The Effects of Roads on Trade and Migration: Evidence from a Planned Capital City *

Melanie Morten †
Stanford University and NBER

Jaqueline Oliveira ‡
Rhodes College

December 5, 2016

Abstract

A large body of literature studies how infrastructure facilitates the movement of traded goods. We ask whether infrastructure also facilitates the movement of labor. We use a general equilibrium trade model and rich spatial data to explore the impact of a large plausibly exogenous shock to highways in Brazil on both goods markets and labor markets. We find that the road improvement increased welfare by 10.8%, of which 91% was due to reduced trade costs and 9% to reduced migration costs. Nevertheless, costly migration is responsible for large spatial heterogeneity in the benefits of roads: the interquartile range of welfare improvement is 5%-29%, as opposed to uniform gains with perfect mobility.

Keywords: Internal migration, Brazil, Infrastructure, Roads
JEL Classification: J61, O18, O54

*We thank Treb Allen, Marcella Alsan, Ana Barufi, Gharad Bryan, Kate Casey, Arun Chandrasekhar, Rafael Dix-Carneiro, Dave Donaldson, Taryn Dinkelman, Pascaline Dupas, Fred Finan, Doireann Fitzgerald, Paul Gertler, Doug Gollin, Saum Jha, Brian Kovak, Kyle Mangum, Ana Minian, Mushfiq Mobarak, David McKenzie, Paula Pereda, Nancy Qian, Steve Redding, Mark Rosenzweig and Sam Schulhofer-Wohl for discussions; and seminar participants at the 36th Meeting of the Brazilian Econometrics Society, Emory University, Harvard/MIT Development Workshop, 2014 NBER Summer Institute, 7th Migration and Development Conference, University of Calgary, WUSTL, Clemson University, University of Los Andes, University of Sao Paulo, Oxford University, University of Houston, UCL/LSE, Duke University, University of Memphis, IIES, and 2016 Lacea/Lames for helpful comments. Anita Bhide, Caue Dobbin and Devika Lakhote provided excellent research assistance. Part of this work was completed while Morten was a visiting scholar at the Federal Reserve Bank of Minneapolis and their hospitality is greatly acknowledged. This paper is a heavily revised version of an earlier version of the paper, "Paving the way to development: costly migration and labor market integration," which also circulated as "Migration, roads and labor market integration: Evidence from a planned capital city." Any errors are our own.

†Email: memorten@stanford.edu

‡Email: oliveiraj@rhodes.edu

1 Introduction

What is the welfare benefit of improving road infrastructure? A large body of literature has focused on the role of infrastructure in facilitating the movement of goods across space. In this paper we ask whether roads also facilitate labor migration and hence generate an additional channel for welfare gains through increased labor market integration.

We use a general equilibrium trade model and rich spatial data to explore the impact that the construction of new highways in Brazil had on both goods markets and factor markets. We focus on Brazil because, in 1960, it adopted Brasilia as its new capital city, which led to the construction of a national road highway system to connect Brasilia with the state capitals. We use this large shock to trace the effect of simultaneous decreases in both trade costs and migration costs.

We first show that when two states became more directly connected by roads they saw larger increases in bilateral trade and migration than states that did not become connected by the new roads. We next quantify the benefit of this increased market integration. To do so, we need to account for the fact that roads directly affected wages and prices as well as the costs of migrating and trading goods. We take a standard model of costly trade across space (Eaton and Kortum, 2002; Monte et al., 2015), and augment the migration decision to depend on preference shocks, as is standard, as well as origin-destination costs of migration.[1] In the model, agents optimally choose their location each period, paying a cost if they migrate. At the same time, locations specialize in production, based on the costs of importing goods from other locations. An improvement of the road network thus affects both the demand for, and supply of, labor.

Our model yields a standard gravity equation for trade flows and migration flows. We estimate migration costs using the observed migration decisions of 18 million individuals. We estimate trade costs using state-to-state flows of traded goods. The instrumental variable (IV) estimates yield an elasticity of migration to travel time between -1.3 and -2.3. For trade, we find an elasticity of trade flows to travel time between -5.8 and -8.3. We combine the migration costs estimates and trade costs estimates with estimates of the migration elasticity to wages and the housing elasticity to population. These last two elasticities are estimated from the data, using a Bartik IV strategy (Bartik, 1991; Di-

[1] The model we write down is closely related to Monte et al. (2015). That paper models origin-destination costs of commuting. Our model does not have commuting, but instead has origin-destination costs of migrating. Tombe and Zhu (2015) and Caliendo et al. (2015) also have models incorporating both trade and migration. Our contribution in this paper is to empirically quantify the relative effect of a large road expansion on trade and labor mobility, considered separately.

amond, 2016). We then solve the spatial equilibrium model by imposing balanced trade to estimate the unobserved productivities in each location that rationalize the observed wage distribution, rental costs, and population distribution.

Our paper then establishes three empirical results. First, we estimate that establishing Brasilia and connecting it to state capitals increased welfare by 10.8%. Of this increase, 91% was due to goods market integration and 9% due to labor market integration. Second, although the trade effect dominates, accounting for costly migration is needed to estimate the level of the welfare benefit correctly. We re-solve our model under the standard assumption that migration is subject only to preference shocks and find that the estimated welfare effect of the same road shock is 16% lower. Standard estimates understate the overall welfare gains from infrastructure by omitting the gains from labor market integration. Finally, we show that costly migration induces heterogeneity in the spatial distribution of welfare across space. In the model, the average meso region gains 20% from Brasilia. However, the interquartile range of gains is 5%-29%. This contrasts to a model without migration costs, where welfare is equalized across space. This last result has important implications for understanding the distributional impact of any spatially concentrated policy.

