

# Spatial Mobility, Economic Opportunity, and Crime

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## Abstract

Neighborhoods are strong determinants of both economic opportunity and criminal activity. Does improving connectedness between segregated and unequal parts of a city predominantly import opportunity or export crime? We use a spatial general equilibrium framework to model individual's decision of where to work and whether to engage in criminal activity, with spillovers across the criminal and legitimate sectors. We match at the individual level various sources of administrative records from Medellín, Colombia to construct a novel, granular dataset recording the origin and destination of both workers and criminals needed to identify key parameters of the model. We leverage the roll out of a cable car system to identify how changes in transportation costs causally affect the location and sector choices of workers and criminals. Our counterfactual exercises indicate that overall criminal activity in the city is reduced and total welfare is improved for almost all neighborhoods when their connectedness is improved.

**Keywords:** *Crime, transit networks, segregation, Medellín*

**JEL Codes:** K42, J46, J24

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# 1 Introduction

Income, economic opportunity and criminal activity are all unequally spatially distributed in cities across the developed and developing world (Cutler and Glaeser, 1997; Athey et al., 2020). Neighborhood segregation is often both the cause and consequence of the interplay between legitimate and illegitimate activity (Card et al., 2008). As a result of such segregation, neighborhoods are often strong predictors of both economic opportunity and criminal activity (Kling et al., 2007; Chyn, 2018; Chetty and Hendren, 2018a; Jacob, 2004; Melnikov et al., 2019).

Canonical models of crime (Becker, 1968; Ehrlich, 1973) which depict criminal activity as a rational choice in the face of limited legitimate economic alternatives would then suggest that investing in transportation infrastructure to better connect poor populations segregated from opportunity to more economically active parts of the city could reduce criminal activity. Yet, cities across the world have been resistant to such transit expansions, with the concern that crime could spread to more affluent victims and properties as potential perpetrators obtain access to more neighborhoods.<sup>1</sup> We investigate these claims by asking: does improving connectedness between segregated and economically unequal parts of a city predominantly import opportunity or export crime?

Empirically evaluating the results of transportation infrastructure investments on both localized and aggregate income, employment, and crime is, however, difficult as these are jointly determined results of a spatial equilibrium. That is, all parts of the city are theoretically affected in some way, making ‘control groups’ for comparison elusive. This issue is exacerbated by the possibility of externalities across sectors and neighborhoods, and the occurrence of neighborhood specific shocks (like gang wars and plant closings) that may coincide in time and space with expansions in public infrastructure. We build on recent developments in economic geography to construct a framework that addresses these issues (Ahlfeldt et al., 2015; Donaldson and Hornbeck, 2016; Tsivanidis, 2018; Zárate, 2019).

A second set of challenges arises in finding variation for identification and obtaining the necessary granular data. We leverage the roll out of a public transit system over a decade to identify parameters of the model; however, to do so we need exceedingly rare

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<sup>1</sup>See, for instance, the example of Atlanta “The Myth That Mass Transit Attracts Crime Is Alive in Atlanta” in Bloomberg (Dec, 2014), and the case of Baltimore “‘Addicts, crooks, thieves’: the campaign to kill Baltimore’s light rail” covered by the Guardian (Aug, 2018). Indeed, there is no shortage of events to study to evaluate the impacts of improving transportation connectedness on income distortion and both localized and aggregate crime. Most major cities in the world over the last century have faced perceived trade offs like these when making decisions whether to invest in the expansion of transportation infrastructure linking prosperous, affluent areas to struggling neighborhoods.

data on the flows of crime from origin to destination. That is, over the period, we need to know where a criminal lives and where they travel to commit crimes in addition to analogous data on flows of legitimate workers. Having such data allows for transparent identification and a tractable analysis that does not rely on the structure of the model.

We use the census of geocoded arrests over more than a decade in Medellín, Colombia matched to individual-level administrative records on employment and home addresses from repeated household level surveys. These novel individual-level administrative data allow us estimate the impacts of several expansions in transportation infrastructure on the level and spatial distribution of income, employment and crime. We combine this with additional data on commuting surveys, house prices, and the location of firms to complete the analysis.

Medellín offers an ideal setting in which to study the spatial diffusion of crime and prosperity in that it was, during our time of study, one of the most violent cities in the world and starkly exhibited the spatial heterogeneity in crime rates and segregation from economic opportunity characteristic of most major urban centers. In this way, Medellín mirrors both major cities from developing regions like Latin America as well as recent histories of many large cities in developed countries like New York, Los Angeles and Chicago. Medellín also experienced several expansions of the metro cable transportation system during our period of study by which previously disconnected poor neighborhoods with varying degrees of baseline criminality became linked to both high crime areas and high income, low crime areas.

We start by documenting reduced form evidence that these expansions decreased the likelihood that inhabitants of poor, high crime neighborhoods near the newly built stations were arrested for crimes, and that lower commute times predict higher formal employment. That is, poor inhabitants of segregated neighborhoods seemed to take advantage of new opportunities, as new cable lines improved access. Yet, these patterns exhibit stark heterogeneity by the baseline spatial distribution of economic opportunity and crime in newly connected neighborhoods. The reductions in crime are strongest in areas that were originally high-crime and segregated from legitimate economic opportunity, while some low baseline crime neighborhoods near the newly built stations even experienced small increases in criminal activity. These heterogeneous and countervailing effects emphasize the importance of modeling and jointly estimating the employment decisions of individuals across both sector and space under the changing travel cost regimes.

Accordingly, we develop a spatial equilibrium model with both legitimate and criminal employment sectors drawing from recent studies ([Ahlfeldt et al., 2015](#); [Tsivanidis, 2018](#)) and structurally estimate the effects of several cable transportation system ex-

pansions on the equilibrium level and spatial distribution of employment, income, and crime. This framework allows us to overcome SUTVA violations, account for correlated neighborhood-level shocks when identifying parameters, and capture the rich heterogeneity in baseline access to different types of opportunities.<sup>2</sup> We build on previous work by incorporating the role of crime, modelling the sectoral choice (the choice between crime and legitimate employment) of individuals. Our innovation includes inter-sectoral spillovers whereby crime may have negative externalities on other forms of economic activity, even as new legitimate economic activity changes the returns to crime (Rossi-Hansberg et al., 2010; Bryan et al., 2019). We identify these externalities by deriving variation from the onset of gang-wars as a result of the extradition of drug lords to the US.

The strength of this generalizable framework is that it allows us to conduct various counterfactual exercises with alternative degrees and directions of expansion of the transportation infrastructure. These counterfactual exercises allow us to answer several important questions. How do improvements in transportation infrastructure affect occupational choice? Does connecting poor neighborhoods to more employment opportunities predominantly import opportunity or export crime? What are the resulting net effects on aggregate crime and GDP as well as inequality across neighborhoods?

We simulate new cable lines that were officially proposed, and were only recently completed. We find that newly connected areas see a sharp reduction in individuals engaging in criminal activity. When low-income, low opportunity areas are connected to work opportunities in other parts of the city, individuals are more likely to switch to legitimate activities. As such, neighborhood segregation is a meaningful driver of aggregate crime in the city. The counterfactual (proposed) lines we construct increase net GDP by between 2.4 and 2.9 billion USD.

We also perform counterfactuals in which we reduce transportation costs to the rest of the city by 10% for each neighborhood in turn. Despite crime being ‘exported’ to certain other low-crime parts of the city, greater connectedness for all but the most connected neighborhoods at baseline yields aggregate reductions in crime, increases in output and welfare, and reductions in inequality. Indeed, the largest gains accrue when connecting neighborhoods with the lowest formal-sector market access at baseline.

Our work speaks to three distinct literatures. First, we build on recent evidence of the distinction between residential segregation and “experienced segregation” or “consumption segregation” in the urban economics literature (Athey et al., 2020; Kling et al., 2007; Chetty and Hendren, 2018a,b) by documenting that reducing “employment seg-

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<sup>2</sup>The Stable Unit Treatment Value Assumption is violated as all neighborhoods are indirectly affected when new transit lines are built.



regation” by linking poor, marginalized neighborhoods to employment opportunities in distant parts of the city can have profound impacts on criminal activity (Melnikov et al., 2019). Our paper is the first to our knowledge to study criminal participation in a quantitative spatial equilibrium framework as relative returns to formal work and crime change across neighborhoods.

Second, we contribute to the recent series of papers developing spatial equilibrium models by adapting these models and methods to the study of criminal activity (Ahlfeldt et al., 2015; Donaldson and Hornbeck, 2016). A few recent studies have used these techniques to study similar expansions in urban transportation infrastructure (Tsivanidis, 2018; Zárate, 2019). We allow for multiple sectors of employment, with spillovers between them: crime affects neighborhood amenities and firm productivity, and legitimate sector activity affects returns to criminality.

Finally, this approach also represents a contribution to the crime economics literature on the link between employment and criminality (Becker, 1968). Recent crime studies have validated the link between legitimate employment opportunities and criminality using variation from trade shocks (Dell et al., 2019; Dix-Carneiro et al., 2018), job loss (Bennett and Ouazad, 2018; Khanna et al., 2020a) and public policies (Khanna et al., 2020b; Fu and Wolpin, 2017) to establish causality. We build on this evidence by showing how crime and prosperity is linked across neighborhoods that differ in access to economic opportunity. Notably, we examine how mass transit systems change this access to opportunities, resulting in a different configuration of both the spatial distribution and overall levels of crime across the city.

## 2 Data

We combine administrative data on households, jobs, crime, commuting times, and house prices from various sources. We link individual records using government-issued individual identification numbers and dates of birth. Since we leverage identification from changes to neighborhood access, we treat the neighborhood as the primary geographic unit in the analysis. There are 269 neighborhoods with an average size of 373 thousand square meters, and 7,756 inhabitants.<sup>3</sup>

The first source of data are from three waves of the *Sistema de Selección de Beneficiarios para Programas Sociales* (SISBEN II and SISBEN III, System for the Identification

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<sup>3</sup>While possible to conduct the analysis at a more disaggregated block level, one may be concerned of making the data too granular (Dingel and Tintelnot, 2020). Since we have a large number of inhabitants per neighborhoods, we use the neighborhood as our unit of observation, and show reduced form relationships at both the neighborhood and block level.

of Potential Beneficiaries of Social Programs) from the [Department of National Planning \(2009\)](#). SISBEN I from 2002, SISBEN II from 2005, and SISBEN III from 2010 allow us to track individuals, their households and residential locations over time. The SISBEN waves are Censuses of approximately the 65-80% of the poorest households in the city, classified into six different socio-economic levels according to the SISBEN score. They include a rich set of demographic information, type of work activity, assets and income, and access to various government programs. Importantly, these data allow us to identify the location of the residence of individuals in Medellín, and track their changes in residences over time.

The second data source, from the *Seccional de Investigación Judicial del Area metropolitana del Valle de Aburrá* ([Judicial Research Unit of the Metropolitan Police of the Aburrá Valley, 2016](#)), is the census of all individuals arrested in Medellín between 2002 and 2015, whether or not they were convicted. These data contain information on the type of crime committed, the date and neighbourhood of arrest, and identifier of the arrested individual. The data also has the specific Act in the penal code that the individual was charged with, allowing one to classify the different types of crime. We classify the crimes into three categories – violent, property, and drug crimes – based on the US Bureau of Justice Statistics’ classifications in the Sourcebook of Criminal Justice Statistics ([BJS, 1994](#)).<sup>4</sup> As the PILA documents the location choices of formal sector workers, we further supplement information from the Census 2005 and the SISBEN to measure overall legitimate activity (formal plus informal). The details are in [Appendix B.2](#).

Third, we use the *Sistema Integral de Protección Social* (SISPRO, System for Social Protection), which contains information from the *Planilla Integrada de Liquidación de Aportes* (PILA, Integrated Register of Contributions) for all formal workers contributing to health and pension schemes ([Ministry of Health, 2019](#)). The PILA has detailed information on payroll, earnings, days worked, firm and worker identifiers, and demographic information of employees. This is our measure of who is engaged in formal sector work, and how much they earn.

To know the location of the workplaces, we obtain data from the *Camara de Comercio de Medellin* (Chamber of Commerce of Medellín), which is the census of all the firms formally registered with the government in Medellín between 2007 and 2018. This database contains identification numbers of statutory representatives, total assets and liabilities reported, and most importantly, the address of establishments.

We augment these data with the Land Registry Data from the Medellín’s Cadastre,

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<sup>4</sup>If an individual was first arrested for violent crime and later for property crime, they show up as an arrest for violent crime.

which reports the use, floorspace and land area, value per square meter of land and floorspace, as well as a number of property characteristics. Finally, we obtain microdata on commuting behavior from regular mobility surveys that measure commute times, mode of transportation, and the location of origin and destinations for each trip, over this period.

We use GIS information on the location of public transport stations and on the road network in Medellin to construct historical commute times for public transport and cars. We do so using the Network Analysis toolkit from ArcGIS, which also allows us to build counterfactual commute times that we use in the model.<sup>5</sup>

## 3 Neighborhoods, Jobs and Crime in Medellín

### 3.1 Segregation and Urban Transit in Medellín

Located in the north-western region of Colombia, Medellín is the second largest city after the capital, Bogotá. It has strong industrial and financial sectors with approximately 2.3 million people or 5.5% of the Colombian population. The urban zone consists of 249 neighborhoods, divided into 21 (*comunas*), 5 of which are semi-rural townships (*corregimientos*).

The city is starkly segregated in terms of where individuals live, work, and where criminal activity is prevalent. Figure 1 describes the spatial distribution of criminal activity and legitimate employment across the city in 2010, along with the transit lines that existed in 2010.

Most criminal activity is concentrated in areas that were historically associated with drug cartels. These include the north-eastern sections of the city, the western edge of the city, and the eastern extremity. There are also pockets of crime near downtown: the center of the city, where the transit lines intersect. Crime is notably low in the affluent south-eastern edge of the city, and for much of the western part of the city.

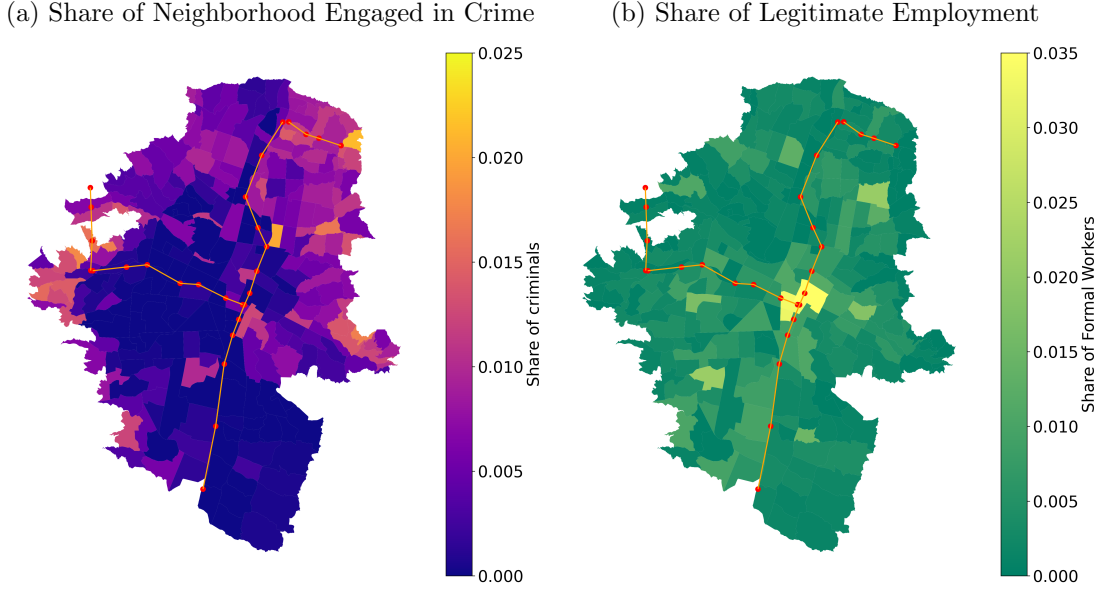
While crime is more prevalent around the edges of the city, economic activity is more starkly present in the center, at the downtown (Figure 1). The commuting infrastructure, as a result, was built to more easily bring people downtown and improve the access to legitimate jobs. There are also pockets of activity in each of the different quadrants of the city, most notably in the south-west.

Before the roll-out of the cable car system in Medellín, most commuting relied on a single North-South metro line running through the heart of the city, at the bottom of the valley. The city displays significant elevation when moving either east or west from this

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<sup>5</sup>We describe the construction of the transport network in Section B.3 in the Appendix.

Figure 1: Segregation in Crime and Legitimate Employment by Neighborhood, 2010



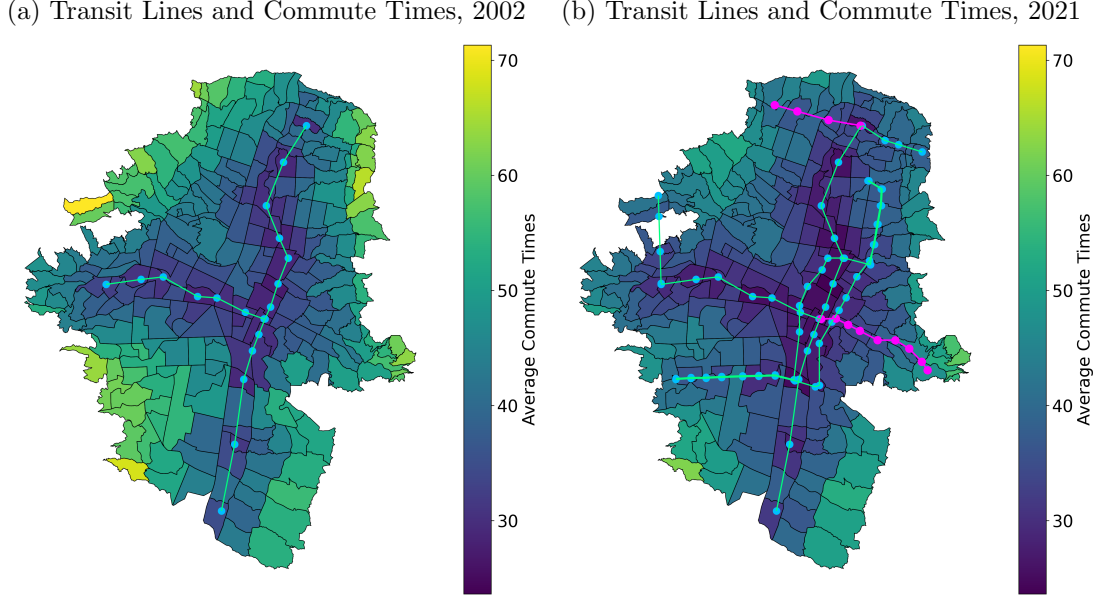
Note: Spatial distribution of where individuals arrested in 2010 reside (left panel), and where individuals in 2010 work (right panel). The dotted lines show the the metro lines in 2010. The data are aggregated to 249 neighborhoods.

central line. In order to expand the transit infrastructure, therefore, simple metro lines were infeasible and costly. As a result, the transit network that emerged relied on cable cars that traversed up the slopes of the hills, and over the residences of the city.

