Estimating the Price Elasticity of Demand for Subways: Evidence from Mexico

Lucas Davis

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Abstract

There is surprisingly little recent evidence on the price elasticity of demand for public transportation, and virtually no evidence from low- or middle-income countries. This study uses fare changes in Mexico City, Guadalajara, and Monterrey to estimate the price elasticity of demand for urban rail transit. The paper documents, for example, that when the price for the Mexico City subway increased from 3 pesos to 5 pesos, ridership fell 12%, and that during a 60-day fare “holiday” for the Monterrey subway ridership increased 67%. Across cities and specifications the implied price elasticities range from -.18 to -.33. The paper then shows how these elasticities can be used to perform policy counterfactuals. In an ancillary analysis using data on electricity consumption the paper finds that the marginal cost of urban rail transit in Mexico is less than $.10 per rider, and the paper calculates the potential efficiency gains from moving fares closer to marginal cost.

Key Words: Urban Rail Transit, Public Transportation, Traffic Congestion, Local Pollution
JEL: H23, H41, R41, R42, R48

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1 Introduction

Worldwide 55% of people live in cities, with this expected to increase to two-thirds by 2050 (United Nations, 2018a). Cities offer significant advantages including educational opportunities, access to labor markets, and rich amenities (Glaeser, 2011). But cities come with their own challenges as well, many closely related to mobility including traffic congestion and local pollution (Zheng and Kahn, 2013).

Public transportation has the potential to ameliorate several of these problems, making cities greener and more mobile. A recent flurry of empirical studies of transit strikes shows that public transportation is even more effective than previously believed (Anderson, 2014; Adler and van Ommeren, 2016; Bauernschuster et al., 2017). For example, Anderson (2014) shows that traffic congestion increased 47% during a transit strike in Los Angeles.

There is also a set of studies that assess economic impacts by looking at openings of urban rail lines and other forms of public transportation (Baum-Snow and Kahn, 2000; Baum-Snow et al., 2005; Chen and Whalley, 2012; Bel and Holst, 2018; Gonzalez-Navarro and Turner, 2018; Tsivanidis, 2018; Gupta et al., 2020; Zárate, 2019). Baum-Snow and Kahn (2000), for instance, shows that urban rail expansions during the 1980s in Boston, Atlanta, Chicago, Portland, and Washington DC, led to increased ridership and higher housing prices.

In contrast to these active research areas, relatively little attention has been paid to the operation of existing public transportation systems. In particular, there is surprisingly little recent evidence on the price elasticity of demand for public trans-
portation. This lack of evidence is especially striking compared to the immense number of existing studies on the price elasticity of demand for private transportation. See, e.g. Levin et al. (2017) and references therein.

For reviews of the older literature on demand for public transportation see Lago et al. (1981), Cervero (1990) and Goodwin (1992). Many of the older studies are not published in peer-reviewed journals and use a variety of different research designs of varying credibility. Not coincidentally, the range of estimates in the available literature is implausibly large, including everything from zero to well above one.

Moreover, there is virtually no existing evidence from low- or middle-income countries. Most population growth and urbanization worldwide over the next few decades is expected to occur in low- and middle-income countries (United Nations, 2018a), and this is where some of the most significant challenges exist in terms of traffic congestion and local pollution (World Health Organization, 2016). Consequently, understanding demand for public transportation in these contexts is particularly important.

In this paper, I estimate the price elasticity of demand for urban rail transit in Mexico. Urban rail transit is especially interesting to study compared to other forms of public transportation because of its large scale, very low marginal cost, and near zero marginal external cost. In addition, Mexico is a compelling setting because of its increasing urbanization and rapid growth in vehicle ownership.

The paper exploits three natural experiments, one each in Mexico City, Guadalajara, and Monterrey. In all three cases there is a significant fare change (larger than 30%),
and I use high-quality data on subway ridership and a regression discontinuity (RD) research design to measure the change in ridership and implied price elasticity. I am not aware of any previous study of any of these three events, nor am I aware of any previous studies that use RD to study public transportation pricing.

I find that ridership responds to the price change in the expected direction in all three cities. When the price for the Mexico City metro increased 67% (from 3 pesos to 5 pesos), ridership fell by 12%. Similarly, when the price for the Guadalajara light rail system increased 36%, ridership fell by 10%. Finally, when the Monterrey metro was offered free of charge for 60 days, I find that ridership increased 67%. Across cities and specifications the implied elasticities range from -.18 to -.33.