Our key contribution is to quantify the relative importance of roads on the goods market and the labor market. It is reasonable, of course, to ask whether a one-time migration cost, which may be small relative to the present value of a higher future income stream, will affect the decision to migrate. We think of migration costs broadly to include both the fiscal cost of moving and utility costs such as being away from friends and family (Sjaastad, 1962). For migrants who return home to visit friends and family after migrating, migration costs also capture the flow costs of such return visits (with both a fiscal component and a time component). Migration costs can also capture any costs of not being able to consume the same types of goods as at home.[2] Empirically, we use geocoded data on migration choices and show that people make migration decisions in a way that is consistent with it being more difficult to move to a place that is further away from the origin.

Our paper contributes to several bodies of literature. First, we focus on an additional channel, labor market integration, of improved infrastructure. A large literature has studied the role of infrastructure improvements on facilitating trade and improving economic development (Michaels, 2008; Banerjee et al., 2009; Faber, 2014; Ghani et al., 2014; Hor-

[2]For example, Atkin (2016) documents that internal migrants in India pay a "caloric tax" to keep eating the types of food they eat in their origin states that are less available in the destination state.

nung, 2014; Donaldson, 2016).[3] Jayachandran (2006) shows that road access is important for the labor market impacts of local productivity shocks. However, we know very little on the impacts of transport infrastructure on permanent migration and labor market integration. We provide empirical evidence that roads affect migration, and then decompose the net benefit of roads into their effects on the goods and factor markets, considered separately. This is important because any attempt to gauge the effects of roads on productivity needs also to take into account labor market reallocation.

Second, we illustrate why migration costs are important to include in general equilibrium models. The migration literature has found strong evidence, in partial equilibrium settings, of migration costs (Kennan and Walker, 2011; Bryan et al., 2014). Yet, due to data constraints, most of the spatial, urban, and trade literatures have assumed that the bilateral component of migration costs is zero (Moretti, 2011; Diamond, 2016; Allen and Arkolakis, 2014; Redding, 2015) or that labor is immobile across space (Donaldson, 2016; Topalova, 2010), although recent work has relaxed these assumptions (Tombe and Zhu, 2015; Caliendo et al., 2015; Mangum, 2015; Bryan and Morten, 2015). We show, by directly comparing estimates with and without the costs, that omitting origin-destination costs of migration biases the estimates of the elasticity of migration to wages, the net welfare effect of roads, and the spatial incidence of the welfare effects of roads.

Third, we contribute to a better understanding of the determinants of internal migration. Many studies have focused on the responsiveness of migration to economic returns (Sahota, 1968; Harris and Todaro, 1970; Pessino, 1991; Tunali, 2000). This literature focuses on a partial equilibrium analysis of migration decisions. We add to this literature by considering the responsiveness of migration to both costs and returns and by considering the general equilibrium effects of migration.[4]

Finally, our paper contributes to the literature on labor misallocation as a mechanism to explain underdevelopment in many developing countries. While the prior literature has looked at institutional barriers (Janvry et al., 2015) and insurance barriers (Banerjee and Newman, 1998; Munshi and Rosenzweig, 2015), we focus on travel time as a barrier: if it is costly to move out of low income locations, labor may not be able to move to its most productive locations. Our paper presents evidence that, while these migration

[3] Bird and Straub (2015) also use the construction of Brasilia as an instrument to study the effect of road construction on regional GDP. Their study focuses on the effect of roads on GDP and they do not examine the effect of roads on migration.

[4] Chein and Assuncao (2009) study the construction of a road in the North of Brazil as an instrument for migration to study the effect of migration on wages, but do not estimate the effect of roads on migration costs directly.

costs are in large part attributed to tastes, they can be considerably reduced by improving access to transportation infrastructure. This finding suggests there is a margin for policy makers to improve the allocation of labor across space.

The plan of the paper is as follows. We discuss the historical context which led to the construction of Brasilia and how we use this natural experiment to provide exogenous variation in the road network in Section 2. Based on the initial empirical results we present the structural model in Section 3 and our estimation strategy in Section 4. We then highlight the key decomposition of the effects of roads on goods and factor markets in Sections 5 and briefly conclude in Section 6.

2 State-to-state trade and migration, before and after Brasilia

During the first half of the twentieth century roads were nearly nonexistent in Brazil. The very few that existed were dirt or gravel roads and served a limited number of urban centers in the southeast. The construction of the new capital city—Brasilia—in the middle of the country was accompanied by the development of a new highway network to link the national capital to the other existing state capitals. Figure 1 shows the location of Brasilia in the epicenter of Brazil.

We start by considering how state-to-state flows of traded goods and of migration responded to the establishment of Brasilia. We source data on state-to-state trade and migration flows obtained from statistical yearbooks. Trade flow data correspond to the value of imports and are available annually, spanning the periods 1942-1949 and 1967-1974. Migration flow data refer to the total number of people in each state who originated from other states. These data are available decennially from 1940 to 1980. We fully describe the data in Appendix B.2.

We use a standard gravity equation to estimate the elasticity of trade/migration flows between origin k and destination n after controlling for origin-year, α_{kt}, and destination-year fixed effects, α_{nt},

$$\log X_{knt} = \alpha_{kt} + \alpha_{nt} + \beta_t \log \text{distance}_{knt} + \epsilon_{knt}.$$

Figure 2a plots β_t by year. The elasticity of trade flows to distance (measured as Euclidean distance in km) is between -3.5 and -2.5; the elasticity of migration flows to distance is between -2.5 to -1.5. In the years after Brasilia, trade and population were less dependent on geography, consistent with the notion that roads promote market integration by

lowering trade and migration barriers.