Over our sample period, cable lines were built in 2004 and 2008, an expanded metro in 2012, tramways in 2015, and a large Bus Rapid Transit (BRT) corridor over the 2012-15 period. Figure 2 describes the roll-out of the transit infrastructure over the course of our analysis period. We also include the average commute times to different parts of the city, where lighter shades are longer commute times.

Figure 2 shows how over the period, as new transit lines were added to the city, the average commute times to various neighborhoods fell substantially, improving access to other parts of the city. For instance, consider the cable line that was built in the north-eastern edge of the city in 2004. These neighborhoods, traditionally had high crime, and displayed relatively high commute times to other parts of the city, perhaps limiting the access to opportunity. After 2004, when the cable line was built, there was a sharp drop in commute times in the newly connected neighborhoods.

Figure 2: Roll out of Transit Lines and Change in Commute Times, 2002-2021



Note: Average commute times originating from neighborhoods in 2002 (left panel) and 2021 (right panel). Between the two years metro cable and tram lines were built reducing average commute times in neighborhoods. Lighter shades represent longer commutes. The data are aggregated to 249 neighborhoods. The pink lines in the north-west and eastern represent lines we perform counterfactual exercises on.

### 3.2 Crime in Medellín

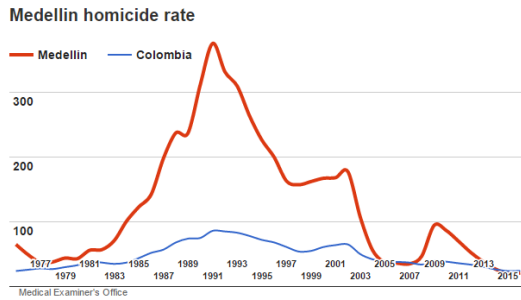
Violence in Colombia has traditionally been high. The emergence of drug cartels in the late 1970s and early 1980s, fueled the emergence of organized crime to support illegal businesses, and guerrilla or paramilitary groups to care for the entire production chain. From the mid 1980s to early 1990s, homicide rates rose rapidly driven by cartels, paramilitaries, and local gangs. Medellín used to be one of the most violent cities in the world (see Figure 3 from CCSPJP (2009)), placing our analysis among a handful that study motivations behind participating in crime in high-crime environments. The high homicide rates are a result of fights among urban militias, local gangs, drug cartels, criminal bands, and paramilitaries based in surrounding areas.<sup>6</sup> Many demobilized militias continue to be involved in crimes like extortion and trafficking, given their experience with using guns and avoiding police (Rozema, 2018).

Homicide rates in the city peaked in the early 1990s during the war with the Medellín Cartel, and over our sample period (2002-2018) rates have fallen substantially since to about 21 per 100,000 inhabitants (Figure 3). Between 2005-13, 12% of all males (across

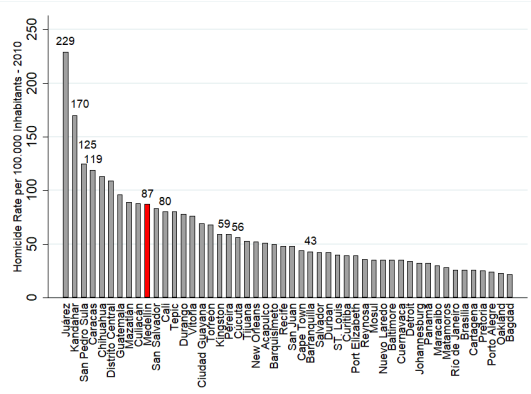
<sup>6</sup>*Operacion Orion*, followed by the demobilization of paramilitary forces led to a sharp decline in homicides, as the military clamped down on urban militias (Medina and Tamayo, 2011).

Figure 3: Homicide Rates in Medellín Over Time, and Relative to Other Cities

(a) Homicide Rates in Medellín, 1997-2015



(b) Highest Homicide-rate Cities, 2010



Note: Homicides rates in Medellín over time (left panel), shows the number of recorded homicides per 100,000 individuals in Medellín (red line) and the average for Colombia (blue line). Data from the *Consejo Ciudadano para la Seguridad Public y la Justicia Penal*. The right panel shows the average homicide rates in 2010 in cities across the world, where Medellín is represented in red.

all age groups) were at some point arrested, while the arrest rate for females was only 1%. Younger individuals are more likely to be engaged in drug trafficking and consumption, whereas slightly older individuals are involved in violent crimes (homicides, extortion, and kidnapping), and the oldest still are involved in property crime.

In ongoing research, Blattman et al. (2018) document Medellín’s criminal world as hundreds of well-defined street gangs (*combos*) which control local territories and are organized into hierarchical relationships of supply, and protection by the *razones* at the top of the hierarchy. They confirm that gangs are mainly profit-seeking organizations, earning money from protection, coercive services such as debt collection and drug sales. Anthropological studies and in person interviews show that economic incentives (such as the focus of our study) drive young men in Medellín to join organized crime (Baird, 2011). As many respondents highlight, the reason to join crime is mostly “economic” or for a profitable career.<sup>7</sup> Knowing this, paramilitaries and gangs actively recruit idle youth that are *amurrao* (local slang, literally: ‘sitting on the wall’) and without a formal sector job.

An interview with El Mono (p191) documents the recruitment process: “*those guys would hang out around here and be nice to me and say ‘come over here, have a bit of money’.*” Having a formal sector job means that one is not “hanging around the neighborhood” when the gangs come recruiting. A desirable outside option would be a job with benefits and social security, yet those with formal sector jobs pay extortion fees to gangs.<sup>8</sup>

<sup>7</sup>See interview with Gato, p264 and interview with Armando, p197.

<sup>8</sup>See interview with El Peludo, p184.

Indeed, the options are often presented as an occupational choice: “*are you gonna work [for the gang] or do a normal job?*”<sup>9</sup>

Often, however, remunerations for gang-members are higher than jobs for those with similar levels of education (Doyle, 2016). New recruits are employed to run guns (*carritos*), before transitioning to extortion and trafficking. Blattman et al. (2018) estimate that foot soldiers of the combos receive well above national minimum wage whereas *combo* leaders earnings “put them in the top 10% of income earners in the city.”<sup>10</sup>

These numbers are high relative to most contexts, but are representative of cities in Latin America. The US has an incarceration rate more than six times the typical OECD nation, where one in ten youths from a low-income family may join a gang, 60% of crimes are committed by offenders under the age of 30, and 72% by males (Kearney et al., 2014). Accordingly, in some regards, arrests in our context are similar to high-crime regions in many parts of the developing world, and especially Latin America (Dell et al., 2018).

## 4 Descriptive and Reduced-form Relationships

### 4.1 Commute Times for Different Activities

We first describe certain features of our setting in relation to commute times and how changes in commute times affect the spatial distribution of crime and legitimate employment. To begin, consider Figure 4 that plots the commute times in our individual-level data for different types of criminal activity and for formal work. We believe we may be among the first to measure commute times for criminal activity. It shows that formal workers travel farthest to access their jobs. In contrast, most crime is committed near where the perpetrator of the crime resides. This is consistent with the fact that most crime in Medellín is localized, and often tied to local street gangs (*combos*), that oversee most criminal activity. This is true of not only low level crimes like petty theft, but also drug trafficking and violent crime.

The differences in commute times have meaningful implications for what would happen when new transit lines are built. On the one hand, the raw densities may suggest that criminal activity is more sensitive to commute times than formal work. If so, changes to commute times may have a sharper effect on the spatial distribution of criminal activity than that on formal employment. On the other hand, the densities may indicate the

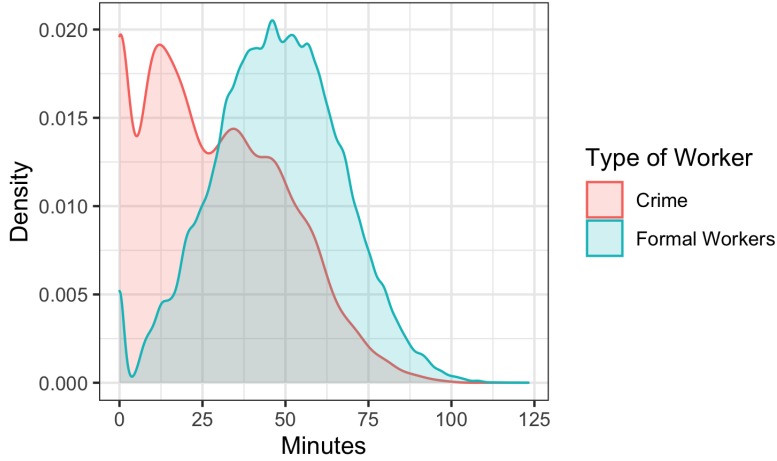
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<sup>9</sup>See *interview with Notes*, p193

<sup>10</sup>During the demobilization of militias in the mid-2000s, many were encouraged to join the formal sector, given identity cards and medical cards (Rozema, 2018). Yet, this disparity in costs across social benefit regimes, discourages formal sector re-integration.



Figure 4: Kernel Density of Commute Time by Activity, 2010



Note: Commute times by activity in 2010. We measure the origin (residence) of individuals, and the destination of their activity (formal work, and different types of crime). We use the road maps, transit networks, and travel times by different modes of transport to estimate commute times for each origin-destination pair in our data. We restrict our data to one individual per observation, where we choose the first arrest in 2010 for the type of crime.

formal work is strongly segregated and confined to certain pockets of the city. As such, reaching those pockets require a fair amount of commute time. New transit lines that reduce these commute times increase access to these pockets of formal opportunities, and may induce individuals on the margin away from criminal activities which dominate the opportunity set when search is restricted to areas close to home. This latter implication of segregation is consistent with the maps shown in Figure 1.

## 4.2 Difference-in-Differences: Effects of Cables Lines on Crime

Let us consider the effects of an expansion in the transportation infrastructure on criminal activity. Building a new cable line may either raise or reduce the amount of crime in newly connected neighborhoods. For instance, building a new cable may increase criminal activity, by lowering the costs of transit for criminals to newly connected destinations. It may also increase access to legitimate employment opportunities, which in turn, may reduce the relative benefit to criminal activities.

Consider crimes committed in neighborhood  $d$  (we use  $d$  for destination of where the criminal activity occurred). A simple difference-in-differences (DiD) design would suggest the following specification:

$$\text{Log}(\text{Crimes})_{dt} = \gamma_t + \gamma_d + \beta_1 (\text{Log}[\text{Dist to New Stations}]_d \times \text{Post}_t) + \epsilon_{1dt} \quad (1)$$

Here,  $\gamma_t$  are time fixed effects that control for changes in aggregate crime and transportation across neighborhoods, and  $\gamma_d$  are neighborhood fixed effects that account for time-invariant neighborhood level differences. Let  $\text{Log}(\text{Distance to New Stations})_d$  is the distance between the neighborhood and the closest new cable station.  $\text{Post}_t$  is an indicator for the period after when the new cable was built. As such,  $\beta_1$  is the DiD estimator for the effect of being further away from a newly built cable station on crime.

Yet, this  $\beta_1$  only tells us the effects of new lines on crime destinations. Cable lines also connect neighborhoods where potential criminals or workers may come from. An analogous question arises, as to what happens at the origin  $o$  when new cables are constructed? Are individuals more likely to take advantage of the cable to go and engage in criminal activity elsewhere in the city, or more likely to use it to access jobs in other areas? A similar specification describes what happens at the origin:

$$\text{Log}(\text{Crimes})_{ot} = \gamma_t + \gamma_o + \beta_1' (\text{Log}[\text{Dist to New Stations}]_o \times \text{Post}_t) + \epsilon_{1'ot} \quad (2)$$

Table 1: The Effects of New Cable Lines on Crime

	Effects on Destinations		Effects on Origins	
	Any Crime	Violent Crime	Any Crime	Violent Crime
Log(Distance to Station)xPost	0.0970** (0.0438)	0.180*** (0.0523)	0.0693*** (0.0232)	0.154*** (0.0316)
Observations	3,486	3,416	3,192	2,996
Data Structure	Destination-by-Time		Origin-by-Time	
Destination Fixed Effects	Yes	Yes	No	No
Origin Fixed Effects	No	No	Yes	Yes
Origin-Destination Distance	No	No	No	No
Time Fixed Effects	Yes	Yes	Yes	Yes
SE Cluster	Dest	Dest	Origin	Origin

Notes: The first two columns show difference-in-differences estimates for being close to a station, and crime destinations. The last two columns show the effects on origins (residences) of crime perpetrators. The data in the first two columns are shaped to be at the time by destination-of-crime level. The data in the last two columns are at the time by origin-of-crime level. Both sets of regressions suggest that crime falls in areas closer to newly built stations.

Table 1 describes these regressions for one of the new cable lines: Linea K. In the first two columns we examine the changes to criminal activity at destinations, and in the last two columns, by the neighborhood of origin of the criminal. Given that some neighborhoods may have no crime at all, we estimate the equations using a Poisson Pseudo Maximum Likelihood (PPML) estimator, and cluster our errors at the neighborhood level.

The first two columns of Table 1 suggest that when a neighborhood is connected to a Linea K station criminal activity at that neighborhood actually falls. Being further away from the station is associated with higher levels of crime in the years subsequent to the opening of the transit line. This is true for all types of crime, including the subset of violent criminal activity.

The last two columns of Table 1 present an interesting complementary result: when residences are connected to the cable, people from those neighborhoods are less likely to be arrested for criminal activity. As such, while the first two columns inform what happens to criminal destinations when connected to transit, the last two describe what happens to the criminal activity of those originating from such locations. Both suggest that locations closer to new stations see a fall in crime.

Yet, such an analysis ignores the richer dimensionality of the data. Indeed, if origins and destinations are close-by then it may be no surprise that origins and destinations display similar patterns. As such, by reformulating the data to be at the origin-by-destination-by-time level, we can control for time invariant features of the origin-destination pair, such as the distance between them  $\Xi_{od}$ , along with time invariant features of destinations  $\gamma_d$  and origins  $\gamma_o$ .

$$\text{Log}(\text{Crimes})_{odt} = \gamma_t + \gamma_o + \gamma_d + \Xi_{od} + \beta_2 \left( \text{Log}[\text{Dist to New Stations}]_{o/d} \times \text{Post}_t \right) + \epsilon_{2odt} \quad (3)$$

Here,  $\beta_2$  is again the DiD coefficient, and we can examine it as a consequences of changes to the distance to the nearest station at either the origin or the destination of criminal activity. In such specifications, to be conservative, we two-way cluster our standard errors at both the origin and destination level.

Table 2 reinforces the results in Table 1 by once again showing that the closer one is to the new station, the greater is the decrease in criminal activity once the new line is introduced. This is true for the destinations of criminal activity (first two columns of Table 2), and the originating residences of these criminals (last two columns of Table 2).

Given the different possible countervailing effects, it may be that what determines the net effects of an expansion in the transportation infrastructure is how long it takes to reach the closest of the stations so as to access the broader transit network. In Appendix C, we explore if changes in the number of minutes to a station affects criminal activity. Table C.1 shows similar results to ones presented in Tables 2 and 1.

While this reduced form analysis is informative of what happens on net in places near new transit centers for the particular instances we study, the net outcomes clearly depending on complex underlying relationships. That is, in order to generalize these

Table 2: The Effects of New Cable Lines on Crime

	Destination Stations		Origin Stations	
	Any Crime	Violent Crime	Any Crime	Violent Crime
Log(Distance to Station)xPost	0.115** (0.0470)	0.218*** (0.0573)	0.0724** (0.0302)	0.163*** (0.0374)
Observations	794,808	727,608	794,808	727,608
Data Structure	Origin-by-Destination-by-Time			
Destination Fixed Effects	Yes	Yes	Yes	Yes
Origin Fixed Effects	Yes	Yes	Yes	Yes
Origin-Destination Distance	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
SE Cluster	Two Way: Destination and Origin			

Notes: The first two columns show difference-in-differences estimates for being close to a station, and crime destinations. The last two columns show the effects on origins (residences) of crime perpetrators. The data are at the origin-by-destination-by-year level.

results to broader policies or interventions which may change commute times to differing degrees and/or for a different set of neighborhoods, we must investigate the confluence of market forces which determine the responses for specific individuals and neighborhoods.

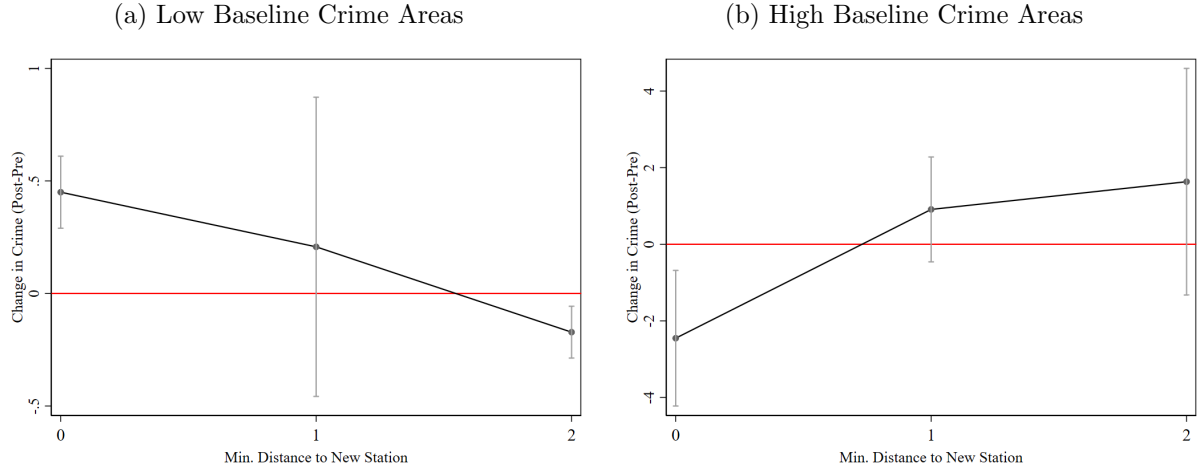
### 4.3 Heterogeneity by Neighborhood Economic Structure

Tables 1 and 2 suggest that when new stations are built, crime outcomes decrease in connected neighborhoods, and less criminals originate from such neighborhoods. This may perhaps reflect that being connected now allows youth to have access to legitimate employment opportunities in other parts of the city, thereby lowering the attractiveness of being involved in crime. This may be likely, if for instance, criminal activity is more localized than formal sector employment.

If most crime centers around local street gangs, then not being able to easily to go other parts of the city may mean that, in neighborhoods that have street gangs, youth will be drawn into crime. If so, to engage in crime individuals in such neighborhoods stay in their neighborhoods, but to participate in the legitimate sector they must travel far by paying a high travel cost. Once these street gang neighborhoods are connected to the cable line, crime may fall, as youth from these neighborhoods can easily access legitimate activity in other parts of the city.