These estimates are directly relevant for policymakers considering alternative pricing structures for urban rail transit. Policymakers in Monterrey, for example, are considering increasing prices to pay for growing operating costs. Other cities are considering reducing prices or even moving to fare-free transit in an effort to boost ridership.¹

The paper shows how these elasticities can be used to perform a specific policy counterfactual. Most urban rail systems are subsidized, in that riders pay a price below average cost (USFTA, 2020). However, most costs associated with urban rail are sunk and invariant with regard to changes in ridership. Thus the marginal cost of ridership is much lower. In an ancillary analysis using data on electricity consumption for Mexican subways, I find that the marginal cost (including externalities) is less

than $.10 per rider, creating a strong economic argument for lower fares.

Using the framework and parameters from Parry and Small (2009) and Parry and Timilsina (2010), I find that lower fares for the three urban rail systems I study would reduce deadweight loss by $50+ million (USD$) annually, while also reducing externalities by $250+ million annually, as riders substitute away from private vehicles and buses. I also briefly discuss how scale economies and capacity constraints complicate policy counterfactuals like these and point to the economic benefits of richer, more dynamic pricing schedules (De Palma et al., 2017).

The paper proceeds as follows. Section 2 motivates the analysis with information about urban growth and vehicle ownership in Mexico, and then describes in detail the natural experiments in Mexico City, Guadalajara, and Monterrey. Section 3 presents the main results in graphical and regression form, including reporting results from alternative bandwidths. Then Section 4 puts the results in context with an economic framework, ancillary evidence on electricity consumption, and estimates from the literature on external costs. Section 5 provides conclusions and next steps.

2 Background

2.1 Urban Growth and Vehicle Ownership

Like many middle-income countries, Mexico is experiencing rapid urbanization (United Nations, 2018a). Table 1 shows that Mexico City, Guadalajara, and Monterrey have all experienced significant population growth since 2000. As incomes have risen over
the last two decades, so has vehicle ownership. The table shows that the number of registered vehicles in all three urban areas has more than doubled since 2000. This rapid growth in private vehicles helps explain why Mexico City, for example, has some of the worst traffic congestion in the world.²

Mexico no longer subsidizes gasoline to the degree that it did in previous decades (Davis et al., 2019), nor is there any attempt to price the externalities from driving. There is no price on carbon dioxide, no price on local pollutants, and no price on traffic congestion. Nor has there been much attempt to encourage carpooling through e.g. high-occupancy vehicle lanes (Hanna et al., 2017). Instead, the country has long attempted to address these externalities using driving restrictions, mostly with disappointing results (Davis, 2008; Gallego et al., 2013).

2.2 Mexico City

Mexico City’s metro is the second largest subway system in North America after New York City, and ninth largest in the world (UITP, 2018). Daily ridership exceeds 4 million trips. The event of interest occurred December 13, 2013, when the price for the Mexico City metro increased from 3 pesos to 5 pesos, a 67% increase. The exchange rate in December 2013 was 12.8 pesos per dollar, so this is an increase from $0.23 to $0.39 per trip.

From a study design perspective a nice feature of the Mexico City metro and all three urban rail systems in this study is that pricing is very simple. There is a single ticket

²See, e.g., the Tom Tom Traffic Index, https://www.tomtom.com/en_gb/traffic-index/mexico-city-traffic/. Mexico City ranks number 13 worldwide in the most recent index.
which allows the rider to go anywhere in the system regardless of distance. The same ticket is used peak- and off-peak, and during all days of the week and holidays. This lack of differentiation is difficult to justify from an economic efficiency perspective but from a study design perspective makes analysis and interpretation particularly straightforward.

Another simplifying feature of all three urban rail systems considered in the analysis is that the great majority of riders pay the standard fare and not some type of discounted multi-trip ticket or monthly- or annual- fixed payment. On the Mexico City metro, discounted fares are available for the elderly, children under 5 and some other vulnerable groups, but this represents a small share of total ridership.

2.3 Guadalajara

Guadalajara’s light rail system (Tren ligero de Guadalajara) is the third-largest urban rail system in Mexico, with daily ridership exceeding 250,000 trips. The total size of the system in kilometers, number of trains, and total ridership are all about an order of magnitude smaller than the Mexico City subway. See Appendix Figures A1, A2, and A3 for additional descriptive information on all three systems.