Before the capital was moved to Brasilia, Brazil's population was concentrated along the coast. The few existing roads ran near the coastline and did not cross into the interior part of the country. Brasilia was built in the interior state of Goias, which then become the epicenter of the new road network. As a result, Goias went from being very poorly connected to the rest of Brazil to being very well connected. We first look to see whether the elasticity of the flows of goods and population with respect to distance responded disproportionately for traffic flow between Goias and other states as compared to that between other states excluding Goias. Figure 2b plots the β_t coefficient estimated separately for pairs that involve Goias and for all other pairs. Pairs involving Goias initially had a larger coefficient on distance than non-Goias pairs, since it is more difficult to travel one kilometer in an area with very few roads. The gap in elasticity between Goias and non-Goias pairs narrowed (in fact, closed) after Brasilia. This is consistent with the lower cost of traveling one kilometer as a result of the increased availability of roads in the area.[5]

Given this result, we know turn to estimating a more precise effect of the road network on trade and migration by using the actual road network. Our goal is to estimate the following gravity equation

$$\log X_{knt} = \alpha_{kt} + \alpha_{nt} + \alpha_{kn} + \beta \log \text{road travel time}_{knt} + \epsilon_{knt}, \tag{1}$$

where X_{knt} is the value of imports at destination n from origin k in year t (or for migration, the share of the population in state n in year t who were born in state k). α_{kt} is an origin-year fixed effect, α_{nt} is a destination-year fixed effect, α_{kn} is a pair fixed effect, $\log \text{road travel time}_{knt}$ is the travel time on the road network between origin k and destination n in year t, and ϵ_{knt} is an independent and identically distributied (i.i.d.) error term. The pair fixed effect, α_{kn}, controls for unobservable attributes of the origin-destination pairs that could favor the movement of goods and workers between them, such as the Euclidean distance or cultural and socioeconomic proximity.

Ordinary Least Squares (OLS) estimates of Equation 1 are biased if road connectivity is correlated with time-varying origin-destination attributes. This might occur if, for example, roads are placed between two localities with lower propensity to trade or with less movement of people. In this case, OLS will be upward biased and yield smaller esti-

[5]The point estimates of the elasticity of trade to distance suggest that the reduction is larger between "treated" (Goias) pairs, although the large standard errors associated with these estimates do not allow us to conclude that the differences between treated and control pairs are significant.

mated elasticities. On the other hand, if roads are intended to connect places with higher propensity to trade or more population movement, OLS will overstate the elasticities. We harness exogenous variation in access to road network generated by the relocation of Brazil's capital city in 1956 to obtain a consistent estimate of β. We explain the identification in detail in the next section.

2.1 Instrument for bilateral travel time: Brasilia

To generate an instrument for travel time we use plausibly exogenous variation in the location of highways in Brazil generated by the construction of a planned capital city, Brasilia. Brasilia was constructed in 1960 in response to the long-standing issue of finding the ideal location for the country's capital city.[6] We argue that it is the timing, not the location, of Brasilia that was a shock. After lying dormant for 50 years, the interest in Brasilia was renewed for political reasons, and once started, the city was constructed very quickly. We provide supporting evidence showing that a host of pre-Brasilia variables are uncorrelated with future road access.

2.1.1 Selection of the new capital city

Brazil was declared a republic in 1889. The first Constitution in 1891 established the site for the eventual capital city. In 1922, the National Congress approved the creation of the new capital within a site that was then called *Quadrilatero Cruls*, a 160 x 90 kilometer rectangle located in the Central Upland (*Planalto Central*) close to the border between the states of Goias and Minas Gerais.[7] This area would eventually become Brasilia. The transfer of the national capital to the interior was delayed during the administration of Getulio Vargas (1930-1946), but it resumed in 1947, when Eurico Dutra became president and new debates over the site and construction of the new capital arose. Finally, in 1955, based on previous reports, the recently created Commission for the New Federal Capital finalized the area in which Brasilia would be placed. The president elected in 1956, Juscelino Kubitschek (1956-1961), created the Company for Urbanization of the New Capital (NOVACAP) and the construction of Brasilia began immediately. After three years

[6] Brazil is not alone in solving the capital-city location problem by constructing an entirely new city. Other countries that have employed this strategy include Australia (Canberra), Belize (Belmopan), Burma (Naypyidaw), India (New Delhi), Kazakhstan (Astana), Nigeria (Abuja), Pakistan (Islamabad) and the United States (Washington, D.C.).

[7] For comparison, this is a land area approximately equal to the size of the state of Connecticut and ten times the size of New York City.

and ten months, Brasilia was officially inaugurated on April 21st, 1960.

2.1.2 The roads connecting the new capital to the rest of the country

Before 1951, the few existing roads in Brazil were limited to the coastal areas of the Southeast and Northeast. National transportation plans (*Planos Nacionais de Viacao*, PNVs) laid out the planned transportation investments in the country. During Getulio Vargas' government (PNVs 1934 and 1944), the transportation plans began considering a national highway system. Between 1951 and 1957, the Brasilia-Belo Horizonte line was laid down, connecting the soon-to-be new capital to the capital of the state of Minas Gerais. In the same period, parts of the Brasilia-Anapolis highway, a road that would link the new capital to the city of Sao Paulo, was initiated. There were also plans to build the 2,276 km-long Belem-Brasilia, or *Transbrasiliana*, highway, which would provide an overland route from the underpopulated Northern states to the demographic and industrial centers of the country located in the south. However, it was not until Juscelino's administration (PNV 1956), during which the automobile industry came of age and the national capital was transferred to the interior, that the country finalized the plans for the highway system. The plans determined that the roads were to be built in order to connect the new capital city to the capitals of the other Brazilian states and the North to the South.[8] We use 1950 as a conservative start date for any effects resulting from Brasilia to account for road construction that began prior to the inauguration of the city.

