Pricing Congestion to Increase Traffic: The Case of Bogotá

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Bogotá: The (pre-covid) most congested city in the world

Based on INRIX's 2020 and 2019 ranks

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Table 3: 10 Most Congested Cities in the World in 2019

2019 IMPACT RANK (2018 IMPACT)	URBAN AREA	COUNTRY	REGION	HOURS LOST IN CONGESTION (RANK 2019)	2018-2019 CHANGE	2017-2018 CHANGE	LAST MILE SPEED (MPH)	BIKE	TRANSIT
1 (2)	Bogota	Colombia	South America	191 (1)	3%	1%	9		
2 (1)	Rio de Janeiro	Brazil	South America	190 (2)	-5%	-1%	11		
3 (5)	Mexico City	Mexico	North America	158 (6)	2%	1%	12		
4 (9)	Istanbul	Turkey	Asia	153 (8)	6%	3%	11		
5 (10)	São Paulo	Brazil	South America	152 (9)	5%	1%	13		
6 (7)	Rome	Italy	Europe	166 (3)	1%	2%	11		
7 (4)	Paris	France	Europe	165 (4)	-4%	-5%	10		
8 (3)	London	United Kingdom	Europe	149 (12)	-9%	-4%	10		
9 (6)	Boston, MA	United States	North America	149 (12)	-5%	9%	12		
10 (13)	Chicago, IL	United States	North America	145 (14)	4%	4%	11		

Medellín also faces significant congestion problems

Both cities responded with "Pico y Placa" (driving restriction/license-plate ban)

Bogotá's 2020 market-based reform

- From September 2020 onward, drivers in Bogotá have the option to pay a daily fee (buy a pass) to be exempted from the restriction
  - Sep 2020 – Aug 2021, only 6-month pass available
  - Starting in Aug 2021, daily pass (and monthly pass) also available
- Daily fee is on average US$9 (it varies from $13 to $5)
- Entire fee collection goes to public transport

Pico y Placa over time: Bogotá (1998) vs Medellín (2005)

	Pre-Covid	**Covid**	**Transition**	**Post-Covid**
	Jan 2017 -- Mar 2020	Apr 2020 -- Aug 2020	**Sep 2020** -- Aug 2021	Sep 2021 -- Present
Bogotá	Pico y Placa in place (50%)	Confinement & P y P suspended	Confinement ends & P y P is back with 6-month pass	P y P daily and monthly passes also available
Medellín	Pico y Placa in place (40%)	Confinement & P y P suspended	Confinement ends & P y P still on hold	P y P is back (no exemption fee)

Diff in Diff Estimation

Based on Waze data (daily average at the city level) provided by the InterAmerican Development Bank

Variables	(1) ln(Vel)	(2) ln(Vel)	(3) ln(Vel)	(4) ln(Vel)	(5) ln(Vel)
Bogotá*Post August 2021	-0.008***	-0.008***	-0.008***	-0.008***	-0.008***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Post August 2021	-0.008***	0.011***	0.006	0.005	0.005
	(0.001)	(0.003)	(0.004)	(0.004)	(0.004)
Bogotá dummy	-0.188***	-0.188***	-0.188***	-0.188***	-0.188***
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Covid-19 peak cases period 2020					0.013***
					(0.002)
Year controls		Yes	Yes	Yes	Yes
Day of the week controls				Yes	Yes
Week FE			Yes	Yes	Yes
Constant	3.291***	3.282***	3.282***	3.291***	3.291***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	853	853	853	853	853
R-squared	0.953	0.969	0.977	0.979	0.980

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Have Bogotá done the right thing? Or have Medellín?