Yet, such a narrative would imply that if the economic structure of the neighborhood were different, then being connected may have had an opposite effect. Suppose, for

Figure 5: Changes in Crime at the Origin by Baseline Crime, and Distance (in km) Bins



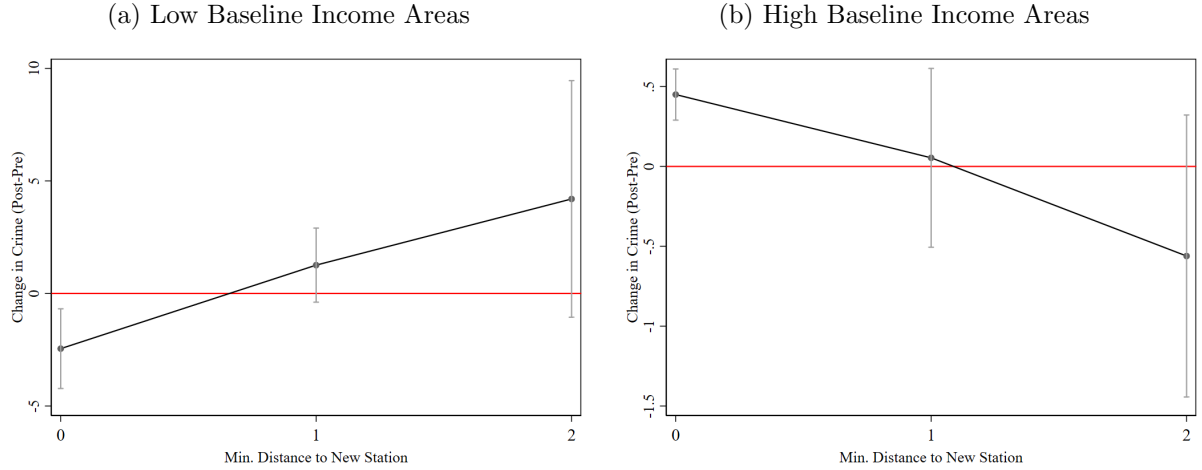
Notes: Figures plot the change in crime over time as a function of the distance to the nearest station. The vertical axes plot the arrest rate in the post-cable period minus the arrest rate (arrests per year) in the pre-period. The horizontal axes show distance bins. The left panel restricts the sample to neighborhoods that have below median baseline crime rates, whereas the right panel is for above median baseline crime rates.

instance, a neighborhood with no street gangs were suddenly added to the transit network, opening up access to other parts of the city, including other gang neighborhoods. Then, we may have an increase in legitimate activity as more individuals come and access these formal sector jobs. But we may also have youth from these newly connected neighborhoods joining criminal enterprises in other neighborhoods that they now have easy access to. Theoretically, this suggests that what we saw in Tables 1 and 2 may depend on the underlying economic structure of the neighborhoods.

To examine this, we consider different aspects of heterogeneity that directly relate to our analysis: i.e., the role played by access to different types of opportunities. We combine all new stations and consider the change (post minus pre) in crime rates and distance traveled to formal jobs after new cable lines were built. To document the changes, we must aim to compare regions near the newly built stations to those farther away. Yet, we should not think of regions further away as ‘control neighborhoods,’ as all neighborhoods will be indirectly affected. To be transparent, we show the effects along various distance bins so as to non-parametrically describe these relationships.

In Figure 5 we see that there were sharp reductions in criminal activity originating from neighborhoods near the stations (between 0 and 1km). Yet, this reduction is confined to neighborhoods that have high baseline levels of crime (right-panel). If anything,

Figure 6: Changes in Crime at the Origin by Baseline Income, and Distance (in km) Bins



Notes: Figures plot the change in crime over time as a function of the distance to the nearest station. The vertical axes plot the arrest rate in the post-cable period minus the arrest rate (arrests per year) in the pre-period. The horizontal axes show distance bins. The left panel restricts the sample to neighborhoods that have below median baseline income, whereas the right panel is for above median baseline income.

the left panel suggests a mild increase in crime in areas that had low levels of baseline criminal activity. The heterogeneity in criminal responses is indicative of how the spatial distribution of economic opportunities is important in determining the local change in crime as a result of changes in access to different neighborhoods. Together, these results show meaningful heterogeneity in the response to criminal activity by baseline access to criminal and economic opportunity. This is an example of the nuance we will include in our structural framework below.

To document the dynamics of the responses, by different types of crime and different types of baseline features of the neighborhoods, we conduct an event study style analysis. We pool the different cable lines, and compare crime outcomes both before and after the cable was opened, relative to the year it was opened. The years before allow us to test for pre-trends in our outcomes, whereas the years after document the dynamics of the changing relationship. Figures C.1 and C.2 show no detectable effects for low baseline crime and income neighborhoods and sharp drops in non-drug crime related activity for high baseline crime and income. Similarly, Figure C.3 shows that the effects on non-drug crimes are a lot larger than the effects on just violent crime, when we restrict the sample to only low income neighborhoods.

## 4.4 Panel Gravity Equations and Neighborhood-by-Time Shocks

Our description so far tells us the effects of being near a newly built rail line. Yet, it does not speak to the consequences on changes in the travel time between neighborhoods. Indeed, that is what we will show below in our model to be the important determinant of changes to the spatial structure of criminal and legitimate activity, and the overall changes to crime levels in the city.

Consider what we have shown so far: being near a station reduces crime. Yet, as this is a difference-in-differences analysis, all it tells us is that it reduces crime *relative* to other neighborhoods. As neighborhoods are connected, these results may indeed be driven by increases in criminal activity to neighborhoods farther away from stations. For instance, if living near a station means a criminal can travel farther away to newer neighborhoods, then crime may increase in such neighborhoods farther away, even as it reduces in neighborhoods near the newly connected station.

The inherent nature of such general equilibrium consequences necessitates a spatial general equilibrium model to make meaningful statements about what happens to crime and legitimate activity in an absolute and aggregate sense. Yet, to identify important parameters of the model, we need to leverage the roll out of the cable in a manner that is no longer confounded by other differences across neighborhoods and time.

Accordingly, we now move towards the standard panel gravity equation setup, where we wish to know how changing the travel time between an origin  $o$  and destination  $d$  affects the flow of criminals from the origin to destination neighborhoods. If the transit elasticity for criminals  $\theta_c$  is higher than for legitimate employment, then crime is more sensitive to travel time, and there may be a greater dispersion in criminal activity as a result of changes to travel time.

In order to execute this analysis, we use the information on travel times between any origin and destination neighborhood pair, and how that changes as and when new cable lines are introduced. This variable *Travel Time Minutes<sub>odt</sub>* varies at the origin-by-destination-by-time level, allowing us to further account for other confounding variables, and strengthen identification.

While the specifications so far control for a large dimension of fixed effects that account for differences across neighborhood-pairs or time, one may be concerned that there are concurrent changes at the neighborhood-by-time level that confound our estimates. For instance, gang wars that happen to coincidentally break out in neighborhoods close to newly built stations (for reasons unrelated to the station's presence) would bias our estimates. Similarly, changes in policing structure at the neighborhoods over time, in a



way that somehow happens correlates with distance to the station would be a potential confounder.

Fortunately, the richness of our data allow us to control for all such effects, by including origin-by-time fixed effects  $\gamma_{ot}$  and destination by time fixed effects  $\gamma_{dt}$ :

$$\text{Log}(\text{Crimes})_{odt} = \gamma_{ot} + \gamma_{dt} + \Xi_{od} + \beta_4 \text{Travel Time Minutes}_{odt} + \epsilon_{4odt} \quad (4)$$

We return to this equation 4 later in our analysis as it helps causally identify the crucial parameters of our model. Here,  $\gamma_{ot}$  and  $\gamma_{dt}$  account for neighborhood-by-time level shocks, such as new gang wars, or changes policing that change over time by neighborhood.  $\Xi_{od}$  controls for time-invariant differences across neighborhood-pairs. As such, the only remaining threat to identification would be if there were time-varying shocks to origin-destination pairs that were unaccounted for by the neighborhood-by-time fixed effects. We show later that  $\beta_4$  is meaningfully informative of crucial economic elasticities that drive the spatial distribution of crime and legitimate activity across the city.

Table 3: The Effects of Travel Time From Origins to Destinations

Travel Time From Origin To Destination	Any Crime	Violent Crime	Formal Work
Minutes From Origin to Destination	-0.0869*** (0.00364)	-0.0848*** (0.00406)	-0.0494*** (0.00967)
Observations	183,060	93,842	173,894
Data Structure	Origin-Dest-Time		
Destination-by-Time FEs	Yes	Yes	Yes
Origin-by-Time FEs	Yes	Yes	Yes
Distance Between Origin and Destination	Yes	Yes	Yes
SE Cluster	Two Way: Destination and Origin		

Notes: Tables show the effect of changes in travel time between origin-destination pairs on the resulting flows in crime and formal workers between these neighborhoods. We estimate this standard gravity equation using pseudo maximum likelihood (PPML) with high dimensional fixed effects, and two-way cluster our errors at the origin and destination level.

In Table 3, we estimate equation 4. Reductions in the travel time between origins  $o$  and destinations  $d$  will raise the amount of criminal activity that flows from origin  $o$  to destination  $d$ . The corresponding elasticities with respect to travel time are  $-0.0869$  for all crimes, and a similar  $-0.0848$  for violent crimes.

Yet, as we show below in the model, what is equally relevant is the change in flows

of legitimate employment as a result of these new cables. If legitimate employment is less responsive to travel costs, then new lines are less likely to greatly affect the flow of formal sector jobs. In the last column of Table 3, we replace the outcome to be formal-sector work, and find that the travel-time elasticity of formal sector flows is lower than that of crime, at about  $-0.0494$ . We return to Table 3 again below and discuss how  $\beta_4$  informs our model's parameters.

## 5 Model

Our economic geography framework is based on recent developments in models of spatial mobility (Ahlfeldt et al., 2015; Tsivanidis, 2018; Donaldson and Hornbeck, 2016; Zárate, 2019). We adapt these models to incorporate the role played by criminal activity. We model the sectoral choice (the choice between crime and legitimate employment) of individuals as a function of firm market access and commuter market access. Importantly, we include inter-sectoral spillovers whereby crime may have negative externalities on other forms of economic activity, even as new economic activity changes the returns to crime (Rossi-Hansberg et al., 2010; Bryan et al., 2019).

Consider a city embedded within a wider economy. The city consists of a set of discrete neighborhoods that are indexed by  $o$  and  $d$ , where  $o, d \in \mathcal{N} \equiv \{1, \dots, N\}$ . These neighborhoods are populated by an endogenous measure of  $\bar{H}$  workers who are perfectly mobile within the city and the larger economy. Workers are risk neutral and have preferences for housing ( $H$ ) and consumption of a final good ( $C$ ). They can participate in two sectors indexed by  $s \in \{c, \ell\}$ , where  $c$  and  $\ell$  stand for crime and legitimate sectors, respectively. A worker  $\omega$  choosing neighborhoods  $o$  and  $d$  as living and working destinations, respectively, and choosing to work in sector  $s$  maximizes the following utility

$$U_{ods\omega} = \frac{\epsilon_{ods\omega}}{\tau_{od}} \left( \frac{C_{ods}}{\beta} \right)^\beta \left( \frac{H_{ods}}{1 - \beta} \right)^{1-\beta}, \quad (5)$$

where  $C_{ods}$  is consumption of the final good and it is taken as a numeraire,  $H_{ods}$  represents housing consumption,  $\tau_{od} \geq 0$  is an iceberg commuting cost incurred by the consumer when moving from origin  $o$  to destination  $d$ ,  $\epsilon_{ods\omega}$  is an idiosyncratic shock, and  $\beta \in (0, 1)$  is the expenditure share on the consumption of the final good.<sup>11</sup> The shock  $\epsilon_{ods\omega}$  represents idiosyncratic preferences that motivate individuals to choose different destinations,  $o$  and  $d$ , and different working sector  $s$ , even when their observable characteristics are the same.

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<sup>11</sup>Iceberg commuting costs affect utility directly, but this specification is isomorphic to one in which commuting costs reduce effective wages earned by individuals due to the time used for commuting.

We assume that the term  $\epsilon_{ods}$  is drawn from a nested Frechet distribution:

$$H(\vec{\epsilon}) = \exp \left[ - \sum_o B_o \left( \sum_s B_{os} \left( \sum_d \epsilon_{ods\omega}^{-\theta_s} \right)^{\frac{\kappa}{\theta_s}} \right)^{\frac{\eta}{\kappa}} \right], \quad \eta < \kappa < \theta_s, \quad s \in \{c, \ell\}, \quad (6)$$

where the parameters  $\eta$ ,  $\kappa$  and  $\theta_s$  control the dispersion of the idiosyncratic shock across residences, sectors and workplaces, respectively. The parameters  $B_o$  and  $B_{os}$  can be thought of as origin and origin-sector specific amenities that attract individuals to different origins/origin-sectors. Given the observed shocks, individuals decide where to reside, where to work, and which sector to work in.

Using the properties of the Frechet distribution, the probability of living in  $o$ , working in sector  $s$ , and commuting to destination  $d$  is:

$$\pi_{ods} = \underbrace{\left( \frac{B_o Q_o^{-(1-\beta)\eta} W_o^\eta}{\sum_{o'} B_{o'} Q_{o'}^{-(1-\beta)\eta} W_{o'}^\eta} \right)}_{\equiv \pi_o} \underbrace{\left( \frac{B_{os} W_{os|o}^\kappa}{\sum_{s'} B_{os'} W_{os'|o}^\kappa} \right)}_{\equiv \pi_{os|o}} \underbrace{\left( \frac{w_{ds}^{\theta_s} \tau_{od}^{-\theta_s}}{\sum_{d'} w_{d's}^{\theta_s} \tau_{od'}^{-\theta_s}} \right)}_{\equiv \pi_{ods|os}}, \quad (7)$$

where  $Q_o$  is the residential floorspace price in neighborhood  $o$ ,  $W_o^\kappa = \sum_{s'} W_{os'|o}^\kappa$  is an origin-specific wage index,  $W_{os|o}^{\theta_s} = \sum_{d'} w_{d's}^{\theta_s} \tau_{od'}^{-\theta_s}$  is an origin-sector specific wage index, and  $w_{ds}$  is the worker's wage for working in sector  $s$  in destination  $d$ .<sup>12</sup>

The choice probabilities imply that, conditional on having chosen an origin and a sector, individuals are more likely to work in a destination that has a large commute-discounted return  $w_{ds}^{\theta_s} \tau_{od}^{-\theta_s}$  relative to the other destinations. On the other hand, conditional on their origin  $o$ , individuals are more likely to choose a sector if their neighborhood of origin has large sector-specific amenity  $B_{os}$ , and if they live close to profitable destinations in that sector,  $W_{os|o}$ , relative to the other sector. Finally, individuals are more likely to choose an origin neighborhood  $o$  if it has large amenities  $B_o$ , low residential floorspace prices  $Q_o$ , and that is close to destinations that are generally profitable  $W_o$ , relative to all other origins.

Workers are assumed to be mobile between the city and the larger economy, which delivers a constant utility  $\bar{U}$ . Defining  $V_{ods}$  as the indirect utility function of living in  $o$  working in  $d$  and participating in sector  $s$ , spatial equilibrium requires expected utility

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<sup>12</sup>The nested Frechet assumption allows us to decompose the overall probability of choosing an origin-sector-destination into three different components:  $\pi_{ods|os}$ , the probability of choosing a destination conditional on having chosen an origin and a sector;  $\pi_{os|o}$ , the probability of choosing a sector conditional on your origin; and  $\pi_o$ , the probability of choosing an origin  $o$ . Note that  $\sum_d \pi_{ods|os} = \sum_s \pi_{os|o} = \sum_o \pi_o = 1$ .

equalization:

$$\bar{U} = \mathbb{E} \left[ \max_{ods} \{V_{ods}\} \right] = \Gamma \left( \frac{\eta - 1}{\eta} \right) \left( \sum_o B_o [Q_o^{-(1-\alpha)} W_o]^\eta \right)^{1/\eta} \quad (8)$$

where  $\Gamma(\cdot)$  is the gamma function.

## 5.1 Production

We assume that there is a single final good, the numeraire, that is costlessly traded within the city and the larger economy. Final good production occurs under conditions of perfect competition and constant returns to scale. We assume that the production technology takes the Cobb-Douglas form. Output of the final good in block  $d$ ,  $y_d$  is:

$$y_d = A_{d\ell} (H_{Ed\ell})^\alpha (L_{d\ell})^{1-\alpha} ,$$

where  $A_{d\ell}$  is final goods productivity,  $H_{Ed\ell}$  is workplace legitimate employment,  $L_{d\ell}$  is commercial floorspace in destination  $d$ , and  $\alpha \in (0, 1)$  is the legitimate employment share. Commercial floorspace can be rented at a price  $q_d$ .

Firms choose their block of production and their inputs of workers and commercial floorspace to maximize profits, taking as given final goods productivity  $A_{d\ell}$ , the distribution of idiosyncratic utility, goods and factor prices  $w_{d\ell}, q_d$ , and the location decisions of other firms and workers. Combining the FOCs of the firm with respect to legitimate employment and commercial floorspace for a firm in block  $d$  delivers:

$$q_d = (1 - \alpha) \left( \frac{\alpha}{w_{d\ell}} \right)^{\alpha/(1-\alpha)} A_{d\ell}^{1/(1-\alpha)}. \quad (9)$$

### 5.1.1 Land Market

We assume that there is a competitive floorspace market at each destination. Specifically, a competitive floor-space provider allocates its total floorspace,  $L_d$ , by choosing a fraction  $\varrho_d \in [0, 1]$  for commercial floorspace and  $(1 - \varrho_d)$  for residential floorspace to maximize total profits. This firm takes as given commercial and residential prices,  $q_d$  and  $Q_d$ , respectively, as well as a tax equivalent land use regulation  $\xi_d \geq 1$  that increases the overall price of residential housing to  $Q_d \xi_d$ . The firm's problem is:

$$\max_{\varrho_d \in [0, 1]} \varrho_d L_d q_d + (1 - \varrho_d) L_d \xi_d Q_d$$

This yields the following no arbitrage condition:

$$\begin{aligned} \varrho_d &= 1 & \text{if } q_d > \xi_d Q_d \\ \varrho_d &\in [0, 1] & \text{if } q_d = \xi_d Q_d \\ \varrho_d &= 0 & \text{if } q_d < \xi_d Q_d \end{aligned} \quad (10)$$

Floor space  $L_d$  is supplied by a competitive construction sector that uses land,  $K_d$ , and capital,  $M_d$ , as inputs. Given the price of the best use of floorspace  $Q_d \equiv \max\{q_d, \xi_d Q_d\}$ , as well as the price of land,  $\mathbb{R}_d$ , and the price of capital,  $\mathbb{P}$ , the firm solves:<sup>13</sup>

$$\max_{M_d, K_d} Q_d M_d^\mu K_d^{1-\mu} - \mathbb{P} M_d - \mathbb{R}_d K_d.$$

Residential land market clearing implies that the demand for residential floor space equals the supply of floor space allocated to residential use in each location  $(1 - \varrho_d) L_d$ . Using utility maximization for each worker and taking expectations over the distribution for idiosyncratic utility, residential floor market clearing is:

$$\mathbb{E}[\ell_{ods}|o] H_{Ro} = (1 - \varrho_o) L_o, \quad (11)$$

where  $H_{Ro}$  is the total number of residents that live in  $o$ , and  $\mathbb{E}[\ell_{ods}|o]$  is their expected demand for housing.