The final highway network connected Brasilia to the rest of the country. The roads run radially from Brasilia towards the country's extremes in eight directions: north, northeast, east, southeast, south, southwest, west, and northwest. One possible instrument would be to construct straight lines between Brasilia and the cities connected to Brasilia by the radial highways. This would not, however, entirely eliminate the concern that the cities connected to the actual radial network were chosen based on their economic attributes. To address this issue we construct a predicted road network, following Faber (2014). Our best understanding, based on reading the planning documents, was that the goal of the highway system was to connect the national capital to the state capitals. We therefore divide Brazil into eight segments and predict, within each segment, the minimum path to connect Brasilia to all state capitals contained in that segment. The resulting network

[8]The state capitals, excluding Brasilia, are: Aracaju, Belem, Belo Horizonte, Boa Vista, Cuiaba, Campo Grande, Curitiba, Florianopolis, Fortaleza, Goiania, Joao Pessoa, Macapa, Maceio, Manaus, Natal, Palmas, Porto Alegre, Porto Velho, Recife, Rio Branco, Rio de Janeiro, Salvador, Sao Luis, Sao Paulo, Teresina, and Vitoria.

is the Euclidean Minimum Spanning Tree (EMST). Figure 1 shows the EMST network, overlaid on the actual radial highway network.

The key identifying assumption is that the regions connected to the EMST network are similar to the non-connected regions with respect to baseline characteristics. This assumption might not hold true if investors had begun development in certain anticipated connection sites. As we outline above, the historical context makes this unlikely because the city was completed very quickly once the government had decided on its final site. Two additional concerns exist. First, even if the municipalities along the path are as good as exogenous, the endpoints of the network, large cities, are clearly not. To address this concern, we drop all observations where one member of the pair is a state capital whenever we use data that is aggregated to a lower level than the state. Second, if the road network simply formalized preexisting historical travel routes between cities, then any effects we attribute to the road network may instead be due to the effects of the initial travel routes and not the new roads. Here, however, since roads were being built between an entirely new city and existing state capitals, it is unlikely that the roads simply replaced preexisting travel routes. To test formally whether regions connected to the EMST are similar to the non-connected regions we examine whether the distance to the EMST network predicts outcomes, such as GDP and population, in the years before Brasilia, after controlling for distance to the coast, distance to the nearest state capital, and distance to Brasilia. Appendix Table 2 displays the results. We cannot reject the hypothesis that the regions connected to the EMST network are the same as regions not connected to the EMST network.

2.2 Gravity estimates: IV results

With the instrument in hand we now turn to estimating the gravity equation. We obtain maps of the Brazilian road network from the Brazilian Ministry of Transportation decennially from 1960 through 2010 (See Appendix B.3). We append these maps with historical sources to identify roads that were constructed prior to 1960 (de Castro (2004)).

To move from the road maps to travel time we use a fast marching algorithm to generate the fastest path between two locations. This algorithm assigns a speed to each pixel on the map. We assign a baseline speed of 100 to pixels that have a road and a speed of 10 to pixels that do not have a road.[9] We complete this exercise for the actual road network and for the EMST road network. A full description of this approach appears in Appendix B.4.

[9]These numbers are based on the results reported by Donaldson (2016).

The EMST travel time will predict roads after the construction of Brasilia. We construct an instrument for pre-Brasilia travel time by rerunning the fast marching algorithm and setting all pixels equal to the non-road speed.[10]

We show the results of estimating the gravity equation in Table 1. The estimated elasticities of trade and migration flows to travel time are negative and significant, suggesting that road connectivity is associated with stronger movement of both goods and people. The OLS coefficients for trade range between -1.7 and -2.4 (first difference and levels, respectively). The OLS coefficients for migration range between -0.3 and -0.5. The IV elasticity to travel time is -5.81 for trade flows and -1.23 for migration flows. Both are statistically significant at the 1% level. The IV estimates are larger than the OLS estimates, which suggests that road placement likely targeted pairs with lower propensities to trade or migrate. The estimates using first differences also yield negative and significant elasticities.

These reduced-form estimates from the trade and migration gravity equations show that road connectivity facilitated the movement of goods and labor across space. However, these estimates cannot quantify the net benefit of roads, nor can they decompose the relative magnitudes of the reductions in migration costs and trade costs. The next section presents the framework we use to address these questions.

3 Model

This section describes the framework we use to quantify the effects of roads in Brazil following the construction of the new capital city in Brasilia. The framework is based on a standard model of costly trade across space (Eaton and Kortum, 2002; Redding, 2015). We augment the migration decision to include origin-destination costs of migrating.

In the model agents optimally choose their location each period. Locations specialize in production based on the costs of importing goods from other locations. A location that can cheaply import goods will have a lower price level for goods. Agents pay a cost if they

[10] The first-stage equation is

$$\log \text{road travel time}_{knt} = \rho_{kt} + \rho_{nt} + \rho_{kn} + \beta \mathbb{I}_{t<1950} \log \text{empty}_{knt} + \beta \mathbb{I}_{t>=1950} \log \text{EMST travel time}_{knt} + \nu_{knt}.$$

Appendix Table 3 shows the first-stage estimating equation for the model in levels and in first differences. The instrument is highly correlated with actual travel time. According to the model in levels, a 1% increase in EMST travel time is associated with a 0.4% increase in the road travel time (the F-stat is about 180.5 for trade gravity and 84.3 for migration gravity). The results using first differences also indicate a strong correlation between road travel time and the instrument.

migrate. This cost has two components, one origin-destination specific and one idiosyncratic. Because there are both trade costs and migration costs, roads affect the demand for *and* the supply of labor. On the demand side, roads reduce the cost of trade, leading locations to specialize in production and potentially increase labor demand. On the supply side, the lower cost of traded goods increase real wages, in turn increasing labor supply; additionally, if roads change the cost of migrating, people can easily move to places featuring higher real wages. The overall effect of an improvement in the road network will depend on the net effect on wages, prices, and equilibrium migration decisions.