Guadalajara’s light rail system runs underground only in the city center, and otherwise runs at grade. Mexico City and Monterrey also have a combination of underground and at grade segments, but with a higher proportion underground. For this reason, I tend to use the more general “urban rail transit” rather than “subway” when referring to Guadalajara.
The event of interest for Guadalajara occurred on July 27, 2019. On this day the price for Guadalajara’s light rail system was increased from 7 pesos to 9.5 pesos. The exchange rate in July 2019 was 19.0 pesos per dollar, so this is an increase from $0.37 to $0.50 per trip. The announcement was made by the governor of the state of Jalisco, Enrique Alfaro Ramírez, days before the increase took place.³ Children and elderly receive a 50% discount but all others pay this same standard fare. Like the Mexico City metro, Guadalajara’s light rail system uses a simple ticket that does not differentiate by time-of-day, day-of-week, or destination.

A challenge with Guadalajara is that the price change occurred relatively recently, so there is less post-event data available. Moreover, with data from all three cities I exclude data after March 2020 because of the sharp decline in ridership due to Covid-19. For Guadalajara, this leaves only 7 months of data post-event. This ends up being enough for estimating the price elasticity, but is a considerably shorter post-period than is available for the other two cities.

2.4 Monterrey

The Monterrey metro, generally referred to as Metrorrey, is the second-largest in Mexico. The metro has two lines with a third line scheduled to open in late 2020 or early 2021. There are 35 total stations and average daily ridership is almost 500,000 trips.³

The event of interest for Monterrey occurred during the summer of 2009. With little advance warning the governor of the state of Nuevo Leon, José Natividad González, announced that the Monterrey metro would be free for 60 days starting May 16th and ending July 14th. The fare holiday was motivated as a form of public assistance during difficult economic times.

Except for that 60 day period, the Monterrey metro otherwise has a price of 4.5 pesos. The exchange rate in June 2009 was 13.2 pesos per dollar, so at the time of the fare holiday the regular price was $0.34 per trip. Multi-trip discounts are available for the Monterrey metro, but offer only a modest discount, for example, 6 trips can be purchased for 24 pesos (4 pesos each). Like the other rail systems, the Monterrey metro does not differentiate by time-of-day or week, or destination. In late 2018 the government of Nuevo Leon discussed increasing the price to as high as 9 pesos, but as of 2020 the price remains 4.5 pesos.

3 Data and Results

3.1 Ridership Data

Figure 1 plots raw ridership data from all three urban rail systems. These data come from the Mexican Statistics Institute (INEGI), which in turn, collects ridership data from the individual urban rail systems. I drop data after March 2020 to exclude the sharp decline in ridership due to Covid-19. I also dropped a single monthly

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5“Es Metrorrey el Mas Caro y El Menos Eficiente”, El Financiero, September 20, 2018.
observation for Mexico City (September 2017) with much lower ridership due to an earthquake which killed 181 people and damaged several subway lines.

Fare changes are indicated with vertical lines. As expected, ridership drops in Mexico City in December 2013 when the fare increases. Ridership also drops in Guadalajara in July 2019, when the fare increases, though the change is less noticeable. Finally, in Monterrey the 60-day fare holiday is indicated using two vertical lines. As expected, ridership increases sharply during the holiday period.

Figure 2 narrows the windows, bringing the events into sharper focus. The changes in ridership become clearer, particularly for Mexico City and Monterrey. There is seasonal variation in ridership for all three systems, peaking in the summer and fall. Accordingly, our preferred estimates in the following section include month-of-year fixed effects. The month-of-year fixed effects have little impact on the estimates for Mexico City or Monterrey, but the decline in Guadalajara becomes sharper (and larger) after including month-of-year fixed effects. Ridership is highly seasonal in Guadalajara, with higher levels in August, September, and October, but these higher levels were considerably more muted in 2019 after the price increase.

### 3.2 Regression Discontinuity Analysis

Figure 3 overlays a cubic polynomial with a discontinuous break at the time of the event. Formally, I estimate least squares regressions separately for each city of the following form,

\[
    \text{ridership}_t = \gamma_0 + \gamma_1 \mathbf{1}(\text{Change}_t) + f(D_t) + \gamma_2 X_t + u_t.
\]
The outcome variable ridership$_t$ is ridership in month $t$. The explanatory variable of interest is $1(\text{Change}_t)$, an indicator variable for observations after the price change.$^6$ All specifications include $f(D_t)$, a third-order polynomial in the time (i.e. the “running variable”). Estimates in the tables below come from regressions which also include month-of-year fixed effects, $X_t$.