- Bogotá's market-based reform constitutes a major innovation in public policy
- It is the first city to consider such a reform
- The reform also considers differentiating the daily fee by car characteristics:
  - its market value
  - its pollution rate (including both local and global pollutants)
- It shows the way to reform existing programs (Mexico City, Sao Paulo) and design future ones (Lima, Santiago)
- This hybdrid scheme should be viewed as a first step toward a full-fledged road pricing scheme (with the fee collection going to public transport)

SOME THEORY:
AN IMPOSSIBILITY RESULT

A simple model

- Consider a unit mass of a continuum of homogeneous drivers.
- The surplus that driver i obtains from x_i kms of driving in a given period, say a week, is given by (Barahona et al, 2020):

$$S_i(x_i, x_{-i}) = x_i^{\alpha} - \gamma x_{-i}^{\beta} x_i$$

  i.e., the difference between the benefit and cost of driving
- where:
  - $\alpha < 1$: diminishing returns to driving
  - $\gamma > 0$: free-flow cost of driving per km (when $x_{-i} = 0$)
  - x_{-i} : total amount of driving excluding i
  - $\beta > 0$: increasing travel cost from congestion

The no-intervention outcome: Too much traffic

- i's equilibrium amount of driving in the absence of government intervention solves:

$$\frac{\partial}{\partial x_i} S_i(x_i, x_{-i}) = \alpha x_i^{\alpha-1} - \gamma x_{-i}^{\beta} = 0 \tag{1}$$

- Imposing symmetry, $x_i = x_{-i}$, yields the no-intervention amount of driving

$$x^{ni} = (\alpha/\gamma)^{1/(1-\alpha+\beta)}$$

  and its consumer welfare $S^{ni} = S(x^{ni}, x^{ni})$

- Given the congestion externality, x^{ni} is obviously above the socially efficient (or first-best) level:

$$x^{fb} = (\alpha/(1+\beta)\gamma)^{1/(1-\alpha+\beta)} = \arg\max_x \{x^{\alpha} - \gamma x^{\beta} x\}$$

Restoring the first-best

Proposition 1. *The authority can restore the first-best amount of driving with a congestion fee τ per km traveled equal to $\tau^{fb} = \gamma\beta(x^{fb})^{\beta-1}x^{fb}$.*

- Driver i solves $\max_{x_i}\{S_i = x_i^{\alpha} - (\gamma x_{-i}^{\beta} + \tau^{fb})x_i\}$, which yields $x_i = x_{-i} = x^{fb}$.
- τ^{fb} is exactly equal to the externality that i imposes upon the remaining drivers evaluated at the socially optimal level of driving.
- In many instances, however, the authority does not have this market-based instrument at her disposal...
- ...she must rely on alternative instruments, such as driving restrictions.

Driving restriction as a proportional rationing scheme

- the main difference between a congestion fee and a driving restriction—leaving aside fiscal considerations—is that the former works as an efficient rationing scheme and the latter does not.
- how inefficient?
- for now we adopt the view that a driving restriction works as a proportional rationing scheme (Barahona et al 2020)
- proportional rationing: all trips are equally likely to be rationed
  - some highly valuable trips must be canceled
  - some trips of negative social value are taken

An "imposibility" result

Proposition 2. *Under the assumption that a driving restriction works as a proportional rationing scheme, any driving restriction leads to welfare losses, no matter its extent* $R \in (0,1)$.

- Driver surplus is now:

$$S_i^r(x_i^r, x_{-i}^r; R) = R(\nu[x_i^u]^\alpha - \gamma[x_{-i}^r]^\beta x_i^u) \tag{2}$$

  where:
  - $R \in [0,1]$ is extent of the driving restriction: $R = 1$ no restriction, $R = 0$ full restriction
  - x_{-i}^r is the total amount driving given R
  - $x_i^u \equiv x_i^u(x_{-i}^r)$ is i's unrestricted amount of driving, so $x_i^r = Rx_i^u$
- From (2) and the envelope theorem:

$$\frac{\partial}{\partial R} S_i^r(x_i, x_{-i}^r; R) = ([x_i^u]^\alpha - \gamma[x_{-i}^r]^\beta x_i^u) - R\gamma\beta[x_{-i}^r]^{\beta-1} x_i^u \frac{\partial x_{-i}^r}{\partial R} > 0$$

- the direct effect (first term) $>$ the congestion effect (second term)

The "imposibility" result can be fixed

Proposition 3. *Despite the increase in congestion, the authority can improve upon a driving restriction* $R < 1$ *with the introduction of an exemption fee* $p \geq 0$ *that allows drivers to use their cars in times of restriction:* $x^{rp} > x^{r}$ *and* $S^{rp} > S^{r}$ *for any* $p \geq 0$, *where* x^{rp} *and* S^{rp} *are, respectively, the amount of driving and consumer welfare under a* (R, p) *restriction.*