The goal of the model is to map migration and trade costs into a quantitative framework. Given trade costs d_{knt}, migration costs κ_{knt}, exogenous productivities A_{nt}, exogenous amenities B_{nt} and an initial allocation of labor $L_{n,t-1}$, the model endogenously determines wages w_{nt}, prices P_{nt}, rents r_{nt} and current labor L_{nt}.

3.1 Labor demand

The production side of the economy is based on a standard model of a location producing goods based on its comparative advantage. Assume that there is a continuum of goods, $j \in [0, 1]$, which are produced in each location n at time t according to a linear production function

$$Y_{nt}(j) = z_{nt}(j) L_{nt},$$

where $z_{nt}(j)$ is a product-location-specific productivity draw for time t, which is drawn from a Frechet distribution

$$F_{nt}(z) = e^{-A_{nt} z^{-\theta}},$$

where the scale parameter, A_{nt}, determines the average productivity for location n at time t (absolute advantage) and the shape parameter, θ, determines the dispersion in productivity draws across goods (comparative advantage).

Labor markets are competitive, which implies that labor is paid its marginal product, where $p_{nt}(j)$ is the farmgate price for good j produced in location n at time t

$$w_{nt}(j) = p_{nt}(j) z_{nt}(j).$$

Within location, labor is perfectly mobile across sectors so labor market arbitrage implies a constant wage rate, $w_{nt}, \ \forall j$. [11]

[11] For the baseline specification we also assume that there is a constant returns to scale technology with

Goods shipped between origin k and destination n are subject to an iceberg cost, $d_{knt} \geq 1$. The cost to a consumer at destination n of buying one unit of good j produced at origin k is

$$p_{knt}(j) = \frac{d_{knt} w_{kt}}{z_{kt}(j)}.$$

3.2 Consumption and prices

Consumers have constant elasticity of substitution (CES) preferences over a continuum of goods j. The consumption index, C_n, is given by

$$C_n = \left[\int_0^1 c_n(j)^{1-\sigma} d_j \right]^{\frac{1}{1-\sigma}}.$$

The dual price index, P_n, is given by

$$P_n = \left[\int_0^1 p_n(j)^{1-\sigma} dj \right]^{\frac{1}{1-\sigma}}.$$

Consumers at location n source each good k from the lowest-cost producer. Following Eaton and Kortum (2002), the share of location n's expenditure on goods produced in location k is given by

$$\pi_{knt} = \frac{A_{kt}(d_{knt} w_{kt})^{-\theta}}{\sum_{s \in N} A_{st}(d_{snt} w_{st})^{-\theta}}, \tag{2}$$

and the price index in location n is given by

$$P_{nt} = \gamma \left[\sum_{s \in N} A_{st}(d_{snt} w_{st})^{-\theta} \right]^{-1/\theta}, \tag{3}$$

where γ is related to the Gamma distribution, $\gamma = \left[\Gamma\left(\frac{\theta - (\sigma - 1)}{\theta} \right) \right]^{\frac{1}{1-\sigma}}$.

Trade is balanced between locations. The value of goods consumed in s from origin k is the share of imports times total expenditure in s, $X_{ks} = \pi_{ks} w_s L_s$. Using the fact that total income in k is the sum of all production implies that the following relationship holds

labor as the only factor of production. This is equivalent to allowing production to depend on capital and labor and assuming perfect capital mobility across sectors. A fixed factor, such as land, would generate decreasing returns to scale. This is easily incorporated into the framework.

for each origin

$$\begin{aligned} w_{kt}L_{kt} &= \sum_{s\in N} X_{kst} \\ &= \sum_{s\in N} \pi_{kst} w_{st} L_{st}, \quad \forall k = 1, ..., N. \end{aligned} \tag{4}$$

3.3 Labor supply and migration

The utility of an individual ω from origin k living at destination n depends on (i) goods consumption, C_{nt}, (ii) housing consumption, H_{nt}, (iii) an individual-specific preference shock, $b_{\omega nt}$, and (iv) migration cost, κ_{knt}, according to

$$U_{\omega knt} = \frac{b_{\omega nt}}{\kappa_{knt}} \left(\frac{C_{nt}}{\alpha}\right)^{\alpha} \left(\frac{H_{nt}}{1-\alpha}\right)^{1-\alpha},$$

where $b_{\omega nt}$ is an i.i.d. preference draw (amenity-value draw) for individual ω from origin k for destination n. This is drawn from a Frechet distribution

$$F_{nt}(b) = e^{-B_{nt}b^{-\epsilon}}.$$

Given a budget constraint, $P_{nt}C_{nt} + r_{nt}H_{nt} \leq w_{nt}$[12] , the indirect utility for individual ω from origin k in destination n is given by

$$U_{\omega knt} = \frac{b_{\omega nt}}{\kappa_{knt}} \frac{w_{nt}}{P_{nt}^{\alpha} r_{nt}^{1-\alpha}}.$$

Utility is higher for places that offer nicer amenities, pay higher wages, feature lower prices of traded goods, have lower housing costs, and lower migration costs. Note also that utility can be separated into a piece that is common to all people in location n, $(w/P^{\alpha}r^{1-\alpha})$, a piece that is common to all people from k in n, $(1/\kappa)$, and a piece that is idiosyncratic, (b).