The RD figures further sharpen the pattern that was already visually discernible in the previous figures. All three cities exhibit changes in ridership in the expected direction. Ridership falls sharply and discontinuously in Mexico City when the price increases. Ridership falls in Guadalajara as well, though the change is harder to see given the pronounced seasonal variation. Finally, ridership in Monterrey jumps up significantly during the fare holiday, and then jumps back down when the fare is reinstated.

The ridership changes appear persistent. In Mexico City, ridership peaks prior to the price increase in 2013, but then never again regains that same level of ridership. In Guadalajara, there are fewer observations after the price increase, but the decrease is persistent for the seven months for which data are available. Finally, higher ridership levels persist in Monterrey throughout the fare holiday. One might have expected ridership to fall after an initial burst of ridership, for example, due to the novelty of the free fare, but, if anything, ridership actually appears to continue increasing through the 60 days. It is always difficult to assess longer-run impacts, but overall,

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$^6$The fare holiday for Monterrey requires a bit of extra explanation. The 60-days fare holiday ran from May 16 until July 14. Thus, $1(\text{Change}_t) = 1$ for June 2009, and $1(\text{Change}_t) = 0.5$ for May and July 2009 as both months were treated for half the month. All other months are untreated, $1(\text{Change}_t) = 0$. Thus, the coefficient $\gamma_1$ in the Monterrey regression reflects the change in ridership associated with the price change, just as it does with the other two city regressions.
the evidence from all three cities points to persistent, not transitory changes in behavior.

### 3.3 Estimates and Standard Errors

Table 2 reports estimates and standard errors from our preferred specification. In Mexico City, the 67% price increase resulted in a 12% decrease in ridership. In Guadalajara, the 36% price increase caused ridership to go down by 10%. Finally, in Monterrey, the 100% price decrease resulted in a 67% increase in ridership. The implied price elasticities range from -.24 to -.33.

Estimates are similar with alternative bandwidths. See Table 3. Point estimates tend to be slightly smaller with a shorter bandwidth, and slightly larger with a longer bandwidth, but in all cases estimates are similar and statistically significant at the 1% level.

Reported standard errors are estimated following Newey and West (1987) with a two-month lag. A standard diagnostic test was used to assess the magnitude of serial correlation. In the preferred specification with month-of-year fixed effects the autocorrelation coefficients are statistically significant for two months in all three cities, motivating the two-month lag.

The only previous comparable estimate I can find in the economics literature comes from a study of the Bay Area Rapid Transit system (BART). In particular, McFadden (1974) estimates a conditional choice model using survey data from 213 Bay Area residents, mostly conducted before BART was fully operational. Without any
price variation, the identification strategy requires strong functional form and other assumptions, finding an own-price elasticity for the BART of -0.86.

It would have also been interesting to measure cross-price elasticities, or the effect of these price changes on air quality, traffic congestion, or some other additional outcome. However, one would expect these secondary effects to be relatively small in magnitude, and difficult to distinguish empirically from naturally occurring month-to-month variation. In addition, the available ridership data for buses and other forms of public transportation tend to be less systematically collected and not as reliable as than the data for urban rail.

4 Economic Implications

The estimates from the previous section provide some of the information about demand behavior necessary to evaluate the economic costs and benefits from alternative prices. This is particular policy relevant in the context of urban rail transit, both because policymakers consider price changes regularly, and because these prices have considerable implications for the broader transportation system, and thus local traffic congestion and other externalities. I focus on the counterfactual of lower prices, but the exercise could just as easily be repeated for higher prices.
4.1 The Low Marginal Cost of Urban Rail

Subways are expensive to build. Recent expansions to the New York City subway, for example, cost more than $2 billion per mile.\textsuperscript{7} But these capital costs are sunk and invariant with regard to changes in ridership. Adding an additional rider to an urban train increases electricity consumption by only a very small amount. Using the data from Mexico, I estimate that each additional rider increases electricity consumption by less than 0.5 kilowatt hours, implying a marginal cost of less than $.07 per rider.

Table 4 reports estimates and standard errors from six least squares regressions, three each from Mexico City and Monterrey. Data on electricity consumption is not available for Guadalajara. The dependent variable in these regressions is monthly electricity consumption for each city’s subway system, as reported to the Mexican Statistics Institute (\textit{INEGI}). The independent variable of interest is monthly total subway ridership.

