ENERGY INSTITUTE AT HAAS

Energy Institute WP 307R

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

Lucas Davis

Revised September 2020

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

Lucas W. Davis*

September 2020

Abstract

The sensitivity of demand for public transportation to fares has important implications for climate change, air pollution, and traffic congestion. However, there is surprisingly little recent evidence on this elasticity and virtually no evidence from low- or middle-income countries. This paper uses fare changes in Mexico City, Guadalajara, and Monterrey to estimate the price elasticity of demand for urban rail transit. In two of the cases there is a significant fare increase (30%+), and in the third there is a 60-day fare "holiday". Ridership responds sharply in the expected direction in all three cities, implying price elasticities which range across cities and specifications from -.19 to -.37. The paper then shows how these elasticities can be used to perform policy counterfactuals.

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

---

*Haas School of Business at University of California, Berkeley; Energy Institute at Haas; and National Bureau of Economic Research; *lwdavis@berkeley.edu*. I am thankful to Severin Borenstein, Gabriel Kreindler, and Eva Lyubich for helpful comments. I have not received any financial compensation for this project nor do I have any financial relationships that relate to this research.

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 challenges, 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; 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 transportation. 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 existing literature is implausibly large, including everything from zero to well above one (Holmgren, 2007).

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 for traffic congestion and local pollution (World Health Organization, 2016). Consequently, understanding demand for public transportation in these contexts is particularly important.

This study uses fare changes to 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 and low marginal 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 the study uses data on subway ridership and a regression discontinuity (RD) research design to measure the change in ridership and implied price elasticity. RD is a natural empirical approach in this context, but has not been used in previous studies.

The analysis shows that ridership responds to price changes 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 9%. Finally, when the Monterrey metro was offered free of charge for 60 days, ridership increased 61%.

The implied price elasticities are -.25, -.32, and -.23 for Mexico City, Guadalajara, and Monterrey, respectively. The preferred specification controls for a cubic polynomial in time as well as month-of-year fixed effects and retail gasoline prices. Estimates are similar with shorter and longer bandwidths, alternative controls, and in specifications excluding observations immediately around the fare change. In addition, the paper tests for asymmetric behavior at the beginning and end of the Monterrey fare holiday, finding suggestive evidence that the decrease at the end of the holiday was smaller than the increase at the beginning.

These estimates are directly relevant for policymakers considering alternative pricing structures for subways. Policymakers in Monterrey, for example, are considering increasing prices to pay for growing operating costs. Policymakers elsewhere are considering decreasing prices or even moving to fare-free transit.[1] The paper discusses

[1] See, e.g., "Cities Offer Free Buses in Bid to Boost Flagging Ridership," *Wall Street Journal*, Jon Kamp, January 14, 2020, "Luxembourg to Become the First Country to Offer Free Mass Transit

the relevant economic considerations and then shows how the estimated elasticities can be combined with the framework from Parry and Small (2009) and Parry and Timilsina (2010) to perform policy counterfactuals.

The paper proceeds as follows. Section 2 motivates the analysis with information about urban growth and vehicle ownership in Mexico, and then describes 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. Section 4 discusses optimal pricing for public transportation and performs a policy counterfactual. Section 5 concludes.

2 Background

2.1 Urban Growth and Vehicle Ownership

Like many middle-income countries, Mexico is experiencing rapid urbanization (United Nations, 2018a). 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 number of registered vehicles in all three urban areas has more than doubled since 2000. See Table 1 for population and vehicle registration statistics. This rapid growth in private vehicles helps explain why Mexico City, for example, has some of the worst traffic congestion in the world.[2]

for All," *New York Times*, Palko Karasz, December 6, 2018.

[2]See, 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.

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 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.

The price structure for the Mexico City metro is very simple. There is a single ticket 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 charge. One of the challenges in previous studies is that prices for different fare categories often change simultaneously and by varying amounts, making results difficult to interpret (see, e.g. Miller and Savage, 2017). 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 one order of magnitude smaller than the Mexico City subway. See Appendix Figures A1, A2, and A3 for additional descriptive information on all three systems.

Gudalajara'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, the paper tends 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, data from after March 2020 is excluded from all three cities to avoid 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.

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

[3]See "Tren Ligero, Macrobús y Rutas Alimentadoras Cobrarán $9.50", *El Milenio*, July 24, 2019 and "Aumenta 36% El Precio del Tren Ligero y Macrobús en Jalisco", *La Izquierda Diario Jalisco*, July 25, 2019.

ending July 14th.[4] 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.[5]

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.[6]

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. Data after March 2020 are excluded to avoid the sharp decline in ridership due to Covid-19. Data are also excluded from September 2017 for Mexico City because of much lower ridership in this month due to an earthquake which damaged several subway lines.

Fare changes are indicated with vertical lines. As expected, ridership falls in Mexico

[4] See "Nati dará agua y Metro gratis por dos meses", *El Milenio*, May 16, 2009.

[5] To put these fares in context, annual GDP per capita in Mexico was $10,000 in 2019 compared to $65,000 in the United States and a global average of $11,000. See, "World Economic Outlook Database, October 2019". International Monetary Fund.

[6] "Es Metrorrey el Mas Caro y El Menos Eficiente", *El Financiero*, September 20, 2018.

City in December 2013 when the fare increases. Ridership also falls in Guadalajara in July 2019, when the fare increases, though this 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.

Narrowing the windows brings the events into sharper focus. See Figure 2. The changes in ridership become clearer, particularly for Mexico City and Monterrey. For Monterrey the figure also reveals an earlier ridership increase seven months before the fare holiday in October 2008. This corresponds to the month of inauguration for four new subway stations.[7] As is shown later, controlling explicitly for this expansion has little effect on the estimates.

There is seasonal variation in ridership for all three systems, peaking in the summer and fall. Accordingly, the 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.

[7] See "History of Monterrey Metro" *Historia del Sistema de Transporte Colectivo Metrorrey*, `http://www.nl.gob.mx/?P=metrorrey_principal`.

3.2 Regression Discontinuity Analysis

Figure 3 overlays a cubic polynomial with a discontinuous break at the time of each event. Three separate least squares regressions were estimated of the following form,

$$ridership_t = \gamma_0 + \gamma_1 1(Change_t) + f(D_t) + \gamma_2 X_t + u_t. \quad (1)$$

The outcome variable $ridership_t$ is ridership in month t. The explanatory variable of interest is $1(Change_t)$, an indicator variable for observations after the price change.[8] 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 with additional controls X_t, including month-of-year fixed effects and retail gasoline prices. There are no major changes in retail gasoline prices around the fare change events. See Appendix Figure A4.[9] Nonetheless, gasoline prices are included in all regressions as previous research has shown substitution toward public transportation during periods of high gasoline prices (Nowak and Savage, 2013).

The RD figures further sharpen the pattern that was already visually discernible in

[8]The fare holiday for Monterrey requires a bit of extra explanation. The 60-days fare holiday ran from May 16 until July 14. Thus, $1(Change_t) = 1$ for June 2009, and $1(Change_t) = 0.5$ for May and July 2009 as both months were treated for half the month. All other months are untreated, $1(Change_t) = 0$. Thus, the coefficient γ_1 in the Monterrey regression reflects the change in ridership associated with the price change, just as it does with regressions for the other two cities.

[9]Monthly average retail gasoline prices in Mexico were collected from publicly-available sources. Data up until 2016 were collected from the Mexican Energy Ministry's *Sistema de Información Energética* and data since 2017 were collected from the Mexican Energy Regulator's *Precios Promedio Mensuales por Entidad Federativa de Gasolinas y Diésel.* Note that retail gasoline prices in Mexico were set administratively for most of this time period (Davis et al., 2019), so tend to vary much less than gasoline prices elsewhere.