[12]Other assumptions are possible here. Monte et al. (2015) assume that landlords reside in a given location and spend all their income on traded goods. This modifies the demand for traded goods to be the sum of the goods share from labor and the expenditure on goods from landlords, yielding $P_{nt}C_{nt} = \alpha w_{nt}L_{nt} + (1-\alpha)w_{nt}L_{nt} = w_{nt}L_{nt}$ instead of $P_{nt}C_{nt} = (1-\alpha)w_{nt}L_{nt}$. This would modify the indirect utility term from $U_{\omega knt} = b_{\omega knt}\frac{1}{\kappa_{knt}}\frac{B_{nt}w_{nt}}{P_{nt}^{\alpha}r_{nt}^{1-\alpha}}$ to $U_{\omega knt} = b_{\omega knt}\frac{1}{\kappa_{knt}}\frac{B_{nt}w_{nt}}{(\alpha P_{nt})^{\alpha}r_{nt}^{1-\alpha}}$. Redding (2015) assume that housing revenue is redistributed as a lump sum to residents. This yields the outcome that total income is the sum of labor income and residential expenditure; $v_{nt}L_{nt} = w_{nt}L_{nt} + (1-\alpha)v_{nt}L_{nt} \Rightarrow v_{nt}L_{nt} = \frac{w_{nt}L_{nt}}{\alpha}$. This would change the demand for both goods $p_{nt}C_{nt} = w_{nt}L_{nt}$ and housing $r_{nt}H_{nt} = (1-\alpha)\frac{w_{nt}L_{nt}}{\alpha}$ and would change the indirect utility term to be $U_{\omega knt} = b_{\omega knt}\frac{1}{\kappa_{knt}}\frac{B_{nt}w_{nt}}{(\alpha P_{nt})^{\alpha}(\alpha r_{nt})^{1-\alpha}}$.

Given the indirect utility function, $U_{\omega knt}$, individual ω chooses to live in the location i that maximizes utility

$$\max_i U_{\omega kit}.$$

Given the assumption pertaining to preferences, migration rates from k to n are

$$\lambda_{knt} = \frac{B_{nt}\left(w_{nt}\right)^{\epsilon}\left(\kappa_{knt}P_{nt}^{\alpha}r_{nt}^{1-\alpha}\right)^{-\epsilon}}{\sum_{s\in N}B_{st}\left(w_{st}\right)^{\epsilon}\left(\kappa_{kst}P_{st}^{\alpha}r_{st}^{1-\alpha}\right)^{-\epsilon}}. \tag{5}$$

The parameter ϵ is the migration elasticity to the real wage. This expression, combined with an initial allocation of labor, $L_{s,t-1}$, yields current labor supply:

$$L_{nt} = \sum_{s\in N}\lambda_{snt}L_{s,t-1}. \tag{6}$$

3.4 Housing market

We assume that all housing is owned by absentee landlords. Following Diamond (2016), we model the price of housing depending on the underlying cost of producing housing units. The price of housing is determined by the marginal cost of constructing housing, which depend on construction costs, CC_{nt}, and land costs, LC_{nt}, as follows

$$P_{nt}^{\text{house}} = MC(CC_{nt}, LC_{nt}).$$

Assuming a steady state equilibrium in the asset market, prices equal the discounted value of rents. Therefore,

$$r_{nt} = \iota MC(CC_{nt}, LC_{nt}).$$

The cost of land, LC_{nt}, depends on the demand for housing services.[13] The housing equilibrium condition can be approximated by a linear expression

$$\begin{aligned}&\log r_{nt} = \log\iota + \log CC_{nt} + \eta\log HD_{nt},\\ &\text{where } HD_{nt} = (1-\alpha)w_{nt}L_{nt}\end{aligned} \tag{7}$$

and η is the housing supply elasticity. Therefore, the cost of housing increases when the

[13] For example, assuming a fixed amount of land $\overline{L}_n$ the total supply of land is $LC_{nt}\overline{L}_n$. The total demand for housing services is $HD = (1-\alpha)w_{nt}L_{nt}$. Setting supply equal to demand yields a land price $LC_{nt} = \frac{HD_{nt}}{\overline{L}_n}$.

demand for housing services increases, which can be due to either an increase in wages or an increase in the labor force.

3.5 General equilibrium

Given exogenous average productivities, A_{nt}, exogenous trade costs, d_{knt}, exogenous migration costs, κ_{knt}, and an initial allocation of labor, $L_{n,t-1}$, the spatial equilibrium is a set of trade flows, π_{knt}, prices, P_{nt}, wages, w_{nt}, migration rates, λ_{knt}, labor allocations, L_{nt}, and rents, r_{nt}, for each region $n = 1, ..., N$ such that the following equations are satisfied:

1. Import trade shares are given by Equation 2

$$\pi_{knt} = \frac{A_{kt}(d_{knt}w_{kt})^{-\theta}}{\sum_{s\in N} A_{st}(d_{nst}w_{st})^{-\theta}}$$

2. Prices are given by Equation 3

$$P_{nt} = \gamma \left[\sum_{s\in N} A_{st}(d_{nst}w_{st})^{-\theta} \right]^{-1/\theta}$$

3. Wages are implicitly determined by the trade balance equations (Equation 4)

$$w_{nt}L_{nt} = \sum_{s\in N} \pi_{nst} w_{st} L_{st}$$

4. Migration rates are given by Equation 5

$$\lambda_{knt} = \frac{B_{nt}\left(w_{nt}\right)^{\epsilon}\left(\kappa_{knt}P_{nt}^{\alpha}r_{nt}^{1-\alpha}\right)^{-\epsilon}}{\sum_{s\in N} B_{st}\left(w_{st}\right)^{\epsilon}\left(\kappa_{kst}P_{st}^{\alpha}r_{st}^{1-\alpha}\right)^{-\epsilon}}$$

5. Labor demand is given by Equation 6

$$L_{nt} = \sum_{s\in N} \lambda_{snt} L_{s,t-1}$$

6. Rental rates are determined by Equation 7

$$\log r_{nt} = \log \iota + \log CC_{nt} + \eta \log(1-\alpha) w_{nt} L_{nt}$$

4 Estimation

This section discusses the estimation of the model. We estimate two sets of parameters: first, parameters determining the migration and trade cost functions and second, two elasticities (the migration elasticity to wages and the elasticity of rents to population) that determine the migration decision.