The estimate range widely across cities and specification, but in all cases the marginal effect of an additional rider is very small, less than 0.5 kilowatt hours. Mexican wholesale electricity prices average $.08 per kilowatt hour (Irastorza and Peñuelas, 2020), so this implies a marginal cost of less than $.04 per rider.

The marginal external costs are also small. Unlike bus public transportation, urban rail does not create traffic congestion or accidents, and the marginal external costs of electricity consumption are modest. The marginal external cost of electricity gener-

ation in the United States, for example, averages $.06 per kilowatt hour (Borenstein and Bushnell, 2018), including damages from carbon dioxide and local pollutants. I’m not aware of similar estimates for Mexico, but the electricity generation portfolio in Mexico is similarly heavy on natural gas generation, so damages are likely to be similar. At $.06 per kilowatt hour, the marginal external cost of urban rail in Mexico would be $.03 per rider, so the marginal social cost (i.e. private plus external) would be less than $.07.

Thus, except for peak periods when crowding becomes an issue (Kraus, 1991), the marginal cost of urban rail transit is very low, probably less than $.07 per rider. This is far below the current fares for all three Mexican urban rail systems, motivating the counterfactual analyses which follow. This is not unusual. Worldwide, prices for most urban rail systems are below average cost, but above marginal cost (Parry and Small, 2009). International Energy Agency (2019) reports a global average for passenger rail travel of 4 tons of oil equivalent per million passenger kilometers, equivalent to 0.37 kilowatt hours per five mile trip, very similar to my estimates for Mexico. Urban rail is more energy-efficient than road transportation because of 85%+ lower rolling friction losses, fewer stops, and the high performance of electric motors compared to internal combustion engines.

### 4.2 Efficiency Increases From Lower Prices

Motivated by the low marginal cost of urban rail ridership, Figure 4 illustrates the potential efficiency gains from reducing fares below current levels. Current ridership, $Q_{Current}$, is determined at the intersection of price with the private marginal benefit
curve. Pricing above marginal cost imposes deadweight loss triangle $DWL$ indicated in the figure. Reducing the price to marginal cost would eliminate this $DWL$. The trips represented by this triangle have a private marginal benefit less than the current price but higher than marginal cost, so represent additional consumer surplus that would be realized with price reform.

In addition, a lower price would create external benefits. Some proportion of increased rail ridership is substitution away from buses, private vehicle transportation, and, increasingly, ride sharing. These other forms of transportation cause traffic congestion, local pollution, and other externalities. For this reason, in Figure 4, I have assumed that the social marginal benefit of urban rail exceeds the private marginal benefit, i.e. that there are external benefits.

This is a second best policy environment. The first-best policy response would be to price all externalities dynamically. For example, private vehicles would face congestion prices equal to the marginal external damages they impose. Were all externalities properly priced, there would then be no external benefit from leading people to substitute away from these transportation modes.

### 4.3 Optimal Pricing for Public Transportation

Previous studies Parry and Small (2009) and Parry and Timilsina (2010) attempt to quantify these externalities. These studies use a static representative agent model of substitution between rail, bus, and private vehicles to derive optimal subsidies for public transportation, incorporating carbon dioxide, air pollution, traffic congestion,
and accident externalities. Particularly relevant is Parry and Timilsina (2010) which is focused specifically on the transportation system in Mexico City.

The following equation, adapted from Parry and Timilsina (2010), shows that the optimal price per mile for urban rail transit, \( p^{R*} \), can be expressed as follows:

\[
p^{R*} = \theta^R + E^R + (E^A)\rho_{AR} + (E^B)\rho_{BR}.
\]

Here \( \theta^R \) is the marginal cost per mile of rail travel, and \( E^R, E^A, \) and \( E^B \) are the external costs per mile of rail \( (R) \), private vehicle \( (A) \), and bus \( (B) \), respectively. Finally, \( \rho_{AR} \) and \( \rho_{BR} \) are cross-price elasticities that reflects how private vehicle travel and bus travel respond to a change in the price of rail transit.