- Let x_i^p denotes i's amount driving with net value above the exemption fee p given x_{-i}^{rp}:

$$\alpha[x_i^p]^{\alpha-1} - \gamma[x_{-i}^{rp}]^{\beta} - p = 0 \tag{3}$$

- From (3), we obtain i's welfare

$$S_i^{rp}(x_i^p, x_i^u, x_{-i}^{rp}; R, p) = R\left([x_i^u]^{\alpha} - \gamma[x_{-i}^{rp}]^{\beta} x_i^u\right) + (1-R)\left([x_i^p]^{\alpha} - \gamma[x_{-i}^{rp}]^{\beta} x_i^p\right)$$

- Showing that $x^{rp} > x^{r}$ can be omitted since it is intuitively obvious

The exemption fee is welfare improving

- We know that:
  - $S^{rp}(R, p = 0) = S^{ni} > S^{r}$ (from Proposition 2)
  - $S^{rp}(R, p \to \infty) = S^{r}$ by construction
- In addition, it can be shown that

$$\frac{\partial}{\partial p} S^{rp}(R, p)\Big|_{p=0} = -\gamma\beta[x^{ni}]^{\beta}\frac{\partial x^{rp}}{\partial p} > 0$$

- so, there will be some price $\bar{p} \in (0, \infty)$ where $S^{rp}(R, p)$ is maximized and

$$S^{rp}(R, \bar{p}) \equiv S^{r\bar{p}} > S^{ni} > S^{r}$$

- Unless p is much larger than $\bar{p}$, we will have

$$S^{rp} > S^{ni} > S^{r}$$

APPLICATION TO BOGOTA

Policy analysis and questions

- Our DiD estimations already showed, not surprisingly, that $x^{rp} > x^{r}$
- Next, we want to test for our second prediction, that $S^{rp} > S^{r}$
- This requires to extend the model to the presence of **heterogeneous commuters**....
- ....with different preferences over available "transportation" modes (e.g., car, public transport, remote working)
- How much of the gain is due to moving from $p \to \infty$ to $p = 0$ (the difference between S^{ni} and S^{r})?
- ....and how much to moving from $p = 0$ to $p > 0$ (the difference between S^{rp} and S^{ni})?
- How far is the existing p from $\bar{p}$?

Heterogeneous commuters

Table 1: Income-group characteristics

Group No.	Income group	Fraction of total	Average monthly income per household	Car ownership	Marginal utility of time ($/hr)
1	Low	12%	$184	11%	0.60
2	Middle-low	40%	$288	21%	1.36
3	Middle	34%	$502	39%	2.59
4	Middle-high	10%	$1,027	66%	4.60
5	High	5%	$1,564	82%	12.38

Note: This table contains household characteristics for five income groups based on information provided by the BMDS, Bogota's 2019 Moibility Survey (MS-2019), and our own model calibration.