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 shaded areas in the figure represent a 95% confidence interval constructed using Newey-West standard errors with a two-month lag.

3.3 Estimates and Standard Errors

Table 2 reports estimates and standard errors from the 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 9%. Finally, in Monterrey, the 100% price decrease resulted in a 61% increase in ridership. The implied price elasticities calculated using the midpoint method range from -.23 to -.32.

Estimates are similar with alternative bandwidths. See Table 3. Point estimates tend to be smaller with a shorter bandwidth, and larger with a longer bandwidth, but in all cases estimates are similar and statistically significant at the 1% level. The standard errors reported throughout the paper are Newey-West with a two-month lag. A diagnostic test was used to assess the magnitude of serial correlation. The autocorrelation coefficients are statistically significant for two months or less in all three cities, motivating the two-month lag.

Estimates change little in alternative specifications. Table 4 reports estimates from specifications that do not control for gasoline prices, that exclude the first month after the fare change, and that exclude one month before and one month after the fare change. Estimated elasticities are similar across specifications, providing reassurance that the results are not driven by gasoline controls, very short-run behavioral responses, or anticipation effects.

These estimates are smaller than most estimates in the previous literature. For example, McFadden (1974) estimates a price elasticity for Bay Area Rapid Transit (BART) of -0.86, using survey data from 213 respondents and a conditional choice model. Holmgren (2007) finds using a meta-analysis a price elasticity of -0.59 for the United States, Canada, and Australia, and -0.75 for Western Europe. Despite rapid growth, private vehicle ownership in Mexico remains less common than in these higher-income settings, so the lower price elasticities may reflect reduced scope for substitution to private vehicles.

It would have also been interesting to attempt to measure cross-price elasticities, or to attempt to measure the effect of these price changes on air quality or traffic congestion. 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 the data for urban rail.

3.4 Persistence

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, the decrease in ridership is persistent throughout 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 in Monterrey 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 throughout the 60 days.

There is suggestive evidence that the fare holiday in Monterrey led to a higher baseline level of ridership. Figure 3 and the regression estimates in Tables 2, 3, and 4 impose a symmetric response to the holiday, with equal changes in ridership at the beginning and end of the holiday. However, when these changes are allowed to be asymmetric, the decrease at the end of the holiday is smaller than the increase at the beginning. See Appendix Figure A5 and Appendix Table A1. Although the difference is not statistically significant, this is consistent with new riders learning about the metro because of the fare holiday and then sticking with it even after the fare holiday has ended.[10]

Thus the evidence from all three cities points to persistent, not transitory changes in behavior. That said, it is important to emphasize that the RD design measures short-run, not long-run price elasticities. The coefficient of interest, γ_1 is identified

[10] In related work, Larcom et al. (2017) find that a significant fraction of commuters on the London subway make persistent changes in routes following a strike which forced experimentation.

using the immediate change in ridership coincident with fare adjustments, so does not capture longer-run adaptations such as changes in where people live or work. The previous literature has tended to find somewhat larger long-run price elasticities, e.g. about 25% larger in the meta-analysis by Holmgren (2007), though these longer-run impacts are more difficult to credibly identify as it becomes challenging to disentangle the causal effect of price changes from omitted variables and broader trends.

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 subway fares. This section discusses the relevant economic considerations, leaning heavily on the framework and parameters from Parry and Small (2009) and Parry and Timilsina (2010). The section then illustrates how the estimated elasticities can be used to perform policy counterfactuals. The section focuses on the specific counterfactual of setting fares equal to zero, but the exercise could just as easily be repeated for alternative counterfactuals.

4.1 Optimal Pricing for Public Transportation

Parry and Small (2009) and Parry and Timilsina (2010) use a static representative agent model of substitution between rail, bus, and private vehicles to derive optimal subsidies for public transportation. Particularly relevant is Parry and Timilsina (2010) which focuses on the transportation system in Mexico City.

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

$$p^{R*} = \theta^R + E^R + (E^A)\rho_{AR} + (E^B)\rho_{BR}. \tag{2}$$

Here θ^R is the marginal cost per passenger mile of rail travel, and E^R, E^A, and E^B are the unpriced external costs per passenger mile of rail (R), private vehicle (A), and bus (B), respectively. Parameters ρ_{AR} and ρ_{BR} are cross-mode elasticities which describe how changes in rail usage affect passenger miles traveled via private vehicle and bus, respectively.

Thus the first two terms, θ^R and E^R, are the marginal cost and marginal external cost of rail travel. Parry and Timilsina (2010) use $\theta^R = 9.2$ cents and $E^R = 0$, so the marginal social cost of rail travel is 9.2 cents per passenger mile and a typical 5-mile trip would therefore have a marginal social cost of 46 cents.[11] Here and throughout all dollar amounts have been normalized to reflect year 2020 dollars.

The last two terms, $(E^A)\rho_{AR}$ and $(E^B)\rho_{BR}$ quantify substitution away from private vehicles and buses. The analyses by Parry and coauthors incorporate carbon dioxide, air pollution, traffic congestion, and accident externalities. In particular, Parry and Timilsina (2010) assumes $E^A = 29.0$ cents, and $E^B = 14.2$ cents per passenger mile

[11] The θ^R was determined assuming that 90% of operating costs are marginal, and that only 10% are fixed costs. This is mostly labor. The pure energy component of marginal cost is quite small. 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. For example, 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, i.e less than 5 cents.

for private vehicles and buses, and that $\rho_{AR} = -0.35$ and $\rho_{BR} = -0.35$, i.e. that 70% of changes in rail travel are diverted equally from private vehicles and buses. The other 30% is assumed to be a change in the overall level of travel, and without externality implications.[12] Multiplying, $(E^A)\rho_{AR} = -10.2$ and $(E^B)\rho_{BR} = 5.0$, so each passenger mile via rail offsets 10.2 cents of damages from private vehicles and 5 cents of damages from buses.[13]

Thus Parry and Timilsina (2010) find that these last two negative terms are significantly larger in magnitude than the first two positive terms, i.e the reduced externalities from substitution away from private vehicles and buses more than outweighs the social marginal cost of rail travel. That is, under their assumptions the optimal price for urban rail in Mexico City is negative and equal to -6.0 cents per mile.

Parry and Timilsina (2010) do not perform an analogous exercise for Monterrey or Guadalajara, but external costs are likely to be similar in these other cities. Avoided carbon dioxide emissions are equally valuable anywhere and while Monterrey and Guadalajara have smaller populations, the population densities are roughly comparable.[14] Moreover, the optimal price for Mexico City is sufficiently negative that even

[12]See, in particular, Table 2 and Section 3.3 in (Parry and Timilsina, 2010). The dollar amounts here have again been normalized to reflect year 2020 dollars. In addition, the external cost for buses reported here is a weighted average over two different forms of bus transit they consider in their model. Also, in the interest of parsimony the equation here assumes that all externalities accrue on a per-mile basis rather than distinguishing between gasoline- and mileage-based externalities.

[13]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, for example, $31 in Nordhaus (2017). This would have relatively little impact on the overall results, however, as local pollution and traffic congestion are far larger components quantitatively.

[14]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.

if the traffic congestion and local air pollution components were somewhat smaller for Guadalajara and Monterrey the optimal price might still be below zero.

4.2 Additional Considerations

Negative prices are impractical for public transportation because they would invite professional "riders". But the results from Parry and Small (2009) and Parry and Timilsina (2010) do suggest that lower, or perhaps even zero fares for urban rail transit could make sense in some circumstances. Accordingly, Section 4.3 considers the policy counterfactual of fare-free travel. However, before this exercise, there are several additional economic considerations that should be discussed. To fully quantify these other factors goes well beyond this current analysis but it is nonetheless valuable to briefly outline the broader issues.