The first two terms reflect the social marginal cost of rail travel. The last two terms reflect interactions with unpriced externalities from private vehicles and buses. If there is no substitution between these modes, or the externalities from these other modes are already priced, then these terms are equal to zero. Based on this equation, Parry and Timilsina (2010) find that the optimal urban rail price for Mexico City is -4.6 cents per mile. That is, the reduced externalities from substitution away from private vehicles and buses more than outweighs the first two positive terms.\(^8\)

\(^8\)In particular, Parry and Timilsina (2010) assume that the marginal cost per mile of rail travel, \( \theta^R = 6.8 \) cents per mile, and that external costs in cents per mile are \( E^R = 0, E^A = 21.4, \) and \( E^B = 10.5, \) for urban rail, private vehicle, and bus, respectively, where for bus externalities I’ve taken the weighted average over the two forms of bus transit they model in their analysis. Regarding substitution patterns, Parry and Timilsina (2010) assume \( \rho_{AR} = -0.35 \) and \( \rho_{BR} = -0.30, \) i.e. that 35% and 30% of changes in rail travel are diverted from private vehicles and buses, accordingly. The other 30% is assumed to be a change in the overall level of travel, and therefore without externality implications.
Parry and Timilsina (2010) do not perform an analogous exercise for Monterrey or Guadalajara, but external costs are likely to be largely similar in these other areas. Avoided carbon dioxide emissions are equally valuable in any of the three cities and while Monterrey and Guadalajara have smaller populations, the population densities are roughly comparable.\textsuperscript{9}

These calculations could undoubtedly be refined further. For example, Parry and Timilsina (2010) assume a social cost of carbon of $10 per ton of carbon dioxide whereas recent estimates are considerably higher (Nordhaus, 2017). But rather than revisit all of these assumptions, I am going to consider the policy counterfactual of setting prices equal to zero. It would not make sense to set a negative price as it would invite professional “riders”, and the optimal price for urban rail derived by Parry and Timilsina (2010) is sufficiently negative that it is likely to remain negative under most alternative assumptions.

### 4.4 Efficiency Gains

Table 5 quantifies the efficiency gains from making urban rail transit free. These are back-of-the-envelope calculations and should be viewed as an illustrative, rather than an exact representation.

A 100% price decrease would increase ridership significantly in all three cities. For example, in Mexico City, annual ridership increases from 1.7 billion to 2.1 billion,

\textsuperscript{9}According to INEGI, Densidad de población, Mexico City has a population density of about 6,000 people per square kilometer. In contrast, the municipalities of Monterrey and Guadalajara have population densities of 3,400 and 9,600 people per square kilometer, respectively.
an increase of 415 million riders per year. The Guadalajara and Monterrey systems are smaller in scale but experience similar or even larger percentage increases in ridership.

The foregone revenue would be substantial. Mexico City, for example, currently collects $470 million annually from riders, but this revenue would disappear. This is a transfer, not an economic cost, with these resources transferring from city transportation budgets to subway riders, with consumer surplus increasing by the full amount of the revenue decrease.

Deadweight loss would decrease by tens of millions of dollars per year. For Mexico City alone, the decreased deadweight loss is $46 million annually. Consumer surplus of subway riders goes up by the entire amount of the foregone fare revenue plus the entire amount of the reduced deadweight loss. Subway riders in Mexico City, for example, experience a gain in consumer surplus of $517 million annually. The consumer surplus gains per rider are larger for Guadalajara and Monterrey, but the total increase in consumer surplus is smaller due to the smaller scale of those urban rail systems.

Finally, the external benefits are significant, and several times larger than the decrease in deadweight loss. For Mexico City, for example, annual reduced externalities are worth $236 million as riders substitute away from private transportation and buses. These estimates rely heavily on the assumptions in (Parry and Timilsina, 2010) about substitution patterns between transportation modes and about the economic costs of traffic congestion and the other categories of externalities.
These calculations ignore general equilibrium impacts. Free urban rail transit would be a reduction in overall prices, encouraging economic activity and reducing the distortions from labor taxes and other distortions in the economy. On the other hand, the lost revenue would need to be financed somehow, exacerbating these same pre-existing distortions. See, e.g., Bovenberg and Goulder (2002) for a discussion of tax interaction effects. Parry and Small (2009) finds that the net impact of these general equilibrium distortions is modest in the context of urban public transportation.

5 Conclusion and Next Steps

This paper finds that the price elasticity of demand for subways in Mexico ranges from -.18 to -.33. These estimates come from a regression discontinuity research design that, although novel in this literature, is a natural empirical approach in this context. RD is easy to implement, transparent, and robust, with results varying little across specifications.

Perhaps it is not surprising that demand is relatively inelastic. Transportation is time-intensive, so the pecuniary cost of public transit is only a part of the overall cost of travel. As incomes increase so does the value of time, so one would expect price elasticities to become smaller. This pattern has been noted for private transportation (Hughes et al., 2008), but is likely true for public transportation as well.