We construct a regional database of migration, wages and roads between 1970-2010. The primary datasource is the individual data files from the Brazilian Census, 1970-2010, collected by the Brazilian Institute of Geography and Statistics (IBGE). Our sample of interest consists of males aged 20-65 who report non-zero earnings in their main occupations. We aggregate these data to the meso region. Brazil has 137 meso regions; due to overlapping municipality boundaries we combine two sets of meso regions to give us 135 spatial units consistently defined over time. Each meso region has on average 1.4 million inhabitants. We provide a full description of the data and summary statistics in Appendix B.

4.1 First step: estimate trade and migration costs

The first step of the estimation procedure is to identify the parameters determining the migration cost function and the trade cost function.

4.1.1 Migration costs

The probability that an agent chooses to live in location k at time t, given a starting period in location n is given by

$$\lambda_{knt} = \frac{B_{nt} U_{nt}^{\epsilon} \kappa_{knt}^{-\epsilon}}{\sum_{s \in N} B_{st} U_{st}^{\epsilon} \kappa_{kst}^{-\epsilon}}, \tag{8}$$

where

$$U_{nt} = \frac{w_{nt}}{r_{nt}^{\alpha} P_{nt}^{1-\alpha}}.$$

We parameterize the bilateral cost as

$$\kappa_{knt} = (1 + \text{travel time}_{knt})^{\lambda} e^{\zeta_{knt}},$$

where travel time$_{knt}$ is the travel time between origin k and destination n at time t, and ζ_{knt} is an unobservable component that captures pairwise barriers to migration due, for

example, to limited networking and information flows about local labor market conditions and socio-cultural differences, among other factors.

Taking the log of both sides, and collecting terms in either origin-year or destination-year fixed effects, yields the estimating gravity equation for migration

$$\log \lambda_{knt} = \delta_{nt}^{\kappa} + \delta_{kt}^{\kappa} - \epsilon\lambda \log(1 + \text{travel time}_{knt}) + \varepsilon_{knt}^{\kappa}. \tag{9}$$

In the empirical section we augment this equation by allowing for fixed costs and utility from living in one's state of birth.[14] The coefficient of interest, $\epsilon\lambda$, is the elasticity of migration flows to travel time. This coefficient is the product of the elasticity of migration cost to distance, λ, and the elasticity of migration to the real wage, ϵ.

The results are shown in Table 2. The units of observation in Columns (1) and (2) are bilateral region-year pairs (the share of the population from origin k who moved to destination n in year t) and in Columns (3) and (4) are bilateral region-birthstate pairs (the share of the population from origin k and who were born in state s and moved to destination n in year t). People who do not move are included in the regression as the bilateral share from origin k to destination k. We include a full set of origin-year, destination-year, and year fixed effects in the regression. Starting with Column (1), the components of the migration cost have the expected sign. There is a fixed cost to migrate, reflecting any dislike of moving (with a coefficient of -5.3). The bilateral road travel time is negative and significant, showing that traveling a longer distance is more costly (with a coefficient of -2.7). Column (2) estimates the IV specification where we instrument the bilateral travel time between two locations with the bilateral instrument.[15] The IV for bilateral travel time is negative and significant (with a coefficient of -3.7). The results show a strong negative effect of travel time on migration. As earlier, the OLS estimates are smaller than the IV estimates, understating the elasticity of migration to distance and consistent with roads being built between places that had less movement of people between them. The fixed cost of migrating decreases in magnitude but also remains negative and significant (with a coefficient of -4.2).

Columns (3) and (4) reestimate the model allowing for individuals to gain utility from

[14] The revised estimating equation is $\log \lambda_{knt} = \delta_{nt}^{\kappa} + \delta_{kt}^{\kappa} - \epsilon\lambda_1 \log(1 + \text{travel time}_{knt}) - \epsilon\lambda_2 \mathbb{I}\{n \neq k\} + \epsilon\lambda_3 \mathbb{I}\{n \in SB\} + \varepsilon_{knt}^{\kappa}$.

[15] The first-stage equation for $\log(1 + \text{travel time}_{knt})$ is

$$\log(1 + \text{travel time}_{knt}) = \delta_{nt}^{t} + \delta_{kt}^{t} + \varphi_1 \log(1 + Z_{knt}) + \varphi_2 \mathbb{I}\{n \neq k\} + \varphi_3 \mathbb{I}\{n \in SB\} + \upsilon_{knt},$$

where Z_{knt} is the instrument for bilateral travel time. This is reported in Appendix Table 4.

living in their state of birth. While gross migration flow data are rarely available in population censuses, state of birth is often recorded and is used as a proxy variable for migration costs, so it is reassuring to see that the bilateral components of migration costs are robust after controlling for birth origin. The IV estimate of bilateral travel time are negative and significant (coefficient of -2.2). State of birth has the expected sign, indicating a dislike of moving to a location that differs from the state of birth.