First, it is worth emphasizing that this is a second best policy environment. In particular, equation (2) assumes that the externalities from other transport modes are not already priced. This is an appropriate assumption in many contexts including Mexico, but is nonetheless worth highlighting. The broader point that there is substitutability between taxes on private vehicles and transit subsidies was recently made by Basso and Silva (2014).

It is also important to point out that the optimal price derived in Section 4.1 ignores crowding externalities (Kraus, 1991). Off-peak urban rail systems can absorb additional riders, either because current trains have excess capacity or because additional trains can be added. However, 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 (Hörcher et al., 2017). 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).

Working against these crowding externalities are 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). Parry and Timilsina (2010) abstract from both crowding externalities and scale economies, while Parry and Small (2009) essentially assume that these two factors balance each other out, with the transit agency optimizing over the number of trains, size of trains, and load factor. But of course some systems have capacity constraints that make such optimization impossible during some hours in which case the optimal fare during peak periods would be much higher.

A more comprehensive analysis would also consider equity. The discussion and analysis throughout focuses on economic efficiency and ignores distributional considerations. It is worth highlighting, however, that in Mexican cities it tends to be individuals with below average incomes who use rail transit. Indeed, the availability of public transportation is one of the reasons lower-income households live in cities to begin with (Glaeser et al., 2008), and previous research has shown that transit subsidies are progressive (Basso and Silva, 2014). It is likely, therefore, that any policy counterfactual considered would have significant distributional implications, in addition to significant implications for efficiency.

4.3 Policy Counterfactual

Table 5 describes the policy counterfactual. Specifically, the table uses the estimated price elasticities to quantify the economic costs and benefits of making urban rail transit free in all three cities. These are back-of-the-envelope calculations and should be viewed as illustrative, rather than exact representations.

This exercise relies on the preferred estimates of the price elasticity of demand from Table 2. For these calculations, making urban rail transit free is treated as a 100% decrease in price so the counterfactual quantities are calculated by multiplying current ridership by one plus the elasticity of demand. For example, in Mexico City, annual ridership increases from 1.6 billion to 2.0 billion (1.6 * 1.25) riders per year, an increase of 400 million riders per year. The Guadalajara and Monterrey systems are smaller in scale but experience similar percentage increases in ridership.

The foregone revenue would be substantial. Mexico City, for example, currently collects $350 million annually from riders, but this revenue would disappear. Consumer surplus of riders would increase by this full amount plus the gain in consumer surplus from the additional trips. Revenue impacts are smaller in scale in Guadalajara and Monterrey, but also substantial. Guadalajara currently charges considerably more per rider so the revenue impacts per rider are proportionately larger.

Operating costs would increase. Based on the assumptions in Parry and Timilsina (2010), the marginal cost per passenger trip is 46 cents. So, for example, an extra 400 million passenger trips in Mexico City would increase operating costs by $183 million annually. On the other hand, negative externalities would decrease. Following Parry and Timilsina (2010), each trip via urban rail is assumed to reduce traffic congestion, local pollution, and other negative externalities by an amount valued at 76 cents. So, for example, an extra 400 million passenger trips in Mexico City would decrease negative externalities by $303 million annually.

These calculations rely heavily on the assumptions in Parry and Timilsina (2010). For example, these numbers assume that the most operating costs are marginal, not fixed. If there are economies-of-scale that make it possible to increase ridership without incurring near proportional cost increases, then the cost impacts would be significantly lower. In addition, the framework makes strong assumptions about substitution patterns between transportation modes, as well as about the external costs of traffic congestion and accidents.

These calculations ignore operational efficiencies from not having to collect fares. With fare-free transit there would be no reason to wait in line, resulting in times savings for riders. In addition, fare-free transit would make gates, turnstiles, electronic ticket kiosks, and other fare collection equipment unnecessary, reducing capital and maintenance expenditures. There would also likely be labor savings, with fewer employees needed at subway stations and for ticket enforcement.

5 Conclusion

This paper finds that the price elasticity of demand for subways in Mexico ranges across cities and specifications from -.19 to -.37. 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 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 discussed in the context of 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, forcing many operators to revisit their fare policies and to look for additional government support. Thus now is a particularly opportune time to think more broadly about pricing public transportation.

References

Adler, Martin W and Jos N van Ommeren, "Does Public Transit Reduce Car Travel Externalities? Quasi-Natural Experiments' Evidence from Transit Strikes," *Journal of Urban Economics*, 2016, *92*, 106–119.

Anderson, Michael L, "Subways, Strikes, and Slowdowns: The Impacts of Public Transit on Traffic Congestion," *American Economic Review*, 2014, *104* (9), 2763–96.

Basso, Leonardo J and Hugo E Silva, "Efficiency and Substitutability of Transit Subsidies and other Urban Transport Policies," *American Economic Journal: Economic Policy*, 2014, *6* (4), 1–33.

Bauernschuster, Stefan, Timo Hener, and Helmut Rainer, "When Labor Disputes Bring Cities to a Standstill: The Impact of Public Transit Strikes on Traffic, Accidents, Air Pollution, and Health," *American Economic Journal: Economic Policy*, 2017, *9* (1), 1–37.

Baum-Snow, Nathaniel and Matthew E Kahn, "The Effects of New Public Projects to Expand Urban Rail Transit," *Journal of Public Economics*, 2000, *77* (2), 241–263.

_ , _ , and Richard Voith, "Effects of Urban Rail Transit Expansions: Evidence from Sixteen Cities, 1970-2000," *Brookings-Wharton Papers on Urban Affairs*, 2005, pp. 147–206.

Cervero, Robert, "Transit Pricing Research," *Transportation*, 1990, *17* (2), 117–139.

Chen, Yihsu and Alexander Whalley, "Green Infrastructure: The Effects of Urban Rail Transit on Air Quality," *American Economic Journal: Economic Policy*, 2012, *4* (1), 58–97.

Davis, Lucas W, "The Effect of Driving Restrictions on Air Quality in Mexico City," *Journal of Political Economy*, 2008, *116* (1), 38–81.

_ , Shaun Mcrae, and Enrique Seira Bejarano, "An Economic Perspective on Mexico's Nascent Deregulation of Retail Petroleum Markets," *Economics of Energy & Environmental Policy*, 2019, *8* (2).

Gallego, Francisco, Juan-Pablo Montero, and Christian Salas, "The Effect of Transport Policies on Car Use: Evidence from Latin American Cities," *Journal of Public Economics*, 2013, *107*, 47–62.

Glaeser, Edward, *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier*, New York: Penguin Group, Penguin Press, 2011.

_ , Matthew Kahn, and Jordan Rappaport, "Why Do the Poor Live in Cities? The Role of Public Transportation," *Journal of Urban Economics*, 2008, *63*, 1–24.

Gonzalez-Navarro, Marco and Matthew A Turner, "Subways and Urban Growth: Evidence from Earth," *Journal of Urban Economics*, 2018, *108*, 85–106.

Goodwin, Phil B, "A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes," *Journal of Transport Economics and Policy*, 1992, pp. 155–169.

Gupta, Arpit, Stijn Van Nieuwerburgh, and Constantine E Kontokosta, "Take the Q Train: Value Capture of Public Infrastructure Projects," *NBER Working Paper*, 2020.

Hanna, Rema, Gabriel Kreindler, and Benjamin A Olken, "Citywide Effects of High-Occupancy Vehicle Restrictions: Evidence from "Three-In-One" in Jakarta," *Science*, 2017, *357* (6346), 89–93.

Holmgren, Johan, "Meta-Analysis of Public Transport Demand," *Transportation Research Part A: Policy and Practice*, 2007, *41* (10), 1021–1035.