Commercial land market clearing requires that demand for commercial floor space, which is obtained from the firm maximization problem, equals the supply of floor space allocated to commercial use in each location  $\varrho_d L_d$ . The commercial land market clearing condition is:

$$\left( \frac{(1 - \alpha) A_{d\ell}}{q_d} \right)^{1/\alpha} H_{Ed\ell} = \varrho_d L_d. \quad (12)$$

## 5.2 Crime Sector and its Effect on Productivity & Amenities

We assume that returns to crime are endogenous and given by:

$$w_{dc} = (1 - p_d) A_{dc} H_{Edc}^\rho H_{Ed\ell}^\nu, \quad (13)$$

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<sup>13</sup>We assume that there is a perfectly elastic supply of capital such that there is an exogenous price of capital  $\mathbb{P}$  that does not vary by neighborhood.

where  $H_{Edc}$  and  $H_{Ed\ell}$  are the total number of criminals and legitimate workers working in  $d$ , respectively,  $\rho \in [-1, 0]$  regulates congestion forces in crime at a destination by which it is harder to commit crimes when there are already a lot of criminals in a location, and  $\iota \in [0, 1]$  captures the fact that crime might be more profitable in locations in which there are a lot of legitimate employees.<sup>14</sup> The term  $p_d$  is a destination-specific exogenous probability of getting caught, and  $A_{dc}$  is the exogenous productivity of criminals in destination  $d$ . We use an empirical estimate of the probability of getting caught at a destination  $p_d$  by using the average homicide capture rates at each destination across our sample. We use homicide capture rate since we can obtain the true measure of all homicides that occurred in each neighborhood, which we can then match to our capture data to obtain the total number of captured criminals related to those homicides.<sup>15</sup>

Motivated by the urban literature on crime (Bryan et al., 2019), we assume that the criminal sector has a negative effect on the productivity of firms at a destination. Specifically, overall productivity,  $A_{d\ell}$ , at destination  $d$  is given by:

$$A_{d\ell} = a_{d\ell} \Upsilon_{dc}^\lambda ,$$

where  $a_{d\ell} > 0$  is the fundamental and exogenous component of productivity, and  $\Upsilon_{dc}$  is an endogenous component of productivity that captures negative spillovers of crime to productivity in the legitimate sector in destination  $d$ .  $\lambda \leq 0$  is a parameter that captures how important these negative spillovers are for the legitimate sector. We model these negative externalities spatially as:

$$\Upsilon_{dc} \equiv \frac{H_{Edc}}{K_d} , \quad (14)$$

where  $H_{Edc}$  is the total number of criminals in destination  $d$  and  $K_d$  is total land area in destination  $d$ .<sup>16</sup>

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<sup>14</sup>This specification nests a simpler model in which returns to crime are exogenous when  $\rho = \iota = 0$ .

<sup>15</sup>As shown in Figure A.1 the average arrest rate is low. In this sense, using this empirical estimate of the probability of capture allows us to convert observed captured criminals into total number of criminals working in each destination.

<sup>16</sup>We originally modeled these externalities with an iceberg spillover term to capture the fact that crime in one neighborhood could affect productivity in an adjacent neighborhood:

$$\Upsilon_{dc} \equiv \sum_{k=1}^D e^{-\nu \tau_{dk}} \frac{H_{Ekc}}{K_k}$$

where  $\nu$  is a parameter that captures how relevant crime at different distances is for productivity, and  $\tau_{dk}$  are the iceberg commuting costs between blocks  $d$  and  $k$ . We estimated strong rates of decay, and so simplified the model.

In addition to allowing for crime to impact productivity in a neighborhood, we also allow the relative sector-specific residential amenities  $\frac{B_{of}}{B_{oc}}$  to vary with criminal sector activity in a given neighborhood:

$$\frac{B_{of}}{B_{oc}} = b_{of} \Upsilon_{oc}^\omega. \quad (15)$$

where  $b_{of} > 0$  is the fundamental and exogenous component of relative amenities, and  $\Upsilon_{oc}$  is an endogenous component of relative amenities that captures the effect of having more crime on the sectoral composition of a neighborhood, and is mediated by the parameter  $\omega \leq 0$ .

### 5.3 Equilibrium

Given model parameters  $\{\kappa, \theta_f, \theta_c, \eta, \beta, \alpha, \mu, \delta, \lambda, \iota, \rho, \omega\}$ , the reservation utility in the wider economy  $\bar{U}$ , vectors of exogenous location characteristics  $\{\mathbf{B}_o, \mathbf{B}_c, \mathbf{b}_f, \boldsymbol{\varphi}, \mathbf{K}, \boldsymbol{\xi}, \boldsymbol{\tau}, \mathbf{A}_c, \mathbf{p}_d\}$  the general equilibrium of the model is given by the vectors  $\{\mathbf{w}_f, \mathbf{w}_c, \mathbf{q}, \mathbf{q}, \mathbf{Q}, \mathbf{A}_f, \mathbf{B}_f, \boldsymbol{\pi}\}$ , and total city population  $\bar{H}$  such that the population mobility condition holds (8), origin and sector probabilities are given by choice probabilities in (7), there is legitimate labor market clearing, there is commercial (12) and residential land market clearing (11), criminal wages are endogenously determined by equation (13), firms make zero profits (11), and there is no arbitrage between alternative uses of land (10).

In Appendix D.1 we have a broader discussion of the model's equilibrium. In Appendix D.2, we study a special case of two neighborhoods, and examine further when reductions in transportation costs  $\tau_{od}$  will import opportunities (lower  $H_{Roc}$ ) or export crime (increase  $H_{Eoc}$ ). We particularly examine the roles played by our primary parameters of interest as a function of changing  $\tau_{od}$ , in comparative static exercises: the sector choice parameter  $\kappa$ , the spillover externality  $\lambda$ , and transportation elasticities  $\theta_s$ .

## 6 Parameter Estimation

Our parameter estimation relies on panel variation coming from changes in the commuting network, crime, and economic shocks over time. As such, we include an additional time index  $t$  when writing our estimation specifications. Results are reported in table 4.



## 6.1 Sector-Specific Commuting Elasticities

Following the literature, we parameterize iceberg commuting as an exponential function of commuting time:

$$\tau_{od,t} = \exp(\delta \text{time}_{od,t}) ,$$

where  $\text{time}_{od,t}$  is the average travel time in minutes across public and private transportation modes of moving from  $o$  to  $d$  in period  $t$ .

To estimate commuting elasticities, we use the fact that we observe criminal flows across neighborhoods. From the model equation 7, we derive the following gravity equation relating commuting flows across municipalities and iceberg costs:

$$\log(\pi_{ods|os,t}) = \underbrace{\beta_s}_{\delta \cdot \theta_s} \cdot \text{time}_{od,t} + \gamma_{o,t} + \gamma_{d,t} + \tilde{\epsilon}_{ods,t}$$

$\pi_{ods|os,t}$  is the share of workers that commute to location  $d$  from  $o$  working in sector  $s$  in year  $t$ .  $\text{time}_{od,t}$  is the average commuting time across municipalities  $od,t$  in year  $t$ ,  $\gamma_{o,t}$  are origin-time fixed effects,  $\gamma_{d,t}$  are destination-time fixed effects,  $\tilde{\epsilon}_{ods,t}$  captures measurement error in the observed  $\pi_{ods|os,t}$ .

Our goal is to recover the parameters  $\theta_s$  given  $\beta_s$  and  $\delta_d$ . We estimate this equation via PPML to include zero commuting flows between municipalities in Table 3. Along with our value of  $\delta = 0.01$ , we find  $\hat{\theta}_c = 8.69$  (SE: .364) and  $\hat{\theta}_f = 4.94$  (SE: .967).

## 6.2 Sectoral Labor Supply Elasticity

We now discuss how we recover  $\kappa$ , which corresponds to the labor supply elasticity across sectors that governs the reallocation of workers from the criminal sector to the formal economy. Following Zárte (2019), to capture a measure of average of worker access to wages weighted by distance, we define the **sector-specific commuter market access (CMA)** for location  $n$ , sector  $s$  as :

$$\text{CMA}_{os,t} \equiv \sum_d w_{ds,t}^{\theta_s} \tau_{od,t}^{-\theta_s} , \quad (16)$$

which is an index of accessibility of jobs in location  $o$  to employment in sector  $s$  and captures whether workers that live in  $o$  have good access to jobs from sector  $s$ . We also

define:

$$FMA_{ds,t} \equiv \sum_o \frac{\tau_{od,t}^{-\theta_s}}{CMA_{os,t}} H_{Ros,t} ,$$

as firm market access. One can solve the following system of equations to compute MA measures for both firms and commuters specific to each sector and location:

$$CMA_{os,t} = \sum_d \frac{\tau_{od,t}^{-\theta_s}}{FMA_{ds,t}} H_{Eds,t} \quad (17)$$

$$FMA_{ds,t} = \sum_o \frac{\tau_{od,t}^{-\theta_s}}{CMA_{os,t}} H_{Ros,t} , \quad (18)$$

where  $H_{Eds}$  represents the total number of workers in location  $d$  sector  $s$ ,  $H_{Ros}$  represents the total number of individuals that reside in  $o$  and work in sector  $s$ . Tsivanidis (2018) shows that one can solve for this with data on commuting costs, number of residents and workers in each sector and location. This system of equations is just-identified in terms of  $CMA_{os,t}$  and  $FMA_{ds,t}$  as we have one unique equation for each unknown.

To arrive at estimation equations containing sector-choice elasticity  $\kappa$ , recall that the sector  $s$ -choice probability in time period  $t$  conditional on being in origin  $o$  is:

$$\pi_{ost|o} = \frac{H_{os,t}}{H_{of,t} + H_{oc,t}} = \frac{B_{os,t} CMA_{os,t}^{\kappa/\theta_s}}{\sum_{s'} B_{os',t} CMA_{os',t}^{\kappa/\theta_s}}$$

where the first equality holds by definition and the second equality comes from equation 7. Taking logs of both sides, we arrive at:

$$\ln(\pi_{ost|o}) = \ln(H_{os,t}) - \ln(H_{of,t} + H_{oc,t}) = \frac{\kappa}{\theta_s} \ln(CMA_{os,t}) + \ln(B_{os,t}) - \ln\left(\sum_{s'} B_{os',t} CMA_{os',t}^{\kappa/\theta_s}\right)$$

This yields a regression equation *specific to sector  $s$*  that would allow us to identify  $\kappa$ :

$$\ln(\pi_{ost|o}) = \kappa \frac{1}{\theta_s} \ln(CMA_{os,t}) + \gamma_o + \gamma_t + \eta_{ost} \quad (19)$$

We focus on  $s = f$ , as the first stage using a shift-share instrument to capture variation due to exogenous changes in the returns to formal work was stronger.<sup>17</sup> We estimate  $\hat{\kappa} = 2.806$ , as in the first column of Table 4.

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<sup>17</sup>We were unable to pass weak first-stage tests using the Don Berna variation in returns to crime. As

**Identification** Given that equation 19 expresses a labor supply relationship, there is an endogeneity concern when estimating  $\kappa$ .  $\ln(\pi_{of,t|o})$  and  $\frac{1}{\theta_f} \ln CMA_{of,t}$  will be correlated due to shifts of the relative labor supply curve in addition to shifts along the relative labor supply curve.  $\kappa$ , as an elasticity, is meant to describe shifts along the curve. If we include variation from shifts of the entire relative labor supply curve, our estimate of  $\kappa$  will be biased.

Table 4: Estimating  $\kappa, \eta, \lambda, \omega, \rho, \iota$

	(1) $\kappa$ Log (Formal)	(2) $\eta$ Log(Residents)	(3) $\lambda$ Log(Productivity)	(4) $\omega$ Log(Amenity)	(5) $\rho$ & $\iota$ Log (Crime/Total) + $\theta_C \delta_{od}$
Log $CMA_{fot}$	2.806 (4.213)				
Log $Welfare_o - (1 - \beta) \text{Log Rent}_o$		2.114* (1.096)			
Log $Crime_o$			-0.062	-0.159	-0.172* (0.0878)
Log $Formal_o$					0.103 (0.0643)
Observation Level	Origin-Year	Origin-Year	Destination	Origin	Origin-Destination-Year
Method	2SLS	2SLS	GMM	GMM	2SLS
Instrument(s)	Shift-Share	Shift-Share	Don Berna	Don Berna	Shift-Share, Don Berna
F-Stat (of IV)	50.07	51.64			22.45
Fixed Effects	Origin, Year	Origin, Year			Origin
Observations	926	1,614	260	205	33,577
SE Cluster	Origin	Origin	Origin	Origin	Destination

Notes: Table shows the estimation of additional parameters. Log  $CMA_{fot}$  is the natural log of formal sector commuter market access values by neighborhood. Log  $Crime_o$  is the number of crimes in a neighborhood. Log  $Formal_o$  is the number of formal sector workers in a neighborhood. The outcome in the last column is the crime-share adjusted for commute costs (Log(Crime/Total) +  $\theta_C \delta_{od}$ ). \* Indicates significance at 10% level, \*\* indicates significance at 5% level.

To address this, we estimate the specification in equation 19 using shift-share instruments capturing firm productivity shocks that are correlated with but exogenous to wages and formal employment in Medellín. These external productivity instruments serve as relative labor demand shifters; formal sector firms experiencing exogenous productivity shocks will adjust wages and employment in Medellín accordingly. Shifts in only formal labor demand capture relative employment and wages along the same relative labor supply curve. Thus, our LATE will reflect only variation from shifts along relative supply, allowing us to identify  $\kappa$ .

robustness, since taking a log of a small number magnifies error, we also estimate:

$$\ln(H_{ost|o}) = \kappa \frac{1}{\theta_s} \ln(CMA_{os,t}) + \gamma_o + \gamma_t + \eta_{ost}$$

which yields similar results. This specification puts  $\ln(H_{of,t} + H_{oc,t})$  in the error term, since it varies simultaneously by both origin and period.

Note, that these Bartik instruments will correspond to *destinations* in our data, whereas equation 19 is estimated at the *origin* level. Consequently, we need to determine the degree to which residents in each origin were exposed to these destination-level shocks by using how connected residents in an origin were to each destination. To do this, we use equation 17 to calculate origin-level instruments, where  $z_{dt}$  is the destination level shock to formal sector productivity and  $\tilde{z}_{ot}$  captures shocks aggregated to the origin level.

$$\tilde{z}_{ot} = \sum_d z_{dt}^{\theta_f} \tau_{odt}^{-\theta_F} \quad (20)$$

### 6.3 Residential Choice Elasticity

We now discuss how to estimate the residential choice elasticity. Recall that the probability of someone choosing to live in origin  $o$  in period  $t$  is defined as:

$$\pi_{o,t} = \left( \frac{B_{o,t} Q_{o,t}^{-(1-\beta)\eta} W_{o,t}^\eta}{\sum_{o'} B_{o',t} Q_{o',t}^{-(1-\beta)\eta} W_{o',t}^\eta} \right),$$

where  $B_{o,t}$  is an unobserved residential amenity,  $Q_{o,t}$  is the residential floor-space price, and  $W_{o,t} = (\text{CMA}_{oc,t}^\kappa + \text{CMA}_{of,t}^\kappa)^{\frac{1}{\kappa}}$ . Taking the log of both sides we derive:

$$\ln \pi_{ot} = \ln B_{ot} - (1 - \beta)\eta \ln Q_{ot} + \eta \ln W_{ot} - \ln \left( \sum_{o'} B_{o't} Q_{o't}^{-(1-\beta)\eta} W_{o't}^\eta \right)$$

Written in terms of observables, the corresponding estimation equation becomes:

$$\ln \pi_{o,t} = \eta (\ln W_{o,t} - (1 - \beta) \ln Q_{o,t}) + \gamma_t + \epsilon_{\eta,t},$$

where we set  $1 - \beta = 0.25$  following Ahlfeldt et al. (2015),  $\gamma_t$  is a time-fixed effect, and  $\epsilon_{\eta,t}$  is the error term. We need an instrument for  $(\ln W_{o,t} - (1 - \beta) \ln Q_{o,t})$  to identify  $\eta$  since the residential amenity is unobserved. We use the Bartik shock aggregated to the origin level given by equation 20, since it correlates with  $\text{CMA}_{of,t}$  by shifting wages via variation in industry shocks to productivity across neighborhoods and not the residential amenity. Our estimate is  $\hat{\eta} = 2.114$  from Table 4.

## 6.4 Criminal Productivity Externality

To estimate the crime externality parameter  $\lambda$ , we follow [Ahlfeldt et al. \(2015\)](#) to derive moment conditions using the structural productivity residual. Using first order conditions of the production function for the formal sector with respect to labor and floor space, we derive the following structural relationship linking wages  $w_d$ , the productivity residual  $a_{d,t}$ , land/factor prices  $q_{d,t}$ , and the crime externality  $\Upsilon_{dc,t} = \frac{H_{Edc,t}}{K_d}$ :

$$w_{d\ell,t} = \alpha(1 - \alpha)^{\frac{1-\alpha}{\alpha}} a_{d,t}^{\frac{1}{\alpha}} q_{d,t}^{\frac{\alpha-1}{\alpha}} \Upsilon_{dc,t}^{\frac{\lambda}{\alpha}}$$

Taking logs and differencing this expression from its geometric mean, gives us the following moment function:

$$\Delta \log \left( \frac{a_{d,t}}{\bar{a}_t} \right) = (\alpha - 1) \Delta \log \left( \frac{q_{d,t}}{\bar{q}_t} \right) - \alpha \Delta \log \left( \frac{w_{d,t}}{\bar{w}_{d\ell,t}} \right) - \lambda \Delta \log \left( \frac{\Upsilon_{dc,t}}{\bar{\Upsilon}_t} \right), \quad (21)$$

where  $\bar{a}_t$ ,  $\bar{q}_t$ ,  $\bar{a}_t$ ,  $\bar{\Upsilon}_t$  are geometric means defined as  $\bar{x}_t = \exp(\frac{1}{S} \sum_{d=1}^S \log(x_{dt}))$  and  $\Delta$  differences out time-invariant aspects of productivity. Differencing out time-invariant variation and the geometric mean implies that equation 21 has mean 0. We then arrive at the following moment condition:

$$\mathbb{E} \left[ h(Z) \Delta \log \left( \frac{a_{dt}}{\bar{a}_t} \right) \right] = 0, \quad (22)$$

where  $h(Z)$  is the vector of instruments discussed below. We implement estimation of the crime externality parameters using GMM and find  $\hat{\lambda} = -0.062$  (Table 4, column 3).

**Identification** Like [Ahlfeldt et al. \(2015\)](#), we want to identify  $\lambda$  using only variation coming from changes in commuting access and the resulting change in the crime externality rather than other reasons for changes in  $\Delta \log(\frac{a_{dt}}{\bar{a}_t})$  (e.g., changes in the distribution of productivity in Medellín due to a change in zoning laws). Thus, we want an instrument capturing only the former source of variation. Specifically, we construct instruments based off of how far neighborhoods were from locations affected by the gang areas of a local crime lord (i.e., Don Berna) who was extradited in 2009. The extradition led to a spike in homicides in the neighborhoods that were under Berna's control. Using this as a source of exogenous variation in criminal activity we leverage this to identify the effects of how increases in crime affect economic activity. Variation across different bands of distances help identify  $\lambda$ .