These elasticities are directly relevant for evaluating policy counterfactuals. Ridership in urban rail systems around the world has fallen sharply since March 2020 due to Covid-19. The drop in revenue has put these systems into a budget crisis, and
forced many operators to look for additional government support. Thus today is an opportune time to think more broadly about pricing public transportation.

In the broader discussion, an important additional consideration is scale economies. Economists have long recognized that public transportation is an increasing returns-to-scale technology. The more riders in the system, the shorter the wait times for all riders (Mohring, 1972). This paper calculates the reduced deadweight loss and reduced externalities from lower prices, but scale economies imply that there could be important dynamic implications as well.

Working against these scale economies are crowding externalities (Kraus, 1991). That is, during peak travel, additional riders impose negative externalities, forcing riders to stand or to be uncomfortable, or to have to wait for a second train. De Palma et al. (2017) explore how crowding externalities can be mitigated through capacity investments and dynamic pricing. The natural response would be to charge a “congestion” price during peak hours (Vickrey, 1955, 1963).

A broader, more comprehensive analysis would also consider equity. This paper has focused on economic efficiency and left distributional considerations for future work. It is worth highlighting, however, that in Mexican cities it tends to be individuals with below average incomes who use rail transit. Thus, lower prices would have sharply positive distributional implications, in addition to the positive efficiency effects considered here.
References


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Figure 1: Raw Ridership Data, Monthly Counts

A. Mexico City Metro

B. Guadalajara Light Rail

C. Monterrey Metro
Figure 2: Ridership Data, Narrower Window

A. Mexico City Metro

B. Guadalajara Light Rail

C. Monterrey Metro
Figure 3: Ridership Data, Regression Discontinuity

A. Mexico City Metro

B. Guadalajara Light Rail

C. Monterrey Metro
Figure 4: Efficiency Gains From Lower Urban Rail Prices
Table 1: Urban Growth and Vehicle Ownership

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<th></th>
<th>2000</th>
<th>2018</th>
<th>Growth (%)</th>
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<tr>
<td><strong>Population (Millions)</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mexico City</td>
<td>18.4</td>
<td>21.5</td>
<td>17%</td>
</tr>
<tr>
<td>Guadalajara</td>
<td>3.7</td>
<td>5.0</td>
<td>35%</td>
</tr>
<tr>
<td>Monterrey</td>
<td>3.4</td>
<td>4.7</td>
<td>38%</td>
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<tr>
<td><strong>Registered Vehicles (Millions)</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mexico City</td>
<td>2.5</td>
<td>5.8</td>
<td>132%</td>
</tr>
<tr>
<td>Guadalajara</td>
<td>0.3</td>
<td>0.6</td>
<td>103%</td>
</tr>
<tr>
<td>Monterrey</td>
<td>0.2</td>
<td>0.5</td>
<td>104%</td>
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Table 2: The Effect of Price Changes on Urban Rail Transit

<table>
<thead>
<tr>
<th>A. Price Change, In Percent</th>
<th>Mexico City</th>
<th>Guadalajara</th>
<th>Monterrey</th>
</tr>
</thead>
<tbody>
<tr>
<td>+67%</td>
<td>+36%</td>
<td>-100%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Ridership Change, In Percent</th>
<th>Mexico City</th>
<th>Guadalajara</th>
<th>Monterrey</th>
</tr>
</thead>
<tbody>
<tr>
<td>-12%</td>
<td>-9%</td>
<td>+67%</td>
<td></td>
</tr>
<tr>
<td>(1.5)</td>
<td>(2.2)</td>
<td>(5.2)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Implied Price Elasticity</th>
<th>Mexico City</th>
<th>Guadalajara</th>
<th>Monterrey</th>
</tr>
</thead>
<tbody>
<tr>
<td>-.24</td>
<td>-.33</td>
<td>-.25</td>
<td></td>
</tr>
<tr>
<td>(.03)</td>
<td>(0.08)</td>
<td>(.01)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n=107</th>
<th>n=62</th>
<th>n=108</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r^2 = 0.80$</td>
<td>$r^2 = 0.84$</td>
<td>$r^2 = 0.97$</td>
</tr>
</tbody>
</table>