Hörcher, Daniel, Daniel J Graham, and Richard J Anderson, "Crowding Cost Estimation with Large Scale Smart Card and Vehicle Location Data," *Transportation Research Part B: Methodological*, 2017, *95*, 105–125.

Hughes, Jonathan, Christopher R Knittel, and Daniel Sperling, "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand," *Energy Journal*, 2008, *29* (1).

International Energy Agency, "The Future of Rail: Opportunities for Energy and the Environment," *www.iea.org*, 2019.

Kraus, Marvin, "Discomfort Externalities and Marginal Cost Transit Fares," *Journal of Urban Economics*, 1991, *29* (2), 249–259.

Lago, Armando M, Patrick D Mayworm, and J Matthew McEnroe, "Further Evidence on Aggregate and Disaggregate Transit Fare Elasticities," *Transportation Research Record*, 1981, *799*.

Larcom, Shaun, Ferdinand Rauch, and Tim Willems, "The Benefits of Forced Experimentation: Striking Evidence from the London Underground Network," *Quarterly Journal of Economics*, 2017, *132* (4), 2019–2055.

Levin, Laurence, Matthew S Lewis, and Frank A Wolak, "High Frequency Evidence on the Demand for Gasoline," *American Economic Journal: Economic Policy*, 2017, *9* (3), 314–47.

McFadden, Daniel, "The Measurement of Urban Travel Demand," *Journal of Public Economics*, 1974, *3* (4), 303–328.

Miller, Caroline and Ian Savage, "Does the Demand Response to Transit Fare Increases Vary by Income?," *Transport Policy*, 2017, *55*, 79–86.

Mohring, Herbert, "Optimization and Scale economies in Urban Bus Transportation," *American Economic Review*, 1972, *62* (4), 591–604.

Nordhaus, William D, "Revisiting the Social Cost of Carbon," *Proceedings of the National Academy of Sciences*, 2017, *114* (7), 1518–1523.

Nowak, William P and Ian Savage, "The Cross Elasticity Between Gasoline Prices and Transit Use: Evidence from Chicago," *Transport policy*, 2013, *29*, 38–45.

Palma, André De, Robin Lindsey, and Guillaume Monchambert, "The Economics of Crowding in Rail Transit," *Journal of Urban Economics*, 2017, *101*, 106–122.

Parry, Ian WH and Govinda R Timilsina, "How Should Passenger Travel in Mexico City Be Priced?," *Journal of Urban Economics*, 2010, *68* (2), 167–182.

_ **and Kenneth A Small**, "Should Urban Transit Subsidies Be Reduced?," *American Economic Review*, 2009, *99* (3), 700–724.

Tsivanidis, Nick, "The Aggregate and Distributional Effects of Urban Transit Infrastructure: Evidence from Bogotá's Transmilenio," *UC Berkeley Working Paper*, 2018.

Union Internationale des Transports Publics (UITP), "World Metro Figures 2018," *Statistics Brief*, 2018.

United Nations, "World Urbanization Prospects 2018," *Department of Economic and Social Affairs, Population Division*, 2018.

_ , "The World's Cities in 2018–Data Booklet (ST/ESA/SER. A/417)," 2018.

Vickrey, William S, "A Proposal for Revising New York's Subway Fare Structure," *Journal of the Operations Research Society of America*, 1955, *3* (1), 38–68.

_ , "Pricing in Urban and Suburban Transport," *American Economic Review*, 1963, *53* (2), 452–465.

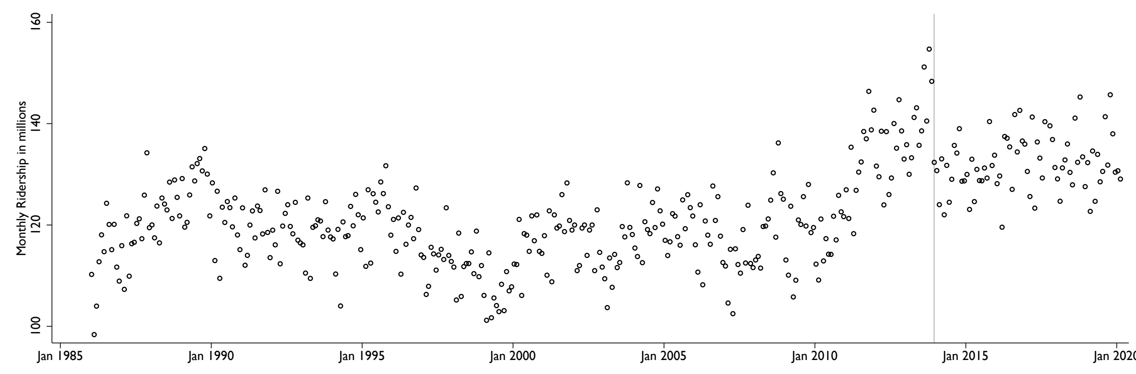
World Health Organization, "Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease," *ISBN: 9789241511353*, 2016.

Zárate, Román David, "Factor Allocation, Informality and Transit Improvements: Evidence from Mexico City," *UC Berkeley Working Paper*, 2019.

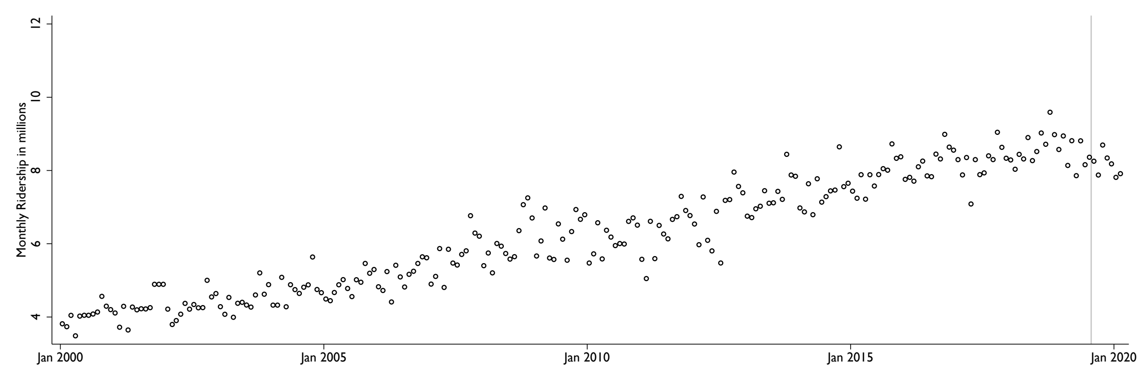
Zheng, Siqi and Matthew E Kahn, "Understanding China's Urban Pollution Dynamics," *Journal of Economic Literature*, 2013, *51* (3), 731–72.