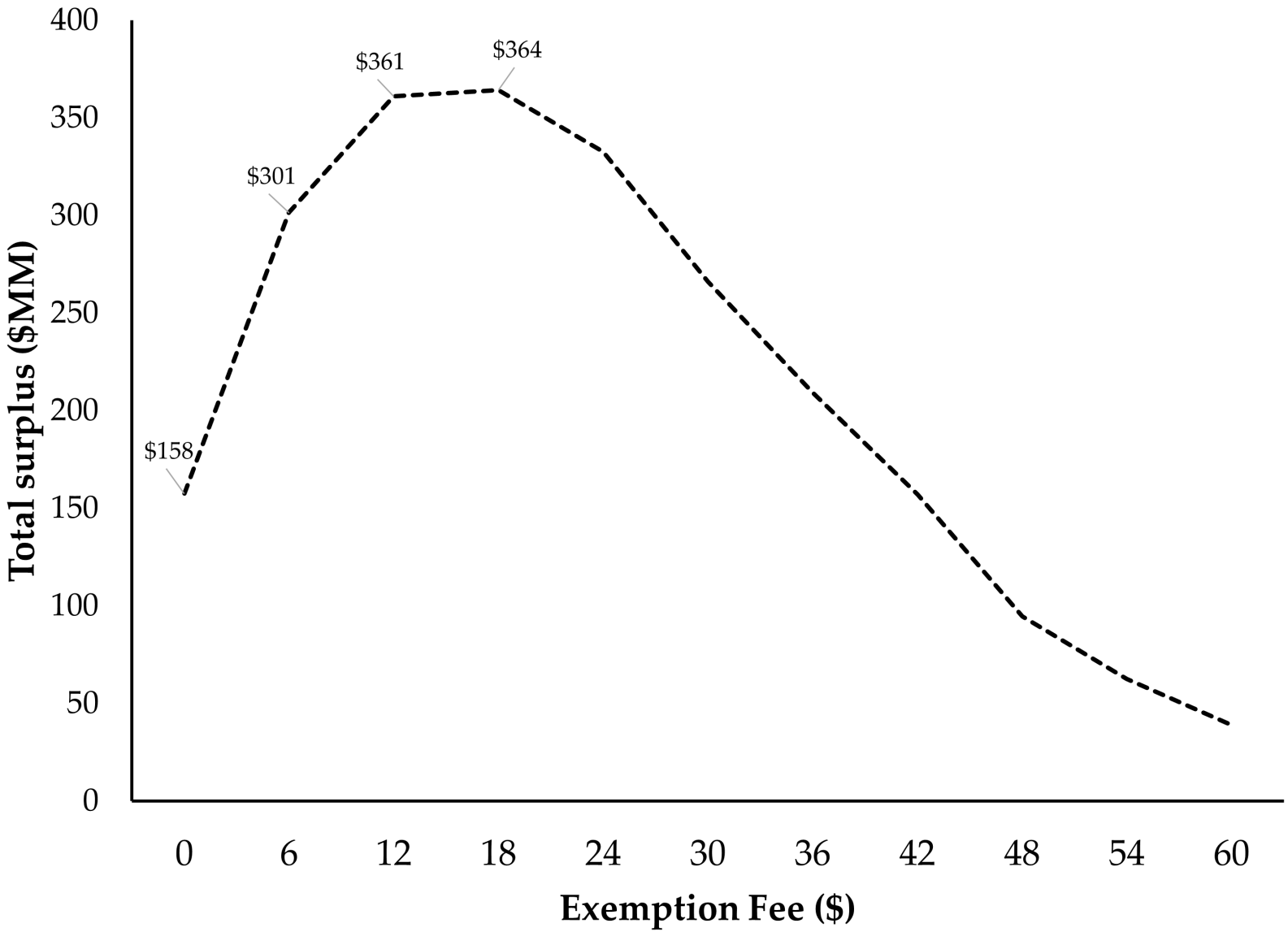
Calibration

Table 2: Model fit

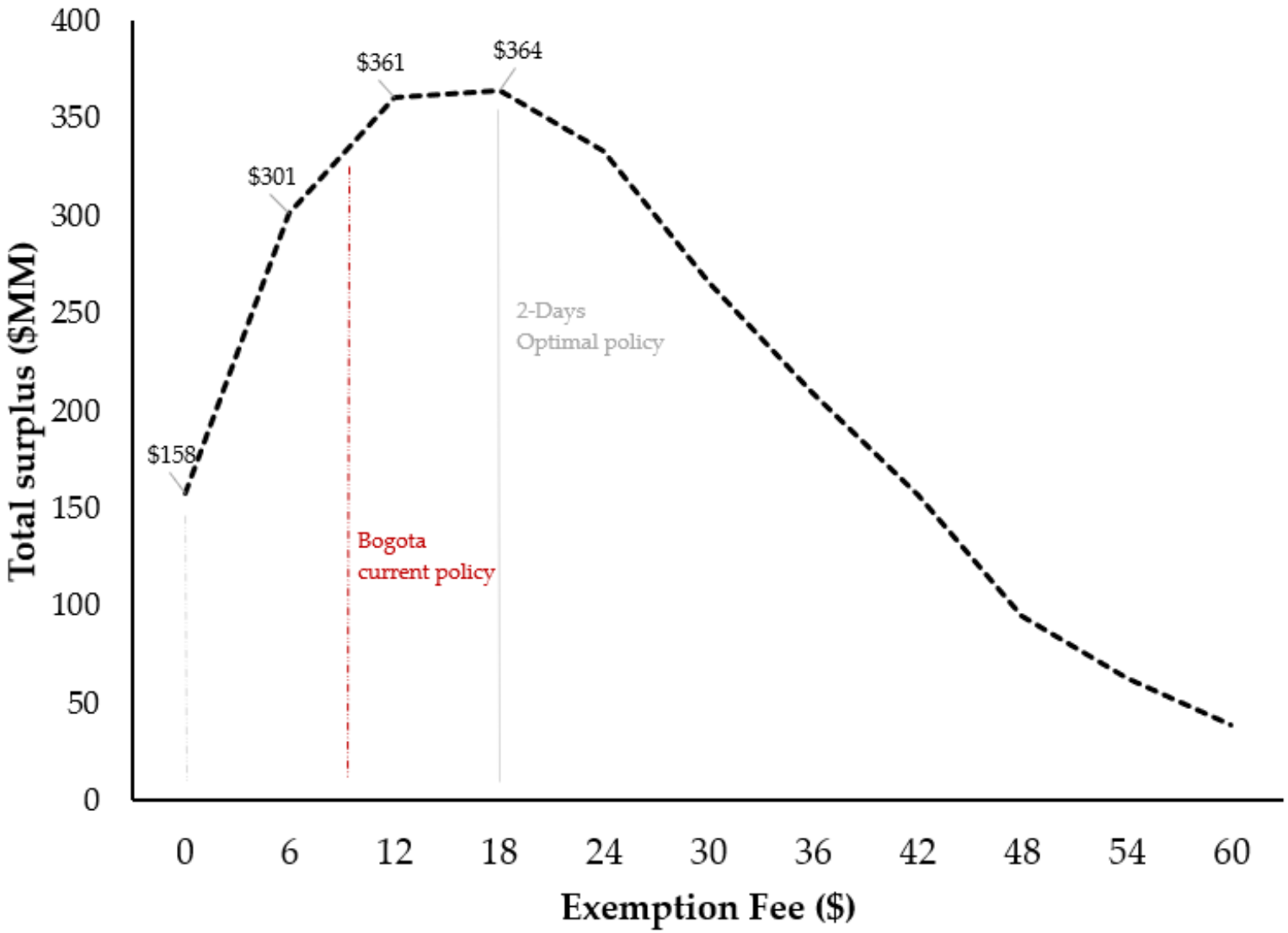
	PT modal share		Remote working	
Income groups	Observed	Model prediction	Observed	Model prediction
Low	85%	85%	0%	2%
Middle-low	72%	69%	0.1%	4%
Middle	61%	62%	5%	12%
Middle-high	44%	42%	15%	15%
High	25%	20%	25%	30%
Overall	55%	59%	10%	12%

Note: This table shows how our model calibration matches observed data. The first and second columns contrast the observed modal shares of the public transportation to the predictions of our model. The third and the fourth columns report estimations of remote working pre-pandemic with predictions of our model.