Note: This table reports results from three separate least squares regressions. In each regression the coefficient of interest is an indicator variable equal to one for observations after the fare change. All regressions control for a third-order polynomial in time and month-of-year fixed effects. Implied elasticities are calculated using the arc/midpoint method. Standard errors are estimated following Newey and West (1987) with a two-month lag.
Table 3: Estimated Price Elasticities, Alternative Bandwidths

<table>
<thead>
<tr>
<th>City</th>
<th>Baseline Specification (1)</th>
<th>Shorter Bandwidth (2)</th>
<th>Longer Bandwidth (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico City</td>
<td>-.24 (.03)</td>
<td>-.18 (.04)</td>
<td>-.27 (.04)</td>
</tr>
<tr>
<td>Guadalajara</td>
<td>-.33 (.08)</td>
<td>-.29 (.09)</td>
<td>-.30 (.07)</td>
</tr>
<tr>
<td>Monterrey</td>
<td>-.25 (.01)</td>
<td>-.24 (.01)</td>
<td>-.26 (.02)</td>
</tr>
</tbody>
</table>

Note: The baseline specification uses an eight-year bandwidth, four years on either side of the fare change. The shorter bandwidth includes three years on either side of the fare change, while the longer bandwidth includes five years on either side of the fare change. All specifications include a third-order polynomial in time and month-of-year fixed effects. For Guadalajara in all specifications there are only 7 months after the fare change to as observations after March 2020 are dropped to exclude the period affected by Covid-19. Implied elasticities are calculated using the arc/midpoint method. Standard errors are estimated following Newey and West (1987) with a two-month lag.
Table 4: The Marginal Electricity Usage of an Extra Subway Rider

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico City</td>
<td>0.45</td>
<td>0.30</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>(.04)</td>
<td>(.03)</td>
<td>(.06)</td>
</tr>
<tr>
<td>Monterrey</td>
<td>0.10</td>
<td>0.16</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>(.00)</td>
<td>(.02)</td>
<td>(.02)</td>
</tr>
</tbody>
</table>

Year Fixed Effects | No | Yes | Yes |
Month-of-Year Fixed Effects | No | No  | Yes |

Note: This table reports regression coefficients from six separate least squares regressions. The dependent variable is monthly electricity consumption in kilowatt hours (kWhs) for that city’s subway system. The independent variable of interest is monthly total ridership. Thus the table reports the predicted change in electricity consumption in kWhs for one additional rider. Electricity consumption is not available for Guadalajara. The regressions use monthly observations since 2000, \( n = 229 \) for Mexico City and \( n = 230 \) for Monterrey. Robust standard errors are reported in parentheses.
<table>
<thead>
<tr>
<th></th>
<th>Mexico City</th>
<th>Guadalajara</th>
<th>Monterrey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Elasticity</td>
<td>-.24</td>
<td>-.33</td>
<td>-.25</td>
</tr>
<tr>
<td>Current Price Per Rider (in dollars)</td>
<td>$0.22</td>
<td>$0.40</td>
<td>$0.20</td>
</tr>
<tr>
<td>Current Annual Ridership (Millions)</td>
<td>1,726</td>
<td>102</td>
<td>114</td>
</tr>
<tr>
<td>Predicted Annual Ridership after 100% Price Decrease (Millions)</td>
<td>2,140</td>
<td>136</td>
<td>143</td>
</tr>
<tr>
<td>Annual Foregone Fare Revenue (Millions, USD$)</td>
<td>$471</td>
<td>$54</td>
<td>$29</td>
</tr>
<tr>
<td>Annual Reduced Deadweight Loss (Millions, USD$)</td>
<td>$46</td>
<td>$7</td>
<td>$3</td>
</tr>
<tr>
<td>Annual Increased Consumer Surplus (Millions, USD$)</td>
<td>$517</td>
<td>$61</td>
<td>$32</td>
</tr>
<tr>
<td>Annual Reduced Externalities (Millions, USD$)</td>
<td>$236</td>
<td>$19</td>
<td>$17</td>
</tr>
</tbody>
</table>
Figure A1: Mexico City Metro, Descriptive Information

A. Number of Trains

B. Kilometers of Track

C. Total Kilometers Traveled

D. Electricity Consumption
Figure A2: Guadalajara Light Rail System, Descriptive Information

A. Number of Trains

B. Kilometers of Track

C. Total Kilometers Traveled
Figure A3: Monterrey Metro, Descriptive Information

A. Number of Trains

B. Kilometers of Track

C. Total Kilometers Traveled

D. Electricity Consumption