Figure 1: Ridership Data

A. Mexico City Metro



B. Guadalajara Light Rail



C. Monterrey Metro

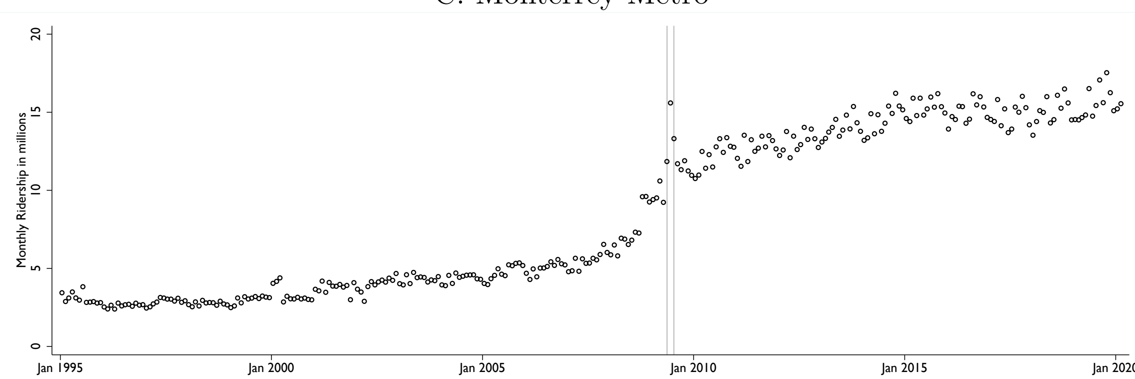
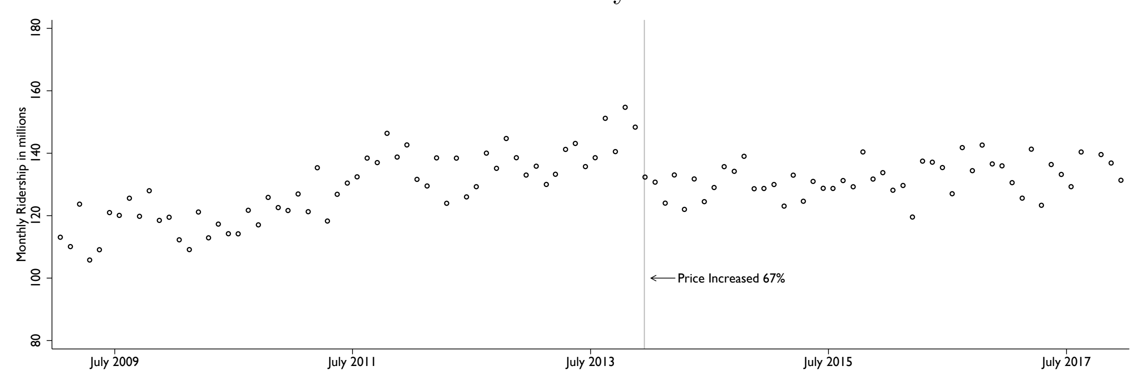
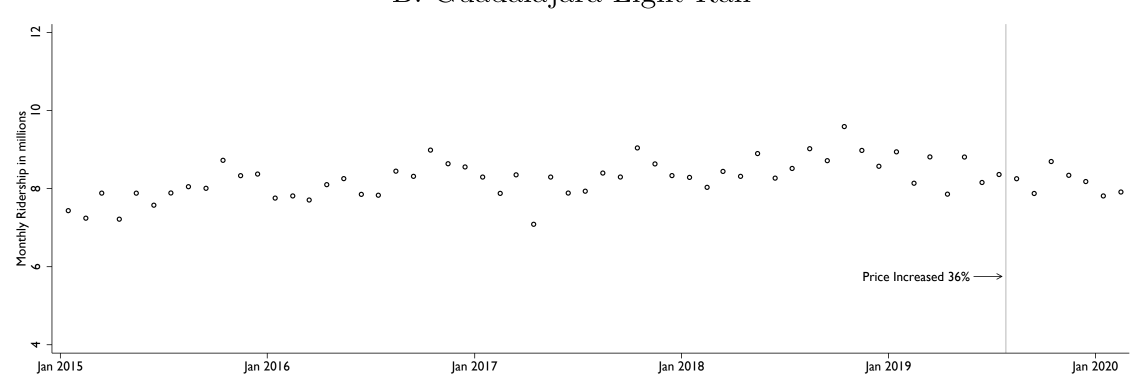


Figure 2: Ridership Data, Narrower Window

A. Mexico City Metro



B. Guadalajara Light Rail



C. Monterrey Metro

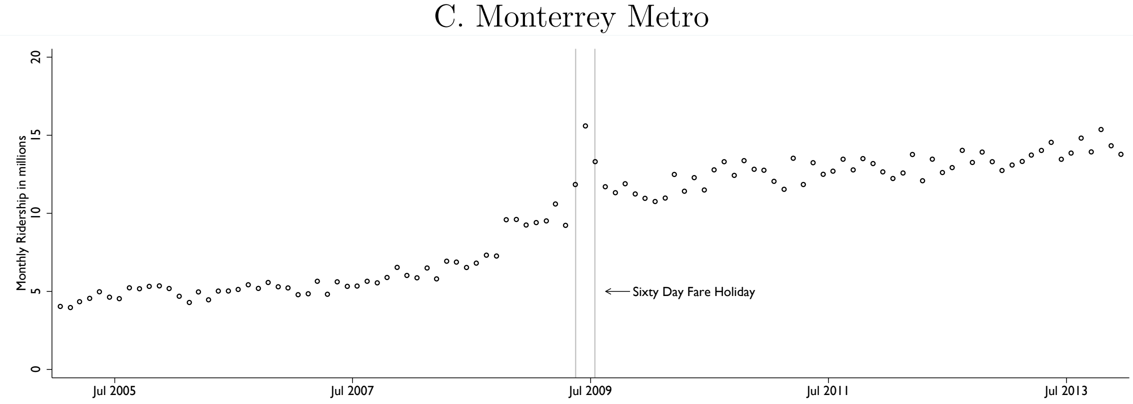
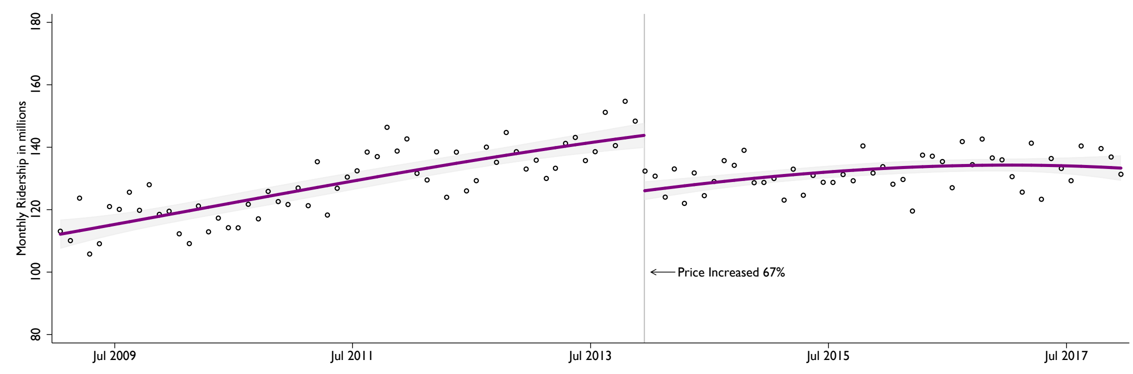
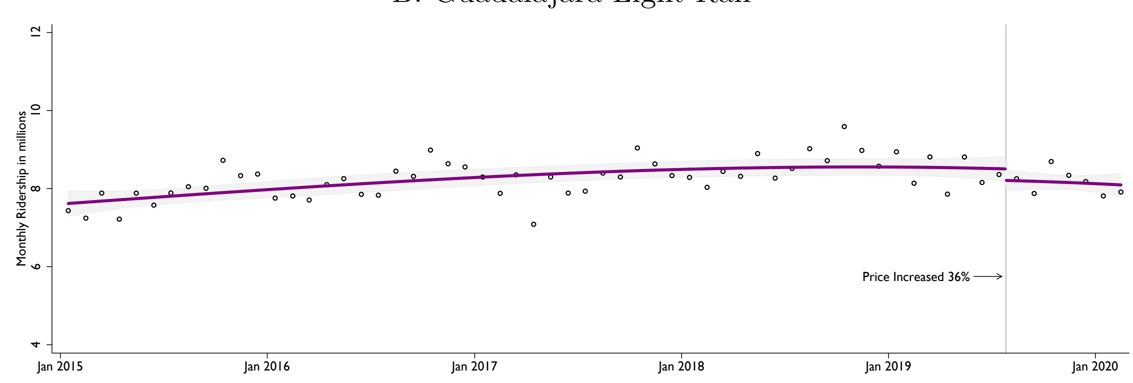