## 6.5 Criminal Residential Amenity

Our moments for estimating the effect of crime on residential amenities come from the sector choice probability equation:

$$\pi_{ost|om,t} = \frac{L_{os,t}}{L_{o,t}} = \frac{B_{os,t}W_{ost|o,t}^\kappa}{B_{oc,t}W_{oct|o,t}^\kappa + B_{of,t}W_{oft|o,t}^\kappa} \quad (23)$$

Using equation 23 and taking the ratio for  $s = f$  to  $s = c$ , we get:

$$\frac{L_{of,t}}{L_{oc,t}} = \frac{B_{of,t}W_{oft|o,t}^\kappa}{B_{oc,t}W_{oct|o,t}^\kappa} = b_{o,t}\Upsilon_{o,t}^\omega \frac{W_{oft|o,t}^\kappa}{W_{oct|o,t}^\kappa} \quad (24)$$

where:

$$\frac{B_{of,t}}{B_{oc,t}} = b_{o,t}\Upsilon_{o,t}^\omega \quad (25)$$

Like before, we can take the difference across periods and divide by the geometric means to get:

$$\Delta \ln \left( \frac{b_{o,t}}{\bar{b}_{o,t}} \right) = \Delta \ln \left( \frac{L_{of,t}}{\bar{L}_{of,t}} \right) - \Delta \ln \left( \frac{L_{oc,t}}{\bar{L}_{oc,t}} \right) - \omega \Delta \ln \left( \frac{\Upsilon_{o,t}}{\bar{\Upsilon}_{o,t}} \right) - \kappa \Delta \ln \left( \frac{W_{of|o,t}}{\bar{W}_{of|o,t}} \right) + \kappa \Delta \ln \left( \frac{W_{oc|o,t}}{\bar{W}_{oc|o,t}} \right) \quad (26)$$

As in the case of the crime productivity externality, we can get the following structural moment condition for each sector:

$$\mathbb{E} \left[ h(Z) \Delta \log \left( \frac{b_{os,t}}{\bar{b}_{os,t}} \right) \right] \quad (27)$$

and estimate  $\hat{\omega} = -0.159$  in Table 4, column 4.

## 6.6 Returns to Crime

Recall, that the share of criminals living in origin  $o$  choosing to commit a crime in destination  $d$  is:

$$\pi_{odct|oc,t} = \frac{w_{dc,t}^{\theta_c} \tau_{od,t}^{-\theta_c}}{\sum_{d'} (w_{d'c,t} / \tau_{od',t})^{\theta_c}}$$

Substituting in our equation 13 for the returns to crime and taking logs:

$$\pi_{odct|oc,t} = \frac{\tilde{A}_{dc,t}^{\theta_c} H_{dc,t}^{\rho\theta_c} (H_{df,t})^{\iota\theta_c} \tau_{od,t}^{-\theta_c}}{\sum_{d'} (w_{d'c,t}/\tau_{od',t})^{\theta_c}}$$

$$\log(\pi_{odct|oc,t}) = \theta_c \log(A_{dc,t}) + \rho\theta_c \log(H_{dc,t}) + \iota\theta_c \log(H_{df,t}) - \theta_c \tau_{od,t} - \log\left(\sum_{d'} (w_{d'c,t}/\tau_{od',t})^{\theta_c}\right),$$

where  $\tilde{A}_{dc,t} = (1 - p_{d,t})A_{dc,t}$ . This can be translated into the following estimation equation:

$$\log(\pi_{odct|oc,t}) = \rho\theta_c \log(H_{dc,t}) + \iota\theta_c \log(H_{df,t}) - \theta_c \tau_{od,t} - \gamma_o + \epsilon_{od,t} \quad (28)$$

This depends only on observables  $(\pi_{odct|oc,t}, H_{dc,t}, H_{df,t}, w_{df,t}, \tau_{od,t})$  and separately estimated parameter  $\theta_c$ . Under this setup, we control for unobserved criminal productivity  $\tilde{A}_{dc,t}$  using fixed effects. We find  $\hat{\rho} = -0.172$  and  $\hat{\iota} = 0.103$  (Table 4, column 5).

## Identification

A number of unobservables could cause the total number of criminals in a given destination  $H_{dc,t}$  to covary with the share of criminals commuting from origin  $o$  to destination  $d$ . For example,  $d$  could be the headquarters for a gang with a strong presence in  $o$  in period  $t$ . We have assumed that crime affects productivity, so there is a simultaneity problem when estimating  $\iota$ . As such, we use the Don Berna instrument to identify  $\rho$  and the Bartik shocks to identify  $\iota$ .

## 6.7 Other Parameters

We take some parameters from the literature. Specifically,  $(1 - \beta), (1 - \mu), (1 - \alpha)$ , which are, respectively, the share of residential floor space in consumer expenditure, the share of land in construction costs, and the share of commercial floor space in firm costs. These are set following Ahlfeldt et al. (2015) to  $\alpha = 0.8$ ,  $\mu = 0.75$ ,  $\beta = 0.75$ .

For the time disutility parameter  $\delta$  we follow the growing consensus in the literature (Ahlfeldt et al., 2015; Tsivanidis, 2018; Zárate, 2019) and set it to  $\delta = 0.01$ .



## 6.8 Model Inversion

Given the value of the parameters, we can recover the fundamentals of the model  $\{B_{os}, A_d\}$ .<sup>18</sup> In order to do so, we first solve for commuter and firm market access given observed residential and labor decisions through equations 17 and 18.

Given the recovered  $\{CMA_o, FMA_o\}$ , one can obtain the model-implied wages from the sectoral labor supply equation:

$$H_{ds} = w_{ds}^\theta FMA_{ds}$$

Given the recovered distribution of wages both in the formal and in the criminal sector, we recover productivity in the formal sector using the production function as well as profit maximization:

$$A_d = \left(\frac{w_d}{\alpha}\right)^\alpha \left(\frac{q_d}{1-\alpha}\right)^{(1-\alpha)}$$

Finally,  $\{B_{os}\}$  are shifters that attract workers from particular sectors to certain neighborhoods of residence. In order to see this, note that taking the ratio of the share of individuals from a particular origin that choose to work in the formal sector relative to the criminal sector, this is given by:

$$\frac{\pi_{of|o}}{\pi_{oc|o}} = \frac{B_{of}}{B_{oc}} \left[ \frac{CMA_{of}^{1/\theta_f}}{CMA_{oc}^{1/\theta_c}} \right]^\kappa$$

Thus, we can recover the relative amenities  $B_{of}/B_{oc}$  by fitting the number of formal workers relative to criminals given observed sectoral commuter market access.

## 7 Policy Counterfactuals

What are the sectoral choice effects of transportation infrastructure investments? Does connecting poor neighborhoods to the Central Business District (CBD) import opportunity or export crime? What are the resulting welfare effects? We first answer these questions through the lens of the model focusing on two network-based counterfactuals motivated by public policy. We then conduct a different exercise, where we try to unpack which neighborhoods we should target with transportation improvements. Here, we reduce the average commute time at each origin neighborhood, and examine the welfare

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<sup>18</sup>For this version of the results we assume that  $B_o = 1 \quad \forall o$ , and that  $\xi_d = 1 \forall d$ .

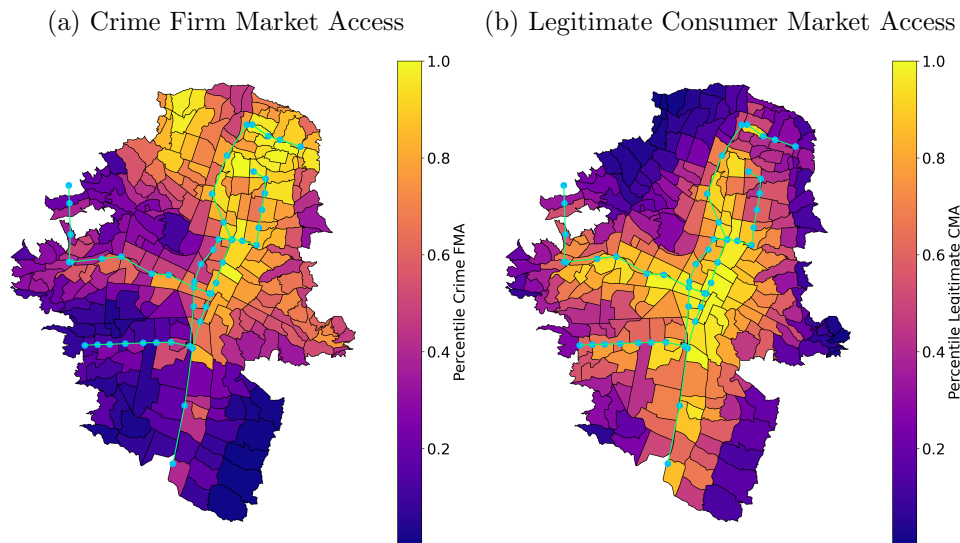
and criminality consequences of such an intervention.

## 7.1 Equilibrium Effects of Recent Network Lines

We examine the dynamics surrounding crime rates and city-level welfare, when we build new network-based public transport lines. We discipline our analysis by focusing on the lines that were recently built, or are under construction. First, we evaluate the impacts of a new cable line that is currently under construction on the north-western part of the city. We then evaluate the consequences of a tram line built in 2016 by the government in Medellin that connected the eastern part of the city to the CBD.

These two lines provide interesting nuances given the baseline market access and composition of the neighborhoods. The eastern edge of the city has high baseline crime activity, but also easy access to legitimate sector firms via a dense pre-existing bus network. The north-western part has even higher crime rates, but lower legitimate-sector consumer market access as there existed little public transportation. The differences in the outcomes describe how baseline characteristics affect the equilibrium outcomes for both criminality and welfare.

Figure 7: Sectoral Firm Market Access, 2015



*Notes :* These maps show the percentiles of recovered Sectoral Firm Market Access for both crime and legitimate-sector work in 2015.

Importantly, the newly connected neighborhoods under both counterfactuals were relatively poor neighborhoods where criminals tended to live. Figure 7 shows the percentiles of the Sectoral Firm Market access for both crime and legitimate-sector work in

2015 across neighborhoods. The map shows a stark contrast between crime and legitimate work FMA in both the north-western and eastern parts of the city. Specifically, crime FMA is large relative to legitimate-sector FMA there: individuals living in these neighborhoods tended to choose the criminal sector instead of the legitimate sector in 2015.

Ex-ante, the effect of connecting these neighborhoods to the CBD on individuals' sector choice is ambiguous. On the one hand, reducing commute costs to the CBD increases legitimate-sector CMA for connected neighborhoods since they will now be able to commute to neighborhoods with large returns for legitimate-sector work. On the other hand, reducing commute costs also increases criminal CMA since, in principle, criminals are connected to more profitable crime destinations near the CBD. The overall effects will depend on the change in relative sectoral CMA, which, in turn, will depend on the estimated parameters.

In order to understand the counterfactual effects of the tram line on sector choice and welfare, we proceed as follows: we first invert the model to obtain unobserved amenities and productivities consistent with the data in 2015. Then, given the estimated parameters, we feed the model with the observed change in commuting costs as a result of the new lines and solve the model for the endogenous variables.<sup>19</sup> We then analyze the economy's response to the commute cost shock.

### 7.1.1 The North-West Cable Line

We first study the sector choice and welfare impacts of a cable line that is currently under construction. The government of Medellín constructed a new cable line that connects the north western part of the city to the rest of the transportation network. This line started operating in June, 2021.

Based on Figure 7, we know that the north-western part of Medellín is a high crime Firm Market Access region, which reveals that criminals tend to live in these neighborhoods. In order to evaluate the welfare effects of the cable line we construct counterfactual commute times considering the new public transport stations. We invert the model and obtain unobserved fundamentals in 2015 consistent with the data. We then feed the model with the counterfactual change in commute times and study the resulting equilibrium.

Figure 8 shows the main results of this exercise. The map plots the percent change in the probability of becoming a criminal for each neighborhood in Medellín. According to

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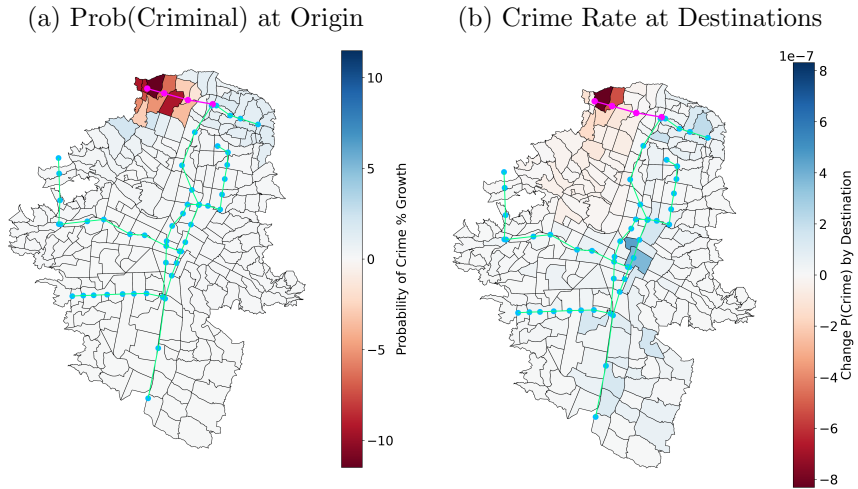
<sup>19</sup>In the presence of externalities, there is potential for multiple equilibria. Following Ahlfeldt et al. (2015) we assume that the equilibrium selection rule is the closest to the equilibrium observed in the data before the shock.

the model, the new cable line reduced the probability of becoming a criminal in treated neighbors by as much as 11.5%. For the neighborhoods that saw at least a reduction of 10 mins in average commute times, crime participation rates fell by 9.4% on average. The percent decrease in the probability of becoming a criminal is larger for more remote neighborhoods: it is these neighborhoods that benefit the most from being connected to the transportation network given that they previously did not have access to profitable legitimate-sector work opportunities.

So far, we have discussed the extensive margin of sector choice. We now explore the intensive margin of crime by focusing on the destination decisions conditional on sector and origin. The right panel of Figure 8 shows the change in the probability of committing a crime by destination conditional on becoming a criminal.

Conditional on having chosen to become a criminal, the decline in commute times allows individuals to commit crimes in more profitable destinations (e.g., near downtown). In this sense, criminals substitute away from local crime and start committing crimes in neighborhoods with high model-implied returns to crime, particularly in the CBD.

Figure 8: Change in crime rate: North-west Cable line



*Notes :* Left-panel map shows the model implied percent change in the probability of becoming a criminal conditional on origin,  $\pi_{oc|o}$  across neighborhoods of origin, given the change in commute costs. Right-panel map shows the model implied percent change in the probability of committing a crime conditional on origin,  $\pi_{od|o}$  across neighborhoods of destination, given the change in commute costs.

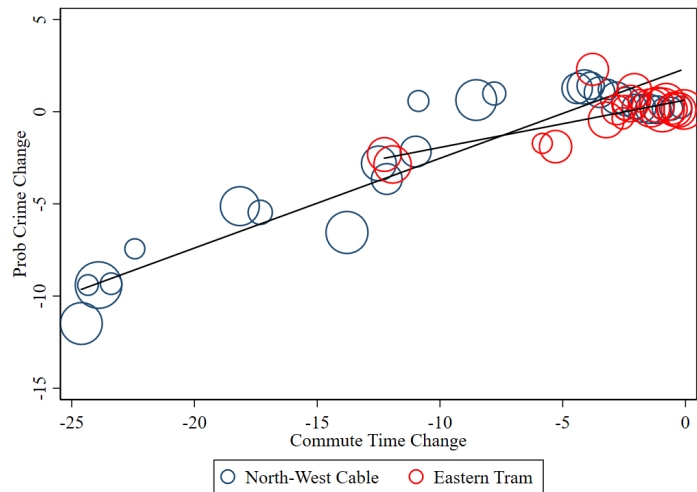
Finally, we study the welfare effects of this particular investment in transportation infrastructure. in order to do so, we assume that the total population of Medellín does not change after the reduction in commute times, and compute the change in expected utility after the shock. That is, we evaluate the change in expected welfare due to the

construction of the new cable line assuming that there is no in nor out-migration from Medellin. Consistent with the results found so far, the model predicts a positive welfare impact on the average city resident of 0.48%, and a GDP increase of \$2.62 billion USD (net of costs).<sup>20</sup>

### 7.1.2 The Eastern Tram Line

The meaningful impacts in the north west were partly driven by a lack of pre-existing public transportation infrastructure in that part of the city. In comparison, we examine the effect of a tram line that connected parts of the city that already had an existing bus network. In 2016 the government of Medellin invested in a tram line that connected neighborhoods in the eastern part of Medellin to the CBD.

Figure 9: Relationship Between Change in Commute Cost and Sector Choice



*Notes :* The scatterplot shows the relationship between the percent change in average commute costs at the origin level and the percent change in the probability of becoming a criminal at the origin level as well by counterfactual. We binned the changes using equal distance.

According to our estimates, the tram increased legitimate-sector CMA relative to criminal CMA in treated neighborhoods, therefore reducing the probability of becoming a criminal by up to 3%. Yet, there were also neighborhoods with increases in criminal participation, as we now connected certain low-crime low-income neighborhoods along the route, to more high-criminal opportunity neighborhoods at the extreme eastern edge of the city.

<sup>20</sup>GDP is the sum of factor payments to legitimate factors (i.e., legitimate-sector earnings and housing rents). We discount GDP by 10% over a 50 year period. The costs for the cable are paid upfront (not discounted). The costs are the documented costs in the official budgets after the cable is functional.

Why was the overall impact on crime rates smaller under this tram line than under the north-west cable line? In order to see this more clearly, Figure 8 shows the relationship between the decline in average commute costs and the change in the probability of becoming a criminal by origin for each line. The relationship is somewhat non-linear, but shows larger reductions in criminal participation for neighborhoods with larger declines in average commute costs. Importantly, comparing to the north-west cable counterfactual considered in Section 7.1.1, the investment in the new cable line had a smaller and more geographically concentrated impact on the probability of becoming a criminal. That is, the figure also shows that the reductions in commute costs for the north-west cable were far larger than that for the eastern tram line, as the east already had a meaningful pre-existing bus network.

The smaller effect on the probability of becoming a criminal is due to one main reason: the new tram line connected neighborhoods that were already relatively well connected to the public transport system via an extensive bus network. The overall change in legitimate-sector Consumer Market Access for these neighborhoods was not as large as it was for the much more disconnected neighborhoods in the north-western part of Medellin. The smaller increase in relative Commuter Market Access explains the relatively smaller decline in the probability of becoming a criminal in this counterfactual.<sup>21</sup>

Performing the welfare exercise, we find that building the tram increased expected utility in the city by a much smaller 0.08%. The smaller welfare impact is due, on the one hand, mechanically to the smaller size of the infrastructure project and thus to the smaller decline on overall commute costs in the city. More importantly, it is due to the fact that there is a smaller reduction in the negative externalities imposed by crime precisely because the new line connected relatively well connected neighborhoods thus not having as large of an impact on the amount of criminals in the city.

