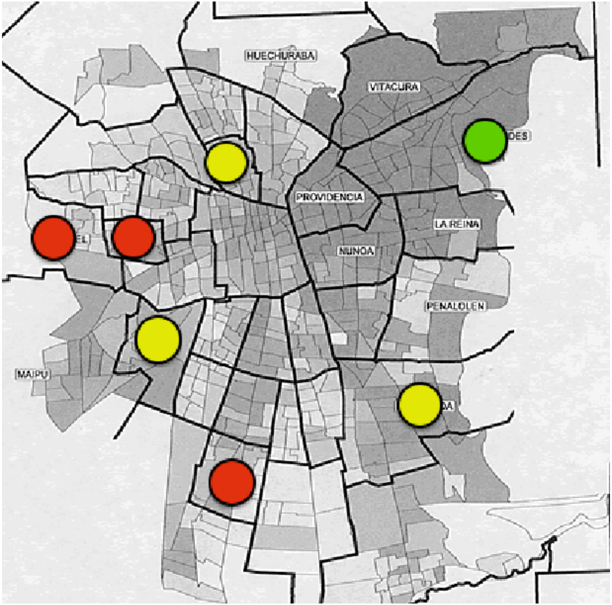

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