Figure 3: Regression Discontinuity Analysis

A. Mexico City Metro



B. Guadalajara Light Rail



C. Monterrey Metro

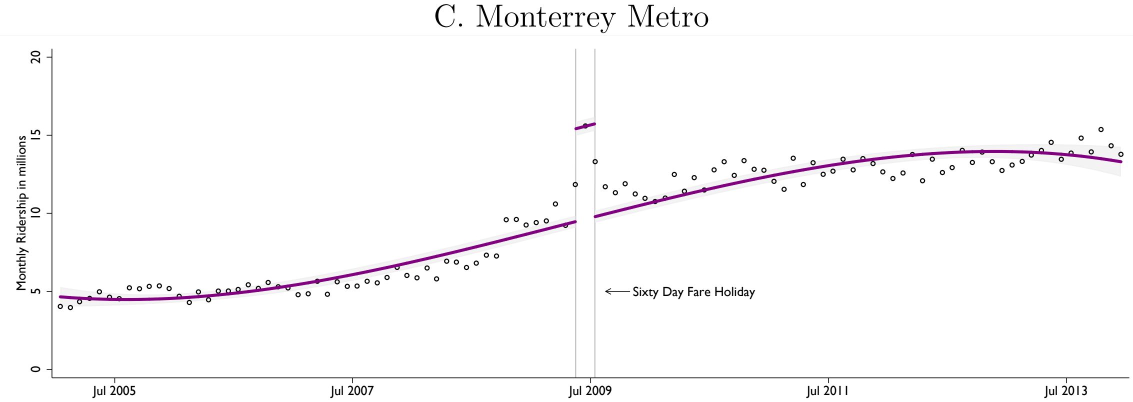


Table 1: Urban Growth and Vehicle Ownership

	2000	2018	Growth (%)
	Population (Millions)		
Mexico City	18.4	21.5	17%
Guadalajara	3.7	5.0	35%
Monterrey	3.4	4.7	38%
	Registered Vehicles (Millions)		
Mexico City	2.5	5.8	132%
Guadalajara	0.3	0.6	103%
Monterrey	0.2	0.5	104%

Note: Population data come from United Nations (2018b). Registered vehicle data come from the Mexican Statistics Institute (*INEGI*), `https://www.inegi.org.mx/programas/vehiculosmotor/`.

Table 2: The Effect of Price Changes on Urban Rail Transit

	Mexico City	Guadalajara	Monterrey
A. Price Change, In Percent			
	+67%	+36%	-100%
B. Ridership Change, In Percent			
	-12%	-9%	+61%
	(1.5)	(2.5)	(4.6)
C. Implied Price Elasticity			
	-.25	-.32	-.23
	(.03)	(.09)	(.01)
	n=107	n=62	n=108
	$r^2 = 0.80$	$r^2 = 0.84$	$r^2 = 0.97$

Note: This table reports coefficients and standard errors from three separate least squares regressions. In all regressions the outcome variable is monthly total ridership and the explanatory variable 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, month-of-year fixed effects, and average retail gasoline prices. Ridership changes are reported in percent relative to the ridership level just prior to the price change. Implied elasticities are calculated using the arc/midpoint method. Standard errors are Newey-West with a two-month lag.

Table 3: Estimated Price Elasticities, Alternative Bandwidths

	Baseline Specification (1)	Longer Bandwidth (2)	Shorter Bandwidth (3)	Even Shorter Bandwidth (4)
Mexico City	-.25	-.27	-.19	-.23
	(.03)	(.03)	(.05)	(.05)
Guadalajara	-.32	-.28	-.28	-.23
	(.09)	(.09)	(.09)	(.06)
Monterrey	-.23	-.23	-.24	-.23
	(.01)	(.01)	(.01)	(0.01)

Note: This table reports coefficients and standard errors from twelve separate least squares regressions. The baseline specification uses an eight-year bandwidth, four years on either side of the fare change. The longer bandwidth includes five years on either side of the fare change. The shorter bandwidth includes three years on either side of the fare change, while the even shorter bandwidth includes two years on either side of the fare change. All specifications include a third-order polynomial in time, month-of-year fixed effects, and average retail gasoline prices. For Guadalajara in all specifications there are only 7 months after the fare change 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 Newey-West with a two-month lag.

Table 4: Estimated Price Elasticities, Additional Alternative Specifications

Mexico City	Guadalajara	Monterrey
A. Baseline Specification		
-.25	-.32	-.23
(.03)	(.09)	(.01)
B. Without Controlling for Gasoline Prices		
-.25	-.34	-.25
(.04)	(.09)	(.01)
C. Excluding First Month After Fare Change		
-.26	-.34	-.25
(.03)	(.10)	(.01)
D. Excluding One Month Before and One Month After Fare Change		
-.25	-.37	-.25
(.04)	(.11)	(.01)

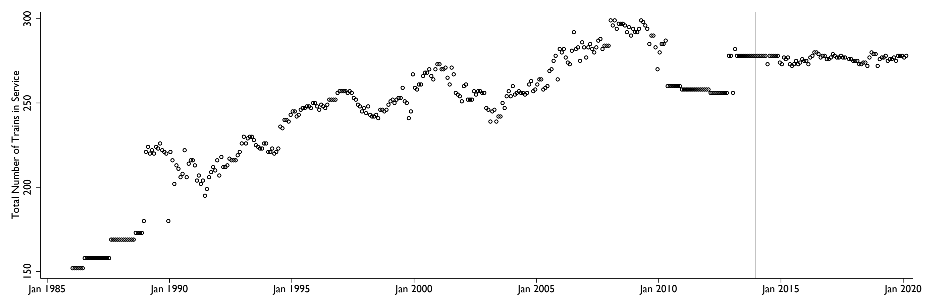
Note: This table reports coefficients and standard errors from twelve separate least squares regressions. In all regressions the outcome variable is monthly total ridership and the explanatory variable of interest is an indicator variable equal to one for observations after the fare change. Unless otherwise stated, all regressions control for a third-order polynomial in time, month-of-year fixed effects, and average retail gasoline prices. Implied elasticities are calculated using the arc/midpoint method. Standard errors are Newey-West with a two-month lag.

Table 5: Illustrative Policy Counterfactual

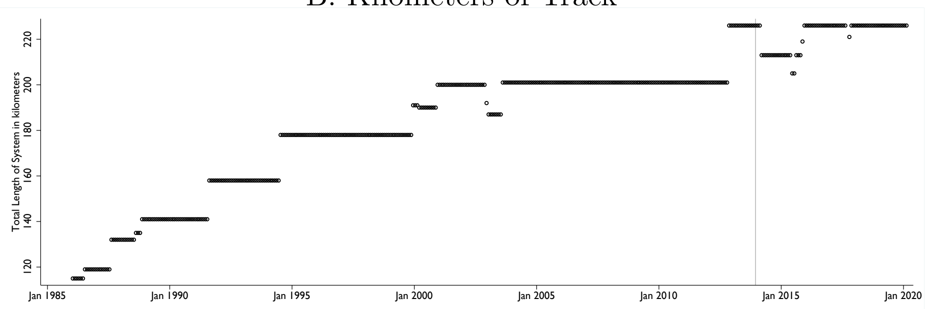
	Mexico City	Guadalajara	Monterrey
Price Elasticity of Demand	-.25	-.32	-.23
Current Price Per Passenger Trip (one way fare, in dollars)	$0.22	$0.43	$0.20
Current Annual Total Passenger Trips (in 2019, millions)	1,595	100	187
Predicted Annual Total Passenger Trips if the price were zero (in millions)	1,994	132	230
Annual Foregone Fare Revenue (Millions, USD$)	$351	$43	$37
Annual Increased Operating Costs (Millions, USD$)	$183	$15	$20
Annual Reduced Negative Externalities (Millions, USD$)	$303	$24	$33