## 7.2 Which Neighborhoods Should we Target?

The consequences described above tell us about recent policy-driven expansions to the transit sector, and the heterogeneity in the impacts suggest that it may be more important to connect certain neighborhoods than others. Which targeted neighborhoods are likely to produce the best city-level outcomes?

To answer this question, we reduce the average commute times in each origin  $o$  neighborhood by 10 percent. That is, for each  $o$ , we do  $\tau'_{od} = 0.9\tau_{od} \forall d$ . This is similar

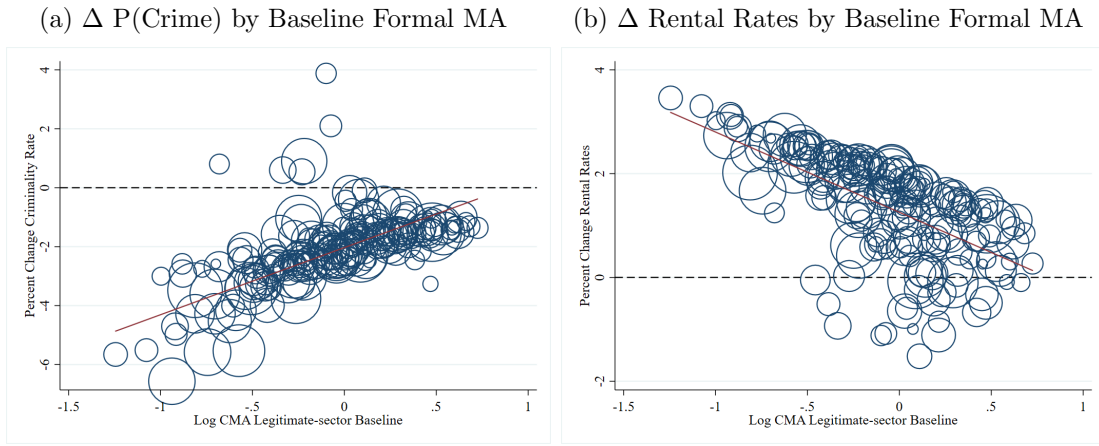
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<sup>21</sup>Similar to the last counterfactual, when studying criminal destination decisions, we find that criminals substitute local for distant crime by changing the location of their crimes towards the CBD.

to a policy where we subsidize ride-sharing facilities or taxis, or give cars to residents of the targeted neighborhoods.

Yet, reductions in commuting costs for residents in a certain neighborhood will affect all other neighborhoods as well, as it changes criminality and legitimate-sector activity not just in the intervention neighborhood, but also crime and work destinations in other parts of the city. To examine the overall consequences, we create city-level resident-weighted averages as outcomes of interest. We focus on outcomes in relation to the baseline access to legitimate-sector opportunities.

Figure 10: Reducing Commute Costs by Each Neighborhood: P(Crime) and Rent



*Notes:* Scatter plots show the relationship between changes in city-level outcomes against the baseline legitimate-sector market access for the treated origin  $o$ , where treatment is a ten percent reduction in commute costs ( $\tau'_{od} = 0.9\tau_{od} \forall d$ ). That is, each point x-axis is the legitimate-sector CMA of the neighborhood that receives the transport subsidy. The outcome in the left panel is the city-level criminality rate (i.e.,  $P(\text{crime}|\text{origin}) \times \text{Population}_o$ ). Similarly, the outcome in the right panel is the city-level rental rates.

Figure 10 has a clear message: connecting neighborhoods that have the lowest legitimate-sector CMA at baseline are likely to lead to the largest reductions in city-level criminality, and largest increases in rental prices.

The left panel shows that in treating almost all neighborhoods in the city would lead to reductions in city-level crime. Yet, there are a handful of neighborhoods, which when treated with reductions in commute costs, display an increase in city-level crime. These neighborhoods already have extremely high legitimate-sector CMA, and so any transportation improvements there may simply allow residents to access criminal activity elsewhere in the city. As we show below, these handful of neighborhoods are where there was already high firm-market access.

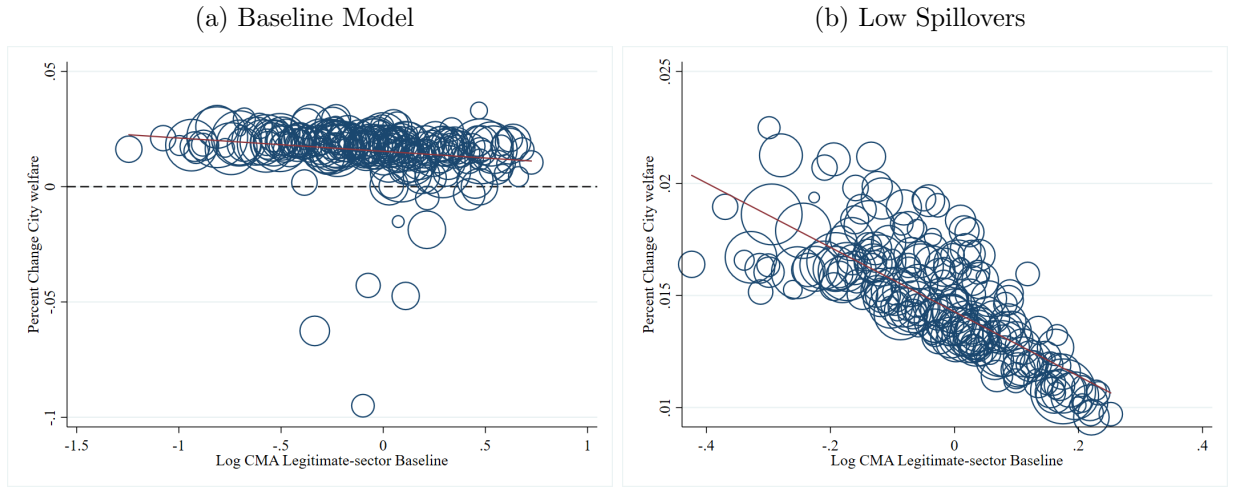
The right-side panel shows that rental prices increase when residents of almost any



neighborhood (except the CBD) sees a reduction in commute costs. This partly reflects the amenity and productivity boosts that emerge out of lower crime, but also the ability to access distant legitimate-markets with the help of lower commute costs.

Figure 11a shows the welfare consequences of these reduction in transport costs. Across almost any treated neighborhood, there is an increase in city-level welfare, and this increase is slightly higher when areas that have less access to legitimate sector opportunities are treated (left panel). Yet, there are six neighborhoods (1% of all neighborhoods) that, when treated with reductions in transportation costs, lower aggregate city welfare.

Figure 11: Reducing Commute Costs by Each Neighborhood:  $\Delta$  Welfare by Neighborhood



*Notes:* The scatterplots show the relationship between changes in city-level welfare against the baseline legitimate-sector market access for the treated origin  $o$ , where treatment is a ten percent reduction in commute costs ( $\tau'_{od} = 0.9\tau_{od}\forall d$ ). That is, each point x-axis is the legitimate-sector CMA of the neighborhood that receives the transport subsidy. The left axis shows the effects from the baseline model with high cross-sectoral spillovers. The right side shows an exercise with lower spillovers.

### 7.2.1 Cross-Sectoral Spillovers and Non-linear Responses

One obvious question is why are there six neighborhoods where reductions in commute times actually lower welfare across the city? Our investigation of possible channels suggest that is mostly driven by the size of the cross-sectoral spillovers we have in our model (i.e., how crime lowers legitimate-sector productivity, and how less legitimate-sector opportunities lower returns to crime). To investigate the importance of these spillovers, we perform the same set of counterfactuals where we simply reduce the size of the spillover parameter from  $\lambda = 0.062$  to  $\lambda = 0.027$ . For the construction of Line P, the welfare



impacts would have increase from 0.48% to 0.60% if we did not account for the high cross-sectoral spillovers.

In Figure 11b we show the results of the counterfactuals where we subsidize transportation by 10% neighborhood-by-neighborhood, as we did for Figure 11a. Rather interestingly, we see that in a world with low spillovers, all neighborhoods see a substantial improvement in welfare.

Yet, under our set of estimated parameters, there are six neighborhoods that when connected raise the aggregate amount of criminal activity in the city. Since an aggregate increase in criminal activity lowers legitimate-sector productivity (especially when the spillover parameter is large), this lowers overall legitimate-sector wages, and welfare in the city.

These dynamics highlight the importance of modelling cross-sectoral spillovers in standard frameworks used in Urban Economics. Ignoring such spillovers may produce a different set of qualitative and quantitative results.

## 8 Discussion

The spatial distribution of criminal activity and legitimate-sector employment are inter-linked by neighborhood segregation and access to different neighborhoods. Changes to transit networks meaningfully affect these relationships in a manner that can change the overall levels of crime and legitimate-sector employment in cities like Medellín. Studying the impacts of expansions in transportation infrastructure is particularly important given the stark segregation of activities across neighborhoods (Kling et al., 2007; Chyn, 2018; Chetty and Hendren, 2018a; Jacob, 2004; Melnikov et al., 2019). As such, this relates to a long literature that suggests that access to economic opportunity is a meaningful determinant of criminal engagement (Becker, 1968).

We follow this tradition by studying the commuting behavior of criminals and legitimate workers, as it relates to economic opportunity. Doing so requires access to data on flows of workers and criminals and a robust framework to isolate the effect of transit networks on crime and legitimate-sector jobs. Our quantitative spatial general equilibrium framework allows us to examine not only how access to opportunity affects the levels of criminal activity, but also the geographic spread of such activity to different neighborhoods. Our simulations show that improving access to jobs in economically segregated parts of the city can substantially lower crime rates in high-crime environments. Despite some spread of criminal activity to different neighborhoods as a result of connecting segregated regions, aggregate crime, welfare and inequality can all be improved.

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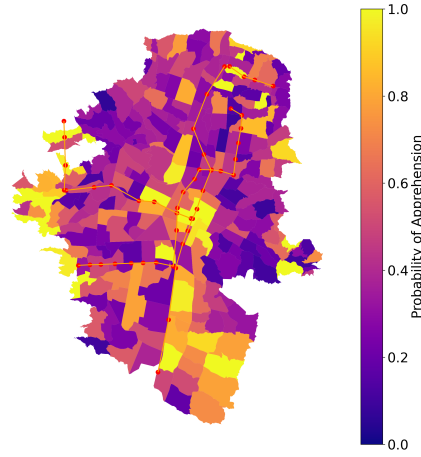
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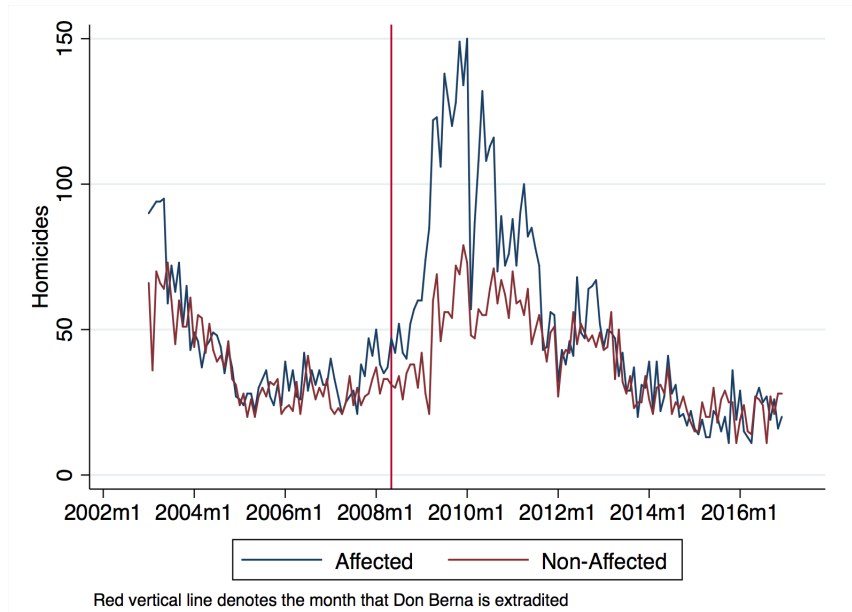
## A Appendix: Additional Figures and Tables

Figure A.1: Average Homicide Arrest Rate by Destination:  $p_d$



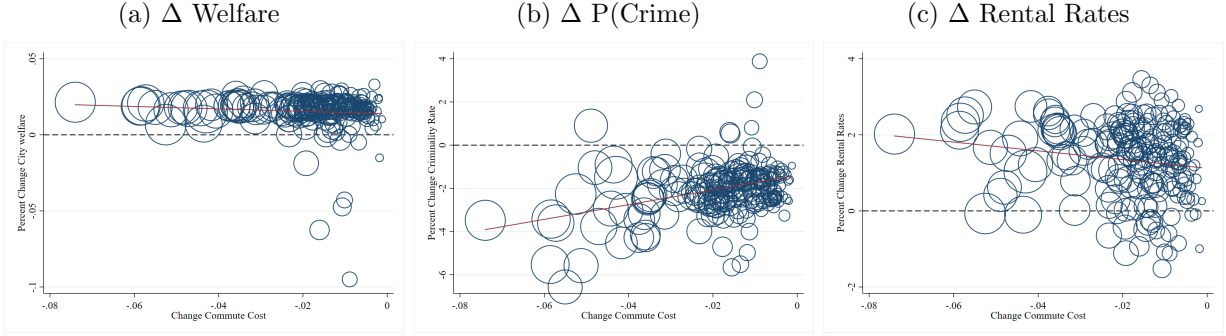
*Notes:* This map shows the average arrest rate  $\#arrests_d/\#homicides_d$  across the sample.

Figure A.2: Change in Homicides After the Extradition of Crime Lord, Don Berna



*Notes:* This map shows the homicide rate by neighborhoods that Don Berna used to be in charge of (affected), and all other neighborhoods (not affected). After his extradition, there was a spike in crime in his neighborhoods.

Figure A.3: Reducing Commute Costs by Each Neighborhood: Robustness



*Notes:* Scatter plots show the relationship between changes in city-level welfare, criminality and rental rates against the absolute change in commute times for the treated origin  $o$ , where treatment is a ten percent reduction in commute costs ( $\tau'_{od} = 0.9\tau_{od} \forall d$ ).

## B Data Construction and Statistics

### B.1 Administrative Data

The administrative data described hereafter is confidential and could only be stored and accessed in person in a fully-secured location at the Central Bank of Colombia.

#### B.1.1 SISBEN

The SISBEN (Sistema de Identificación de Potenciales Beneficiarios de Programas Sociales) data comprise around 70 percent of the poorest people in Colombia. The survey is collected to identify and classify individuals and families according to their living conditions with the aim of making them beneficiaries of social programs. We use three waves of SISBEN carried out in 2002, 2005 and 2009. For each wave we have the identification of the individual, the neighborhood where individual live, if the individual is currently working, the type of security social (subsidized or contributory) used to identify informal workers, among other individual characteristics. For the analysis we keep individuals that take the SISBEN survey at Medellin. That means that we have 1,166,232 individuals in SISBEN 2002, 1,493,832 individuals in SISBEN 2005, and 1,549,364 in SISBEN 2010.

#### B.1.2 PILA

We use information of the Planilla Integrada de Liquidación de Aportes (PILA). The PILA is the Colombian platform to make the monthly Social Security payment of workers. In most cases, this payment is made by the companies. We have access to the

anonymized information of workers between 2008 to 2018. This database contain monthly level information of wage, number of working days, and anonymized identifier of the firm that make the payment.

### **B.1.3 Camara de Comercio de Medellin**

We use information of formally registered firms of Medellin. The entity that register the firms in Medellin is the *Camara de Comercio de Medellin*. We have 80268 firm in average by year between 2007 to 2016 with address. Nevertheless, most of them, 68.7%, are repeated in time. Keeping with non-repeated firms and non-repeated address we have 257,391 standardized address to geocode. We where able to geocode the 87.3% of the address. In average, we have information of 3,027 firms by neighborhood for 268 neighborhoods. For each firm we have the identification of the legal representative by year. We merge this identification with the PILA to obtain the match between the NIT (Colombian identification of the firm) with the anonymized identification of firms in PILA. Thhis allow us to capture 33,312 firms in 8 years, that represent the 81% of formal workers in Medellin.

### **B.1.4 Crime Data**

This study uses data from the census of people captured for the Aburra Valley Region (Valle de Aburrá). The data comes from the judicial research unit of the Metropolitan Police of the Aburra Valley Region (SIJIN). The data contain information on identification of criminal, neighborhood where the arrest took place, date of arrest, criminal group (or gang) the individual belongs to, and type of crime. We have 343,167 crimes reported for the timespan 2002-2015. We were able to geocode 321,339 neighborhoods (the 93,6% of the total neighborhoods in the database). For these geocoded neighborhoods we know that 84% of crimes was committed in Medellin and 16% in other Municipalities. To obtain the origin neighborhoods of this crimes committed in Medellin we merge the identification of the criminal with SISBEN databases. We were able to capture the origin neighborhood for 50.5% of total crimes committed in Medellin.

### **B.1.5 Land Registry Data**

We use cadastral records of Medellin from 2013 to 2018. The unit of observation is the property, that have information of address, neighborhood where is located, price and area of the property, and the type of property (Commercial, Industrial or Residential). In average we have 2625 properties by neighborhood and 687,609 properties by year.

## B.2 Rescaling data with Informal sector

We need data on  $\{H_{Eds}, H_{Ros}\}$  for  $s \in \{c, l\}$  and  $o, d \in \{1, \dots, D\}$ , which is number of employees by sector-neighborhood and number of residents by sector-neighborhood. Instead of observing the true values, we observe proxies  $\{\tilde{H}_{Eds}, \tilde{H}_{Ros}\}$ . Here we explain the difference between these measures and the adjustments we make to get as close to the true values as possible.

### B.2.1 Scaling SISBEN resident counts to census resident counts, $s_o$

One of the main source of difference between our proxies and the true values is that our data is based on the SISBEN, which we know only surveys a fraction of the whole population in a neighborhood. Specifically, SISBEN only surveys a share, call it  $s_o$ , of the total residents in that neighborhood. This is, if  $H_{Ro}$  is the true number of residents in neighborhood  $o$ , we observe:

$$\tilde{H}_{Ro} = s_o H_{Ro}$$

We can estimate  $s_o$ , taking the ratio of the SISBEN residents and the Census at 2005.

### B.2.2 Estimating probability of criminals being captured by destination, $p_d$

$\tilde{H}_{Edc}$  is obtained from the arrest data which tells us the number of captured criminals by destination.  $\tilde{H}_{Edc} \neq H_{Edc}$  because we observe captured criminals instead of total crimes happening at a destination. Theoretically:

$$\tilde{H}_{Edc} = H_{Edc} \times p_d$$

where  $p_{dc}$  is the probability of getting caught. Using a proxy for  $p_{dc}$ , we can then obtain

$$H_{Edc} = \frac{\tilde{H}_{Edc}}{p_d}$$

We compute  $p_d$  as the ratio between captured individuals and crimes committed at neighborhood  $d$  from 2003 to 2015. Crimes committed are obtained from the Colombian police records of homicides and property crimes.