Result I: Major welfare gain from abolishing the restriction



Result II: Existing fee not far from optimal level



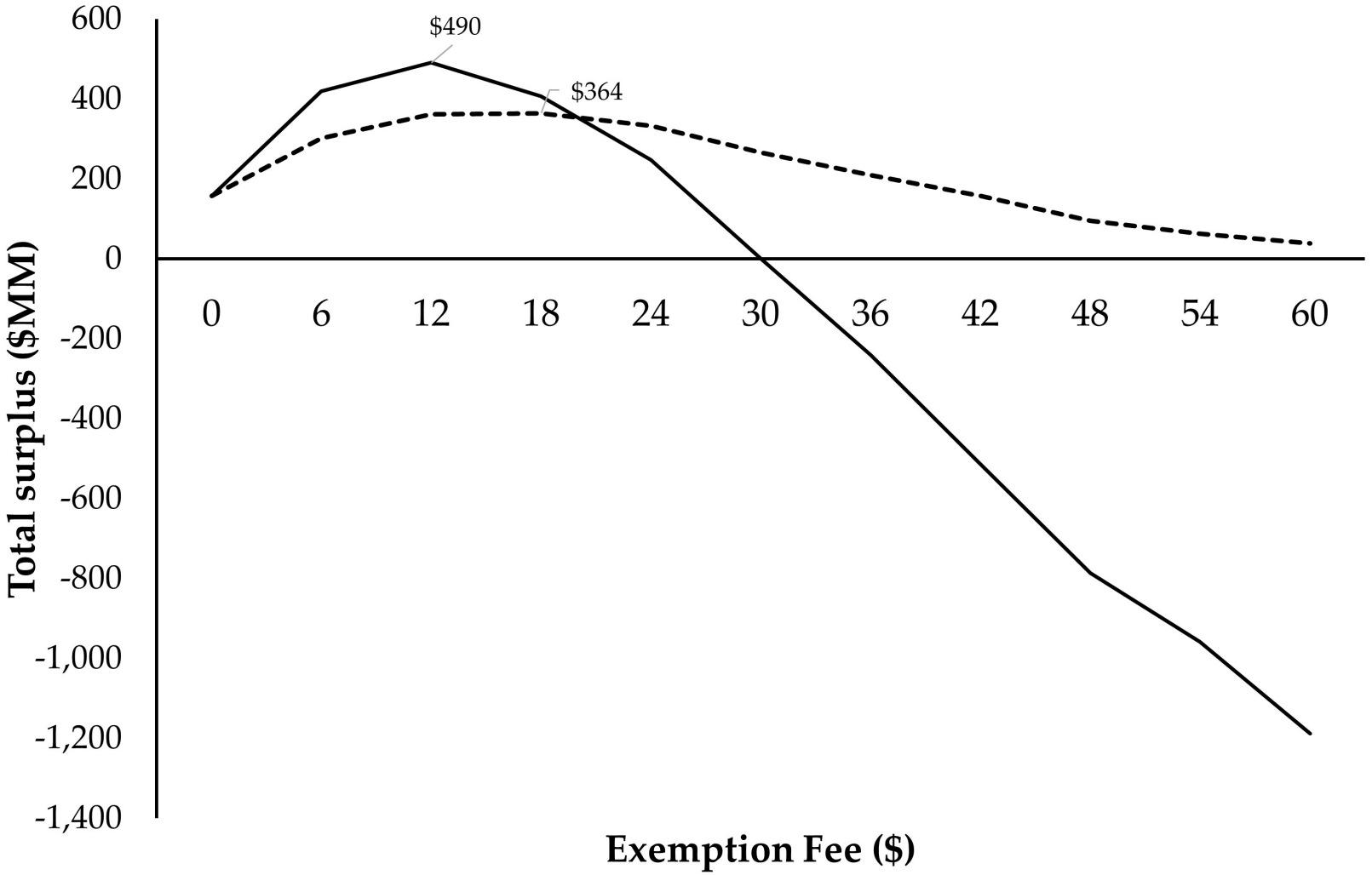
Correcting for higher (post-covid) remote working

Table 3: Pre-covid Remote Working

Income groups	Observed	Model prediction
Low	0%	2%
Middle-low	0.1%	4%
Middle	5%	12%
Middle-high	15%	15%
High	25%	30%
Overall	10%	12%

- if we believe that overall remote working in a post-covid world is up from 12 to 20%, then...
- the optimal fee drops from \$18 to \$11, quite close to the average fee actually paid (\$9)

Result III: Additional gains from full road-pricing



Conclusions: Who was right?

- Bogotá, by reinstalling Pico y Placa **with** an exemption fee? or....
- Medellín, by reinstalling Pico y Placa **without** an exemption fee?
- Theory and evidence shows that Bogotá did the right thing
- But there is more:
  - bringing new resources to improve public transport, while keeping fares from increasing (so leaving everyone better off)
  - differentiating cars by their (local and global) pollution rates
  - paving the way toward a full road-pricing scheme in the near future