Figure A1: Mexico City Metro, Descriptive Information

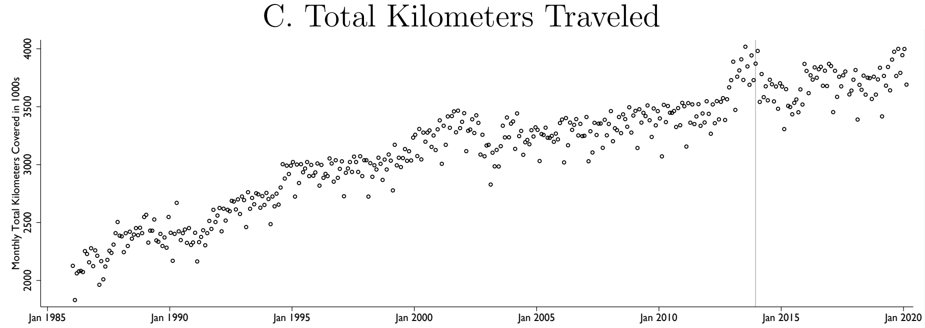
A. Number of Trains



B. Kilometers of Track



C. Total Kilometers Traveled



D. Electricity Consumption

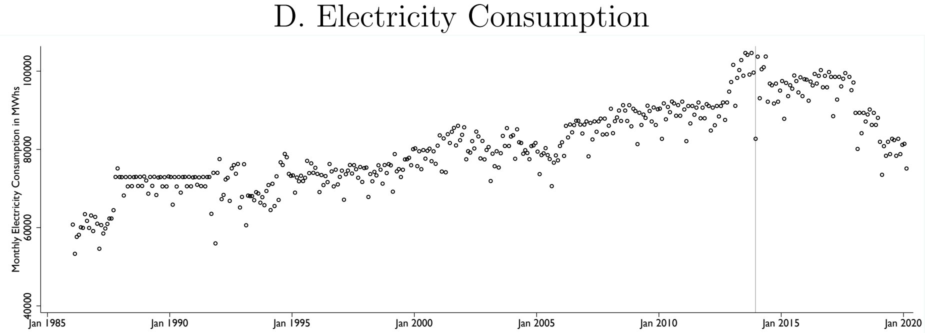
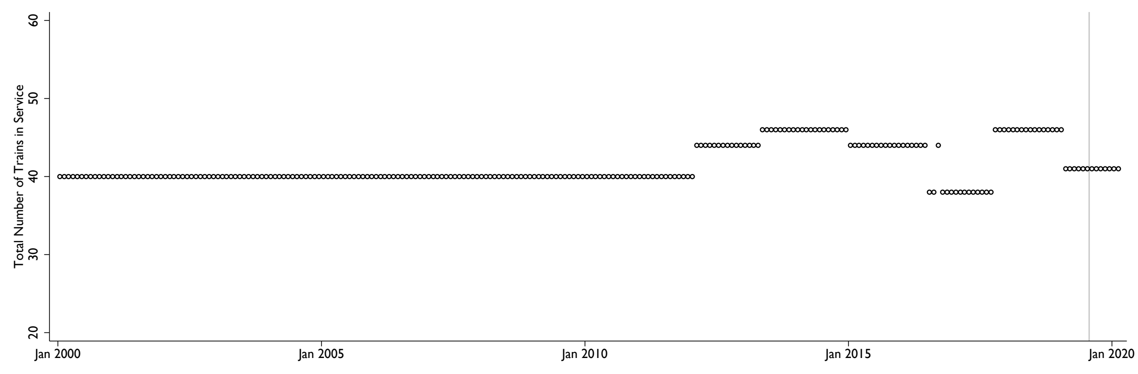
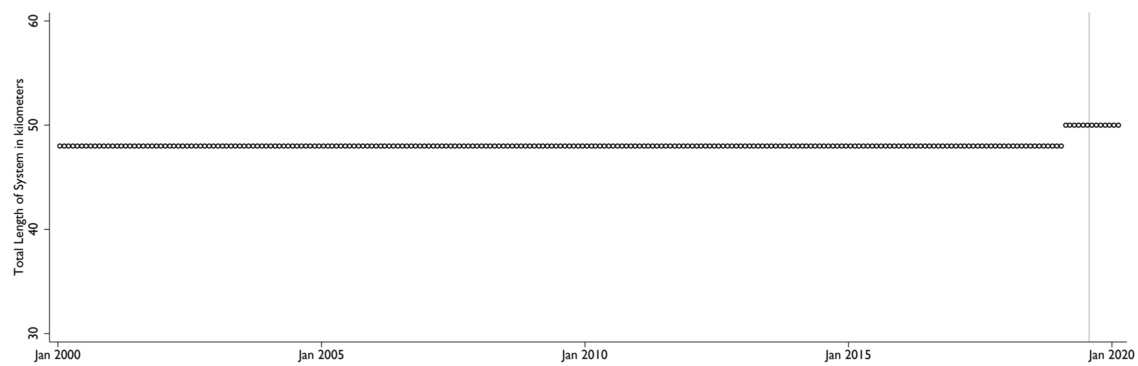


Figure A2: Guadalajara Light Rail System, Descriptive Information

A. Number of Trains



B. Kilometers of Track



C. Total Kilometers Traveled

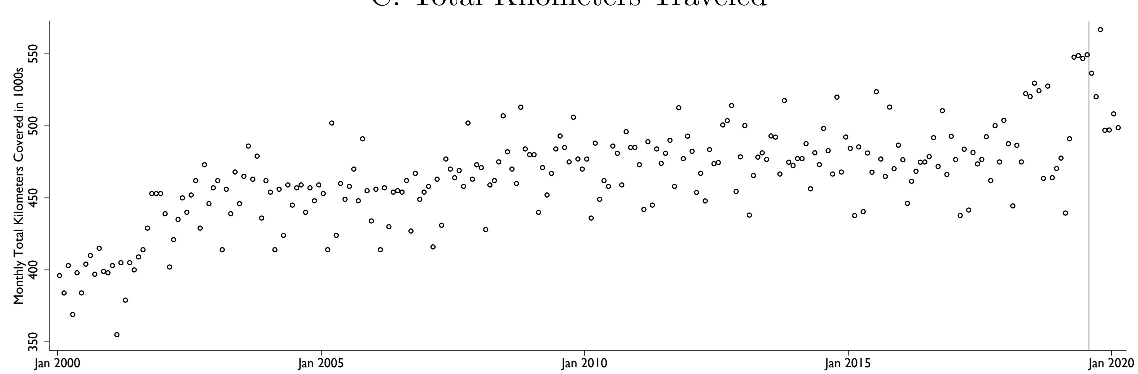
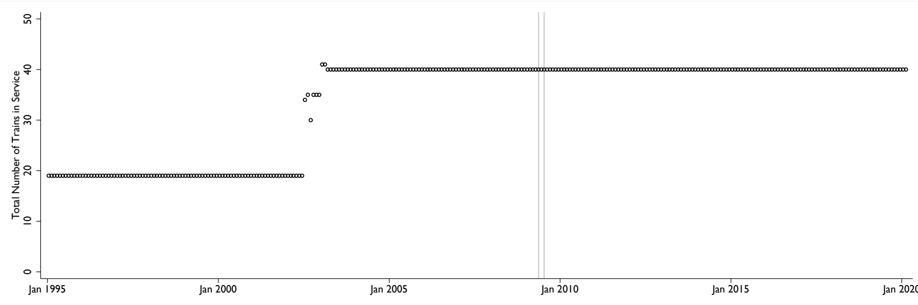
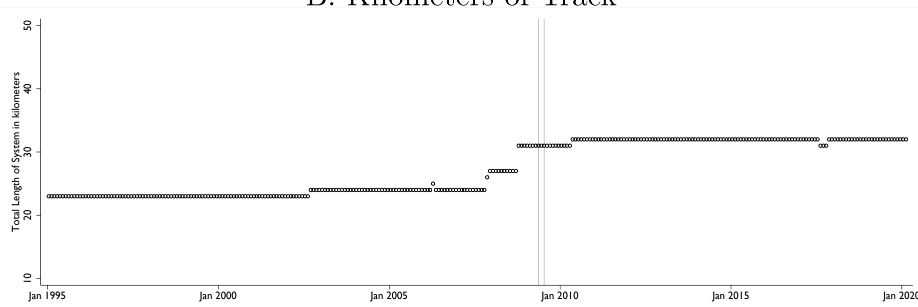