### B.2.3 Scaling crime to get the total number of criminals by origin, $H_{Roc}$

$\tilde{H}_{Roc}$  is obtained by matching the arrest data with the SISBEN.  $\tilde{H}_{Roc} \neq H_{Roc}$  because of the following. We know that:

$$H_{Roc} = H_{Roc}^{Sisben} + H_{Roc}^{Other}$$

We can reasonably assume that  $H_{Roc}^{Other} \approx 0$ , because SISBEN captures the 70% poorest households, which are more likely to participate in crime.

$$H_{Roc} = H_{Roc}^{Sisben}$$

By definition:

$$H_{Roc}^{Sisben} = \sum_d H_{Eodc}^{Sisben}$$

we don't observe the true SISBEN flows  $H_{Eodc}^{Sisben}$  because some criminals are not captured. We observe  $\tilde{H}_{Eodc}^{Sisben}$ . The most general specification would be:

$$\tilde{H}_{Eodc}^{Sisben} = H_{Eodc}^{Sisben} p_{od}$$

where  $p_{od}$  is the probability of being captured in that  $od$  pair. If, as we are assuming in the rest of the paper  $p_{od} = p_d \quad \forall o$ , then we are golden and we can recover true flows as:

$$H_{Eodc}^{Sisben} = \frac{\tilde{H}_{Eodc}^{Sisben}}{p_d}$$

and thus:

$$H_{Roc} = \sum_d \frac{\tilde{H}_{Eodc}^{Sisben}}{p_d}$$

### B.2.4 Scaling legitimate workers to get the total number of workers by origin, $H_{Rol}$

Assuming that  $H_{Ro} = H_{Roc} + H_{Rol}$ :

$$\begin{aligned}\tilde{H}_{Ro} &= s_o H_{Ro} \\ &= s_o (H_{Roc} + H_{Rol})\end{aligned}$$

by the previous discussion, we can obtain  $H_{Roc} = \sum_d \frac{\tilde{H}_{Eodc}^{Sisben}}{p_d}$ , and hence obtain:

$$H_{Rol} = \frac{\tilde{H}_{Ro}}{s_o} - H_{Roc}$$

where we are proxying for  $s_o$  using the share of total population in the Census that we capture with our data, so everything in the right hand side is observed.

From SISBEN we know the share of informal workers by origin,  $i_o$ . Then, we compute  $H_{Roi} = H_{Rol} i_o$  and  $H_{Rof} = H_{Rol} (1 - i_o)$ .

### B.2.5 Scaling formal or informal workers to get the total number of formal or informal by destination

Formal workers flows origin-destination,  $H_{Eodf}$ , is obtained by matching the PILA data with SISBEN. Then  $H_{Edf} = \sum_o H_{Eodf}$ .

Informal workers flows origin-destination,  $H_{Eodi}$ , is obtained assuming the same share of formal workers flows. Then  $H_{Edi} = \sum_o \left( \frac{H_{Eodf}}{H_{Rof}} \right) H_{Roi}$ .

### B.2.6 Adjusting for if origin vs. destination sector totals do not match

Finally, the total number of residents and workers within sectors, even after these adjustments, will not necessarily match. Suppose after all the adjustments we find that

$$\sum_o H_{Ros} < \sum_d H_{Eds}$$

We then do the following final adjustment:

$$H'_{Ros} = \left( \frac{\sum_d H_{Eds}}{\sum_o H_{Ros}} \right) H_{Ros}$$

which clearly implies  $\sum_o H'_{Ros} = \sum_d H_{Eds}$

Now, Suppose after all the adjustments we find that

$$\sum_o H_{Ros} > \sum_d H_{Eds}$$

We then do the following final adjustment:

$$H'_{Rds} = \left( \frac{\sum_d H_{Eds}}{\sum_o H_{Rds}} \right) H_{Rds}$$

which clearly implies  $\sum_d H'_{Rds} = \sum_o H_{Eds}$

### B.3 Constructing Commute Times

In this section we describe how we compute commute times for the public transport for Medellín. Travel times were computed using the Network analysis tool from Arcmap. For most of the transportation modes we use data from the city's government.<sup>22</sup> We obtain private vehicle speed levels by street from OpenStreetMap. We additionally set the regular bus speed by an optimization process where we minimize the distance of our travel times and the Google's times. The parameters of our network can be summarized on the next table.

Table B.1: Spatial Network Calibration

Transport parameters	speed
Train lines	40km/h
Tram	16km/h
Aerial cable	18km/h
Metroplus bus	16km/h
Regular bus	16km/h
Walking speed	5km/h
Train station stop time	15s
Bus station stop time	30s

For private transport (motorbikes and cars) we used the Microsoft Bing API in real time since we were not using counterfactuals for private transport, we computed the private transport travel times between 7am and 10am which covers the rush hour in the city.

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<sup>22</sup>The speed parameters for the metro system can be found here [https://www.metrodemedellin.gov.co/Portals/3/Images/Contenido/REVISTAS-OTROS/2014\\_nuestro-metro.pdf](https://www.metrodemedellin.gov.co/Portals/3/Images/Contenido/REVISTAS-OTROS/2014_nuestro-metro.pdf)

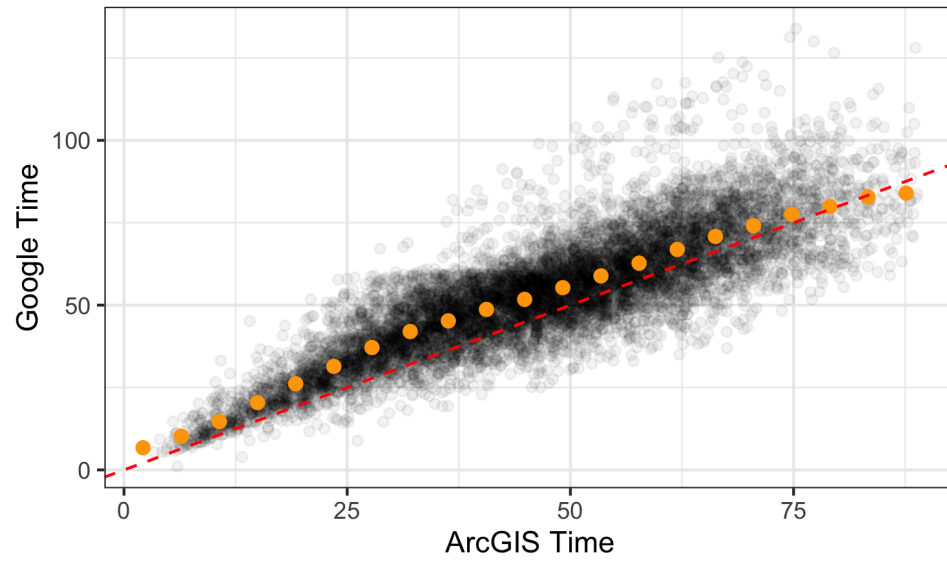
As robustness for our commuting times we compare our results with the Google maps API for public transport, we run a linear regression using a random sample of 10263 trips between different neighborhoods obtaining an R-squared of 0.72, the results of the regression are represented on the next table:

Table B.2: ArcGis Time vs Google Time for public transport

	<i>Dependent variable:</i>
	Time Google
Time ArcGIS	0.906*** (0.006)
Constant	10.653*** (0.282)
Observations	10,263
R <sup>2</sup>	0.715
Adjusted R <sup>2</sup>	0.715
Residual Std. Error	9.854 (df = 10261)
F Statistic	25,686.790*** (df = 1; 10261)
<i>Note:</i>	*p<0.1; **p<0.05; ***p<0.01

Total public minutes represents the travel times for public transport using ArcGIS and Time represents travel times for public transport using the Google API. Ideally, one would expect the slope to be very close to one as it is our case. The following figure shows a binned scatter plot of these variables:

Figure B.1: Comparing Google-based and ArcGIS Commute Times (public transport)



Note: This figure compares travel times using the Google Api vs travel times using the ArcGIS network.  
The red line is the best fit line and the blue line is a 45 degrees line.

## C Additional Reduced-form Relationships

### C.1 Travel Time and Net Effects Across Lines

The time to a cable station  $Minutes\ to\ Station_{ot}$  changes as and when new stations and lines are built. Such a method conveniently allows us to summarize the consequences of simultaneous different changes to parts of the transit network, and leverage information on actual travel times which more closely relates to transit costs:

$$Log(Crimes)_{ot} = \gamma_t + \gamma_o + \beta_3 Minutes\ to\ Station_{ot} + \epsilon_{3ot} \quad (29)$$

Here, the identification of  $\beta_3$  comes only from changes over time in the travel-time to the closest station, as and when new lines are built, once again conditional on neighborhood and time fixed effects. The first column of Table C.1 shows that, on net, origins that see a reduction in travel time to the closest station see a reduction in criminal activity. As such, if ones residence is now closer to a new station, they are less likely to engage in crime. The second column of Table C.1 performs a similar exercise, but at the destination level, and speaks a similar narrative: even destinations of criminal activity fall when travel time to the closest stations reduce as a consequence of new lines being built.

Table C.1: The Effects of Travel Time to Station

Travel Time To Station	In Origin Any Crime	In Destination Any Crime	In Origin Any Crime	In Destination Any Crime
Minutes to Station	0.00183** (0.000915)	0.00519* (0.00268)	0.00192* (0.00108)	0.00537** (0.00274)
Observations	3,192	3,486	794,808	794,808
Data Structure	Orig-Time	Dest-Time	Origin-Dest-Time	
Destination Fixed Effects	No	Yes	Yes	Yes
Origin Fixed Effects	Yes	No	Yes	Yes
Origin-Destination Distance	No	No	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
SE Cluster	Origin	Dest	2-way: Orig Dest	

Notes: Tables show the effect of changes in travel time to the closest station (in minutes) as a result of newly built stations. The first and third column show changes in origins of crime perpetrators, whereas the second and last column show the (destination) location of the crime committed. In the final two columns the data are structured at the origin-by-destination-by-time level.

Finally, in the last two columns, we again leverage the larger dimensionality of the data, with a specification at the  $o - d - t$  level:

$$\text{Log}(\text{Crimes})_{odt} = \gamma_t + \gamma_o + \gamma_d + \Xi_{od} + \beta_{3'} \text{Minutes to Station}_{ot} + \epsilon_{3'odt} \quad (30)$$

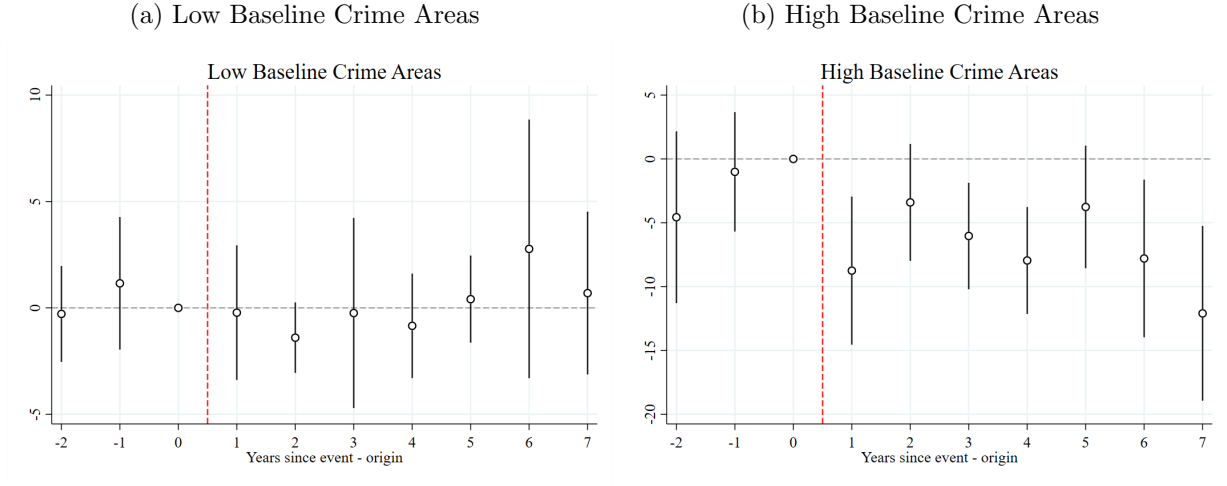
Connecting either origins or destinations to stations, on net, across the different lines, lower the likelihood of being engaged in criminal activity.

## C.2 Event Study Analyses

In documenting the dynamics of the responses, by different types of crime and different types of baseline features of the neighborhoods, we can conduct an event study style analysis, where we pool the different cable lines, and compare crime outcomes both before and after the cable was opened, relative to the year it was opened. The years before allow us to test for pre-trends in our outcomes, whereas the years after document the dynamics of the changing relationship. A lack of pre-trends provides confidence to our empirical strategy.

We rely on Figure 5 and define ‘treated’ neighborhoods as those between 0 and 1km from the new station, and ‘control’ neighborhoods as those between 1 and 2km from the new station. We expect these stations to be similar in other respects, and so drop all neighborhoods that are further away for this exercise. The treated year is the base period.

Figure C.1: Changes in Non-Drug Crime at the Origin by Baseline Crime



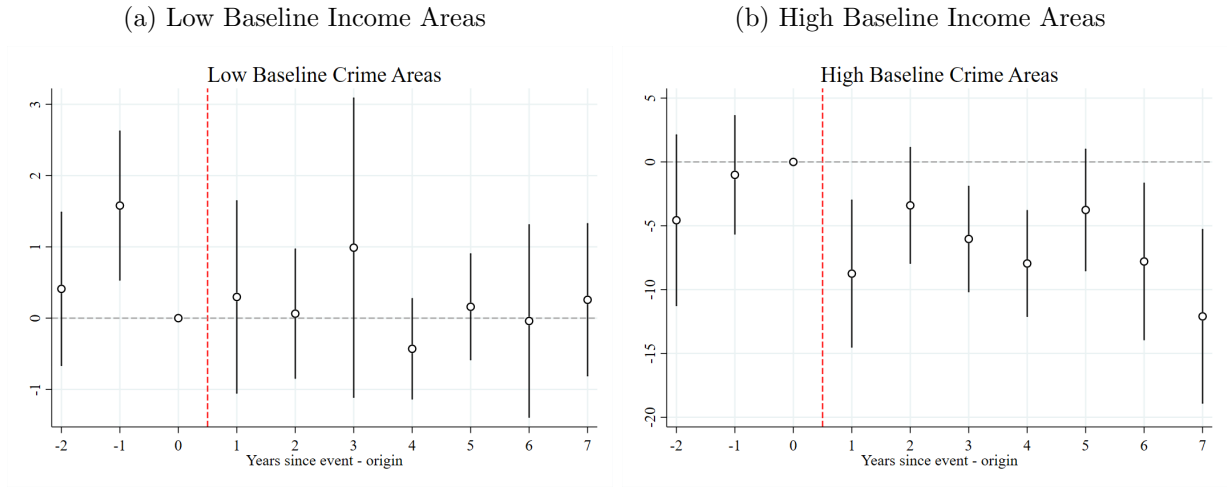
Notes: Figures show event study plots of the change in non-drug related crime over time as a function of being 0 to 1km from a new station. Control neighborhoods are 1-2km from the station. The left panel restricts the sample to neighborhoods that have below median baseline crime rates, whereas the right panel is for above median baseline crime rates.

In Figure C.1, we examine the effects on non-drug crimes, by splitting the sample by baseline criminal activity. In low baseline crime neighborhoods, there are no detectable effects, but in areas that had high criminal activity at baseline, there are sharp drops in non-drug crime related activity, once again documenting the importance of the heterogeneity across neighborhoods in their baseline economic structure.

In Figure C.2, we conduct a similar exercise, now exploring an additional dimension of heterogeneity – that of different types of crime. We change the type of crime to be violent crime, and find a similar pattern that we found in Figure C.1 on non-drug crimes: that the effects are concentrated in neighborhoods that had high baseline criminal activity.



Figure C.2: Changes in Violent Crime at the Origin by Baseline Income

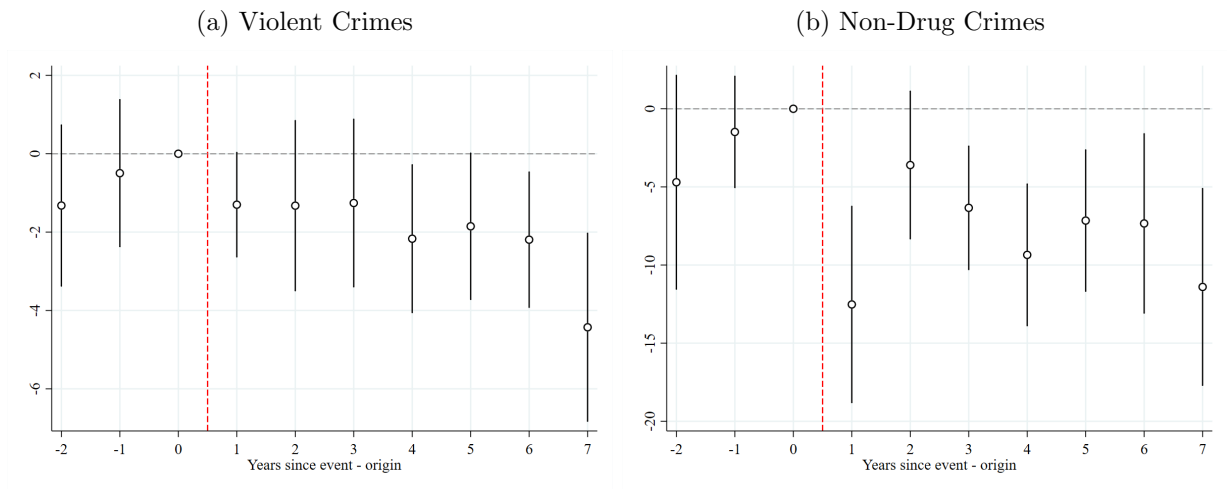


Notes: Figures show event study plots of the change in violent crime over time as a function of being 0 to 1km from a new station. Control neighborhoods are 1-2km from the station. The left panel restricts the sample to neighborhoods that have below median baseline crime rates, whereas the right panel is for above median baseline crime rates.

Finally in Figure C.3, we restrict our sample to only low income neighborhoods, and compare the differences in magnitudes between the violent and the non-drug crimes. The effects on non-drug crimes are a lot larger than the effects on just violent crime.

Together, these results show a lack of pre-trends leading up to the changes in the establishment of new cable lines, and interesting dynamics following the establishment of cables. Finally, they also confirm the meaningful heterogeneity by baseline access to criminal and economic opportunity.

Figure C.3: Changes in Crime at the Origin by Type of Crime



Notes: Figures show event study plots of the change in crime over time as a function of being 0 to 1km from a new station. Control neighborhoods are 1-2km from the station. Sample is restricted to low income neighborhoods.

## D Model Equilibrium and Comparative Statics

In this section, we show that the equilibrium of our model can be characterized by  $3N$  equations (or three equations per neighborhood). We also show in which special cases there exists a unique solution. Finally, by taking  $N = 2$  neighborhoods, we simulate the equilibrium for a family of parameters.

### D.1 General Equilibrium

Given the model parameters  $\{\kappa, \theta_f, \theta_c, \eta, \beta, \alpha, \mu, \delta, \lambda, \iota, \rho, \omega\}$ , the exogenous location characteristics  $\{\mathbf{B}_o, \mathbf{B}_{oc}, \mathbf{b}_{of}, \boldsymbol{\varphi}, \mathbf{A}_c, \mathbf{K}, \boldsymbol{\xi}, \boldsymbol{\tau}, \mathbf{p}_d\}$  and the reservation utility in the wider economy  $\bar{U}$ , the general equilibrium of the model is given by the set of vectors:

$\{\mathbf{w}_f, \mathbf{w}_c, \boldsymbol{\theta}, \mathbf{q}, \mathbf{Q}, \boldsymbol{\pi}, \mathbf{A}_f, \mathbf{B}_f\}$ . In the following proposition, we show that  $3N$  equations characterize the values of  $\{\mathbf{Q}, \mathbf{w}_c, \mathbf{A}_f\}$ . The other vectors  $\{\mathbf{w}_f, \boldsymbol{\theta}, \mathbf{q}, \boldsymbol{\pi}, \mathbf{B}_f\}$  can be written in terms of  $\{\mathbf{Q}, \mathbf{w}_c, \mathbf{A}_f\}$ , the model parameters and the exogenous location characteristics.

**Proposition 1.** For  $o \in \{1, \dots, N\}$ , suppose that  $q_o = \xi_o Q_o$ . Then,  $\{Q_o, w_{oc}, A_{of}\}_{o \in \mathcal{N}}$  are implicitly determined by the following system of equations

$$\begin{aligned} L_o &= \left( \frac{(1 - \alpha) A_{of}}{\xi_o Q_o} \right)^{1/\alpha} H_{Eof} + \frac{(1 - \alpha)}{Q_o} E[w|o] H_{Ro}, \\ w_{oc} &= (1 - p_o) A_{oc} H_{Eoc}^\rho H_{Eof}^\iota, \\ A_{of} &= a_{of} \left( \frac{H_{Eoc}}{L_o} \right)^\lambda. \end{aligned} \tag{31}$$

The variables  $H_{Mof}$ ,  $H_{Eoc}$ ,  $H_{Ro}$ ,  $E[w|o]$ , and  $B_{of}$  can be expressed as functions of  $\{Q_o, w_{oc}, A_{of}\}_{o \in \mathcal{N}}$ .

Proposition 1 says that the general equilibrium can be characterized by the following three set of equations: (i) the residential and commercial land market clearing conditions; (ii) the endogenous return to crime; (iii) the endogenous productivities in the formal sector.

*Proof of Proposition 1.* First notice that the variables  $H_{Eof}$ ,  $H_{Eoc}$ ,  $H_{Ro}$ ,  $E[w|o]$ , and  $B_{of}$  are given by  $H_{Ro} = \bar{H} \sum_d \sum_s \pi_{ods}$ ,  $H_{Edl} = \bar{H} \sum_o \pi_{odf}$ ,  $H_{Edc} = \bar{H} \sum_o \pi_{odc}$ ,  $E[w|o] = \sum_{ds} \pi_{ds|o} w_{ds}$ , and  $B_{of} = B_{oc} b_{of} \left( \frac{H_{Eoc}}{L_o} \right)^\omega$ . From (7), it follows that

$$\begin{aligned}
H_{Ro} &= B_o Q_o^{-(1-\alpha)\eta} W_o^\eta, \\
H_{Ed\ell} &= \sum_o \frac{H_{Ro} B_{of} W_{of|o}^{\kappa-\theta_f} w_{d\ell}^{\theta_f} \tau_{od}^{-\theta_f}}{W B_o}, \\
H_{Edc} &= \sum_o \frac{H_{Ro} B_{oc} W_{oc|o}^{\kappa-\theta_c} w_{dc}^{\theta_c} \tau_{od}^{-\theta_c}}{W B_o}, \\
E[w|o] &= \frac{1}{W B_o} \sum_s B_{os} W_{os|o}^{\kappa-\theta_s} \sum_d (w_{ds}^{\theta_s+1} \tau_{od}^{-\theta_s}), \\
B_{of} &= B_{oc} b_{of} \left( \frac{A_{of}}{a_{of}} \right)^{\omega/\lambda}.
\end{aligned} \tag{32}$$

Here,  $W_o^\eta = \left( \sum_s W_{os|o}^\kappa \right)^\frac{\eta}{\kappa}$ ,  $W_{os|o}^\kappa = \left( \sum_d w_{ds}^{\theta_s} \tau_{od}^{-\theta_s} \right)^\frac{\kappa}{\theta_s}$ ,  $W B_o = \sum_{s'} B_{os'} W_{os'|o}^\kappa$ ,

$$w_{d\ell} = \alpha \left[ (1-\alpha)^{(1-\alpha)} \frac{A_{d\ell}}{(\xi_d Q_d)^{(1-\alpha)}} \right]^{1/\alpha}, \tag{33}$$

and  $\overline{H} \left( \frac{\gamma}{\theta} \right)^\eta = 1$ . As a result, the system of equations given by (31) is a nonlinear system of equations of the variables  $\{Q_o, w_{oc}, A_{of}\}_{o \in \mathcal{N}}$ .

□

**Corollary 1.** Suppose that  $\omega \rightarrow 0$  and  $\lambda \rightarrow 0$ , then there is a unique equilibrium  $\{\mathbf{w}_f, \mathbf{w}_c, \boldsymbol{\theta}, \mathbf{q}, \mathbf{Q}, \boldsymbol{\pi}\}$ , where the crime productivities and residential amenities from the legitimate sector are exogenously given by  $\mathbf{A}_f = \mathbf{a}_f$  and  $\mathbf{B}_f = \mathbf{b}_f$ , respectively.

The proof of the above corollary follows from Lemma S.1, Lemma S.2 and Proposition S.1 in the supplementary material from Ahlfeldt et al. (2015). Note that as  $\omega \rightarrow 0$  and  $\lambda \rightarrow 0$ , the endogenous crime productivities ( $\mathbf{A}_f$ ) and endogenous residential amenities from the legitimate sector ( $\mathbf{B}_f$ ) become exogenous variables. Thus, from (31), we are left with a model in which solving for  $\mathbf{Q}$  is enough to characterize the equilibrium. This is what Proposition 1 from Ahlfeldt et al. (2015) shows, that there is a unique  $\mathbf{Q}$ , from which the other variables of the model can be determined.

## D.2 Comparative Statics with Two Neighborhoods

To understand when reductions in transportation costs  $\tau_{od}$  will import opportunities and when it would export crime, we examine the roles played by our main parameters of interest: the sector choice parameter  $\kappa$ , the spillover externality  $\lambda$ , and transportation

elasticities  $\theta_s$ . We examine whether residents of a location  $H_{Roc}$  engage in less crime (import opportunity), or commit more crimes in other neighborhoods  $H_{Eoc}$  (export crime) in a simple two neighborhood case in which neighborhood one has more criminal residents at baseline, and neighborhood 2 is a productive legitimate downtown with a lot of legitimate employment. We study how sectoral choice and location decisions change as we connect these two neighborhoods through improvements in the transportation network.

Specifically, we take  $N = 2$ , and for these two neighborhoods, we solve the system given by (31). Then, we find the general equilibrium for certain fixed parameters, and present a simulation for the equilibrium values of  $\{H_{Eoc}, H_{Roc}\}_{o \in \mathcal{N}}$  as functions of the transportation cost  $\tau_{12}$ .

We set the parameters of the model to be  $\alpha = 0.5$ ,  $\eta = 1.124$ ,  $\rho = -0.5$ ,  $\iota = 0.5$ ,  $\tau_{11} = \tau_{21} = \tau_{22} = 1$ ,  $p_1 = p_2 = 0.5$ , and  $\xi_1 = \xi_2 = 1$ . The exogenous location characteristics are  $B_{1c} = 4$ ,  $B_{2c} = b_{1f} = b_{2f} = 1$ ,  $B_1 = B_2 = 1$ ,  $A_{1c} = A_{2c} = a_{1f} = 1$ ,  $a_{2f} = 4$ , and  $L_1 = L_2 = 0.1$ . As previously mentioned, the choices of these values are motivated by a baseline scenario in which neighborhood 1 has a lot of crime residents given its large criminal amenity fundamental  $B_{1c}$ , while neighborhood 2 is a productive downtown with large fundamental productivity  $a_{2f} = 4$ .

Figures D.1-D.4 show the graphs of  $\{H_{Eoc}, H_{Roc}\}_{o \in \mathcal{N}}$  as functions of the transportation cost  $\tau_{12}$ , and for different values of  $\{\kappa, \lambda, \theta_c, \theta_f\}$ . Recall that  $H_{Roc}$  represents the equilibrium residential population living in neighborhood  $o$  working in the crime sector, and  $H_{Edc}$  represents the equilibrium labor supplied to destination  $d$  in the crime sector.

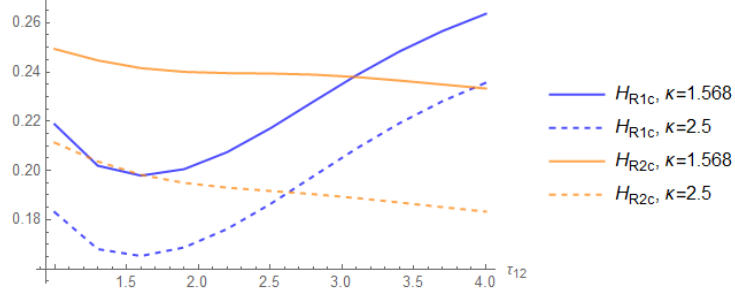
Figure D.1(a) shows the graph of  $H_{Roc}$  for different values of  $\kappa$ . Recall that  $\kappa$  captures the relative labor supply elasticity across sectors: a large  $\kappa$  means that individuals tend to easily switch sectors as relative returns change. As expected, when  $\tau$  is large and, hence, neighborhoods are disconnected, there are more criminals living in neighborhood 1. As we connect this neighborhood to downtown by reducing  $\tau_{12}$ , individuals tend to switch to the legitimate sector as opportunity is imported. Importantly, this comparative static depends on  $\kappa$ : the larger is  $\kappa$ , the more individuals will switch towards legitimate employment as the relative returns of legitimate work increases when they are connected to productive downtown.

A decrease in  $\lambda$  (from  $\lambda = 0$  to  $\lambda = -0.147$ ), meaning larger negative externalities from crime on legitimate productivity, shifts  $H_{Roc}$  upward for both neighborhoods (see Figure D.2(a)). This is due to the fact that, with a large negative externality of crime on legitimate workers, the relative returns of legitimate work relative to crime work will not increase as much given that with some exporting of crime overall productivity in downtown, and hence wages, will be lower given that some criminals will find it profitable

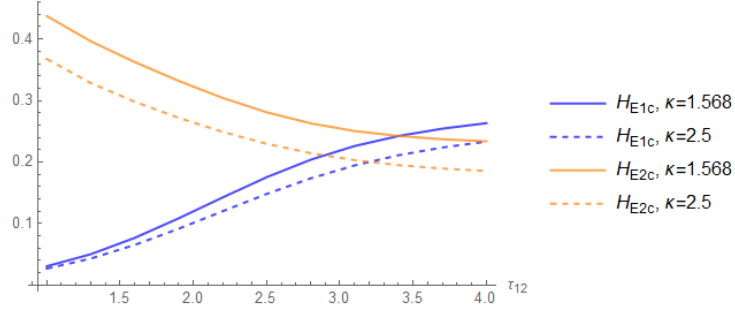
to commit crime there.

Finally, we explore the effect of an increase in the value of  $\theta_f$  (from  $\theta_f = 3$  to  $\theta_f = 6$ ) over  $H_{Roc}$ . This parameter captures the sensitivity of legitimate workers to commute times. A large  $\theta_f$  implies that changes in commute costs will have a large impact on legitimate workers' location decisions. Note that this larger sensitivity to commute costs generates a larger sectoral shift from crime towards legitimate work in neighborhood one. A similar behavior can be observed as  $\theta_c$  changes (see Figure D.4(a)).

On the other hand, Figure D.1(b) shows the graph of  $H_{Edc}$ , which measures the number of criminal workers in a neighborhood, for different values of  $\kappa$ . An increase in  $\kappa$  shifts  $H_{Edc}$  downward for both neighborhoods, again, because it allows for larger sectoral changes and hence more importing of opportunity and more legitimate workers in the city overall. A decrease in  $\lambda$  (from  $\lambda = 0$  to  $\lambda = -0.147$ ) shifts  $H_{Edc}$  upward for both neighborhoods (see Figure D.2(b)) since larger negative externalities of crime imply that legitimate returns will be lower in the city overall and hence there will be smaller sectoral shifts toward that sector.

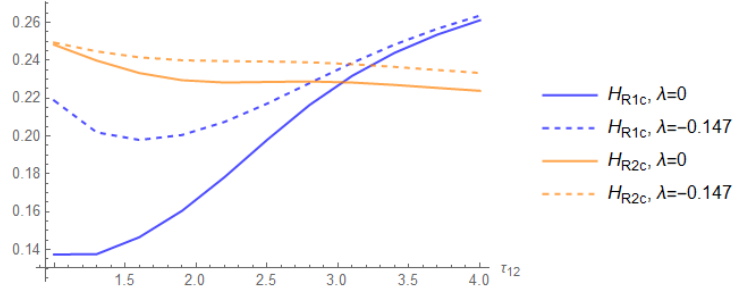


(c)  $H_{Roc}$  for neighborhoods 1 and 2, and two different values of  $\kappa$ . For this graph  $\{\lambda, \theta_c, \theta_f\} = \{-0.2, 3, 7.01\}$ .

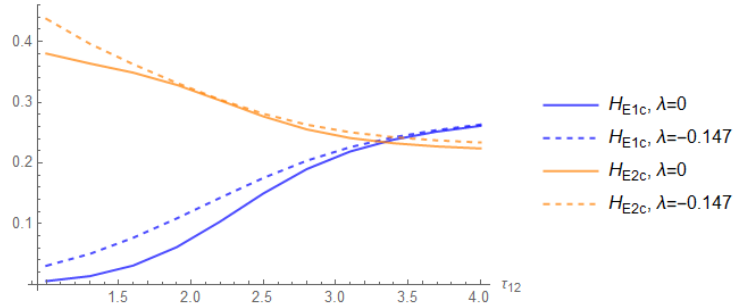


(d)  $H_{Edc}$  for neighborhoods 1 and 2, and two different values of  $\kappa$ . For this graph  $\{\lambda, \theta_c, \theta_f\} = \{-0.2, 3, 7.01\}$ .

Figure D.1:  $H_{Roc}$  and  $H_{Edc}$  as functions of  $\tau_{12}$ , changing  $\kappa$ .

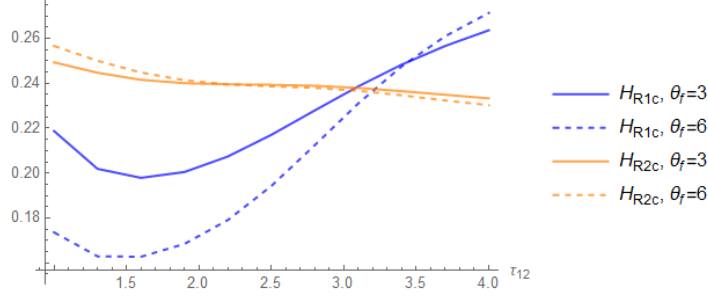


(a)  $H_{Roc}$  for neighborhoods 1 and 2, and two different values of  $\lambda$ . For this graph  $\{\kappa, \theta_c, \theta_f\} = \{1.568, 3, 7.01\}$ .

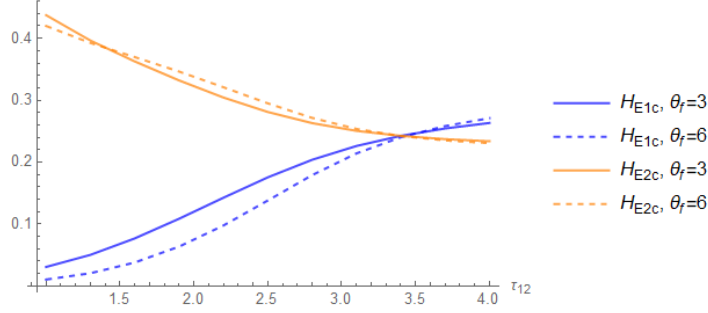


(b)  $H_{Edc}$  for neighborhoods 1 and 2, and two different values of  $\lambda$ . For this graph  $\{\kappa, \theta_c, \theta_f\} = \{1.568, 3, 7.01\}$ .

Figure D.2:  $H_{Roc}$  and  $H_{Edc}$  as functions of  $\tau_{12}$ , changing  $\lambda$ .

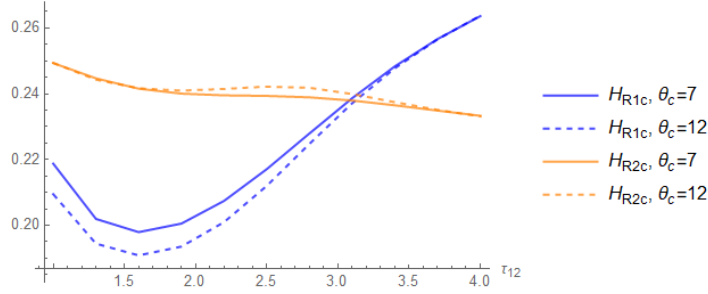


(a)  $H_{Roc}$  for neighborhoods 1 and 2, and two different values of  $\theta_f$ . For this graph  $\{\lambda, \theta_c, \kappa\} = \{-0.2, 3, 1.568\}$ .

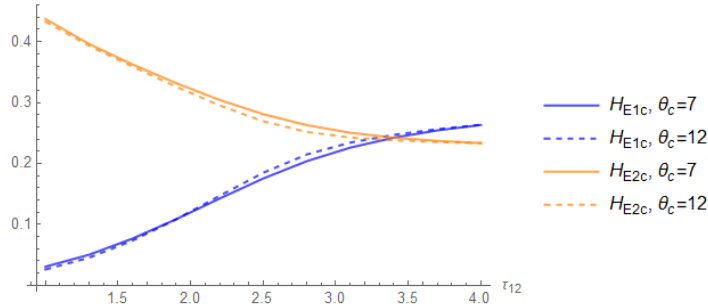


(b)  $H_{Edc}$  for neighborhoods 1 and 2, and two different values of  $\theta_f$ . For this graph  $\{\lambda, \theta_c, \kappa\} = \{-0.2, 3, 1.568\}$ .

Figure D.3:  $H_{Roc}$  and  $H_{Edc}$  as functions of  $\tau_{12}$ , changing  $\theta_f$ .



(a)  $H_{Roc}$  for neighborhoods 1 and 2, and two different values of  $\theta_c$ . For this graph  $\{\lambda, \kappa, \theta_f\} = \{-0.2, 1.568, 7.01\}$ .



(b)  $H_{Edc}$  for neighborhoods 1 and 2, and two different values of  $\theta_c$ . For this graph  $\{\lambda, \kappa, \theta_f\} = \{-0.2, 1.568, 7.01\}$ .

Figure D.4:  $H_{Roc}$  and  $H_{Edc}$  as functions of  $\tau_{12}$ , changing  $\theta_c$ .