Figure A3: Monterrey Metro, Descriptive Information

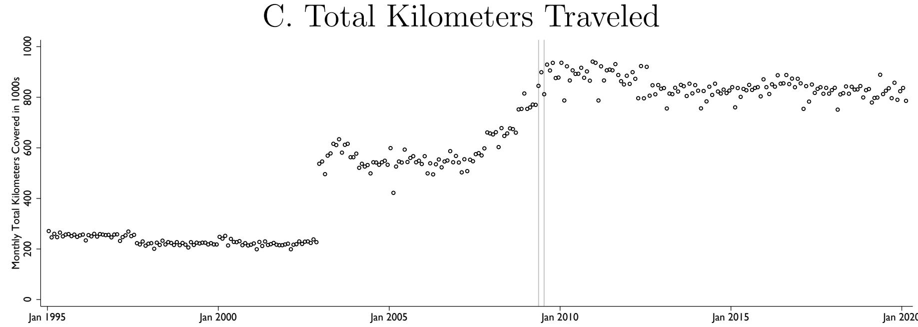
A. Number of Trains



B. Kilometers of Track



C. Total Kilometers Traveled



D. Electricity Consumption

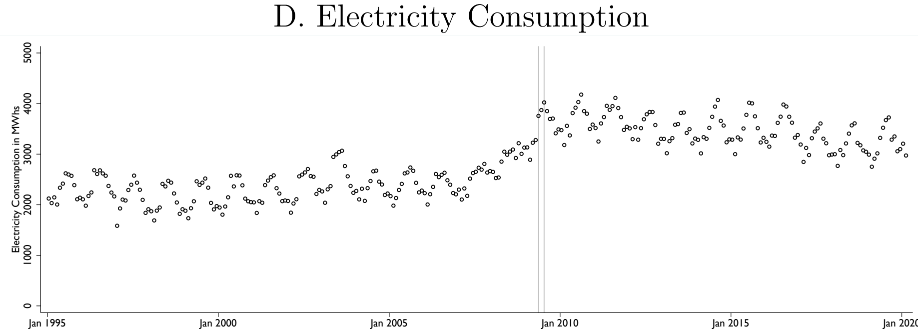
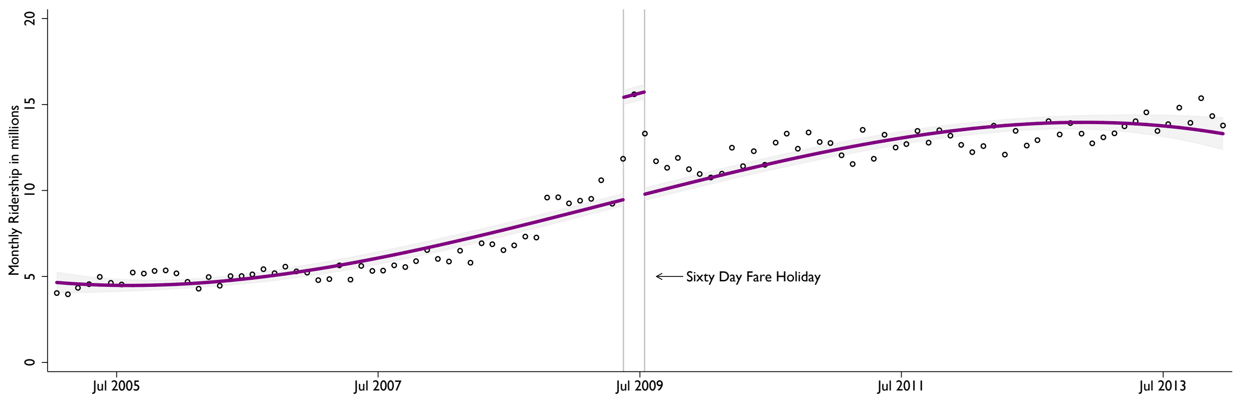


Figure A4: Retail Gasoline Prices

Figure A5: RD Estimates, Alternative Specification for Monterrey

A. Monterrey Metro, Baseline Specification



B. Monterrey Metro, Asymmetric Specification

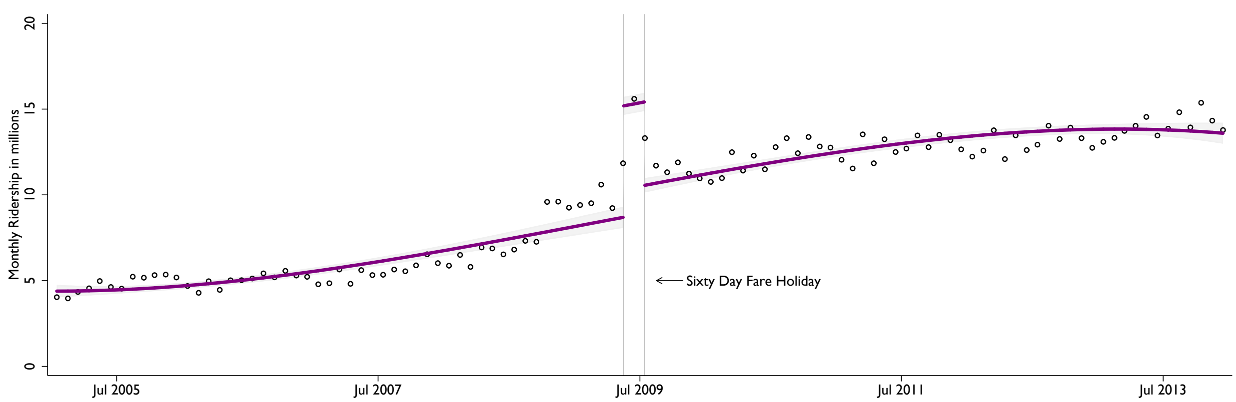


Table A1: Alternative Specifications for Monterrey

	A. Baseline Specification	
	+61%	
	(4.6)	
	B. Controlling for October 2018 Expansion	
	+50%	
	(4.0)	
	C. Asymmetric Specification	
Increase at Beginning of Fare Holiday	Decrease at End of Fare Holiday	Test of Equality
+64%	-56%	
(6.2)	(4.3)	p-value = 0.28

Note: This table reports the estimated ridership change and standard errors from three separate least squares regressions. Panel A reports results from the baseline specification, identical to the estimates for Monterrey reported in Table 2. Panel B reports results from a specification which includes an indicator for observations after October 2008 when four new stations were inaugurated. Finally, Panel C allows for different changes in ridership at the beginning and end of the fare holiday. Panel C also reports the p-value corresponding to a test where the null hypothesis is that the two changes are identical.