To aid interpretation of the coefficients, we convert the coefficients back into iceberg migration costs by exponentiating the estimated migration costs, $-\epsilon\lambda_1 \log(1 + \text{travel time}_{knt}) - \epsilon\lambda_2 \mathbb{I}\{n \neq k\} + \epsilon\lambda_3 \mathbb{I}\{n \in SB\}$, and adjusting by the migration elasticity (which we will estimate in the following section to be 3.4). The results are presented in Appendix Table 7. The average migration cost, across all pairs, is equal to an iceberg cost of 86% of utility. For moves that actually occur, the average cost borne was 82%. Of this incurred cost, the fixed cost contributes 62% of the cost, the travel time 44%, and net state of birth changes move on average towards the state of birth, and so contribute -6% of the total cost.[16]

Why do people still migrate if the costs are so high? The cost that we estimate is the average origin-destination cost. Individuals are also drawing i.i.d. preference shocks for each location. A higher average cost shifts the threshold for migrating to the right of the distribution and individuals migrate only if they have a large enough preference shock to compensate for the cost. We compute the average unobserved preference shock implied by the estimates, modifying the methodology used by Kennan and Walker (2011). We find that the unobserved preference shock is a positive shock of 1.85 times the observed cost. That is, although all migrants incur high average costs, those that migrate do so because they themselves experience a positive net return.

We also rerun the analysis by demographic group. Related studies, conducted mostly in the US, have found that older people and lower skilled people are less likely to migrate (Notowidigdo, 2013; Schulhofer-Wohl and Kaplan, 2015). In Brazil, we find that a higher share of younger people migrate (9% vs 5%), but there is no average difference in migration rates by skill group (the average migration rate of each group is equal to the mean migration rate of 7.1%). The estimated migration cost for incurred moves is very stable across age/skill group (approximately 80% of total utility). We provide full details of this

[16] To check the magnitudes we compute migration costs a second way by backing them out directly from our model. Rewriting Equation 8 and imposing migration cost symmetry yields an estimate of migration costs (this is the "Head-Reis" index used in trade Head and Mayer (2013)) of $\kappa_{knt} = \left[\frac{\lambda_{knt}}{\lambda_{kkt}}\frac{\lambda_{nkt}}{\lambda_{nnt}}\right]^{-\frac{1}{2\epsilon}}$. Computing migration costs in this way yields the same average migration cost of 89% of utility. The difference between the two is that our estimated migration cost is identified from exogenous bilateral shifts. Results available upon request.

decomposition exercise in Appendix D.

One other important issue, common to many migration studies, is that the migration matrices are sparse (many bilateral pairs do not have people moving between them). In our setting, 47% of region-pair-year observations have zero flows. Excluding the pairs with zero observed flows could introduce a sample selection bias. Our results are robust to re-estimating the model using a Poisson pseudo maximum likelihood estimator, following the standard approach to incorporating zeros in models in the trade literature (Silva and Tenreyro, 2006; Tenreyro, 2009)). We report the results in Appendix Table 5.

4.1.2 Trade costs

We follow the same strategy to estimate bilateral trade costs. From the import shares we have:

$$\pi_{knt} = \frac{A_{kt}(d_{knt}w_{kt})^{-\theta}}{\sum_{s\in N} A_{st}(d_{snt}w_{st})^{-\theta}}. \tag{10}$$

Iceberg trade costs are parameterized as

$$d_{knt} = (1 + \text{travel time}_{knt})^{\beta} e^{\vartheta_{knt}}, \tag{11}$$

where travel time$_{knt}$ is as described in Equation (4.1.1), and ϑ_{knt} is an unobservable component which captures other barriers to trade not associated with transportation costs, such as information frictions. Taking the log yields the estimating equation below

$$\log \pi_{knt} = \delta^d_{kt} + \delta^d_{nt} - \theta\beta \log(1 + \text{travel time})_{knt} + \varepsilon^d_{knt} \tag{12}$$

Again, the estimated coefficient, $\theta\beta$, is a composite of the trade elasticity (θ) and the elasticity of trade costs to travel time (β). We set θ exogenously at 4 following Simonovska et al. (2014). Trade data are observed only at the state-to-state level. We estimate trade costs off interstate trade flow data from 1999 to match the period covered by the individual census data; we present the estimation results in Appendix Table 8. We then assume that the trade cost function is stable and then use the estimated parameters to predict the trade costs between mesos. Then, using the structure of the model, we combine the predicted trade costs with observed wage rates to solve for the implied meso-to-meso trade flows consistent with balanced trade. The meso-level price index can then be calculated from the predicted trade flows.

4.2 Second step: estimation of elasticities

In the second step, we estimate two structural parameters: the elasticity of utility to wages, ϵ, and the elasticity of rental rates to income, η. Both wages and rents are endogenous; we generate an instrumental variable strategy to separately identify these parameters.

4.2.1 Decomposing destination-specific utility

In the first-step estimating equation we recover estimates of the destination-specific component of indirect utility. Indirect utility at the destination depends on wages, rents, prices and amenities. We observe wages and rents in our data; however both are endogenous. We do not observe prices; we construct these by simulating meso-to-meso level trade flows, discussed below. We treat amenities as an exogenous residual.

The destination-specific component of indirect utility, $\hat{\delta}^{\kappa}_{nt}$, estimated in the first step, is a function of wages, rents, and prices

$$\hat{\delta}^{\kappa}_{nt} = \log B_{nt} + \epsilon(\log w_{nt} - \alpha \log r_{nt} - (1-\alpha)\log P_{nt}).$$

We model the common amenity value of location n at time t as

$$\log B_{nt} = b_n + b_t + \xi_{nt},$$

where b_n is time-invariant component, b_t captures time trends, and ξ_{nt} is an error term. These assumptions yield the following estimating equation

$$\hat{\delta}^{\kappa}_{nt} = b_n + b_t + \epsilon(\log w_{nt} - \alpha \log r_{nt} - (1-\alpha)\log P_{nt}) + \xi_{nt}. \tag{13}$$

In this equation wages, rents, and the price index are endogenous. In addition, the price index is unobserved.

4.2.2 Price index

Prices at the meso level are not observed.[17] To account for heterogeneity in the cost of living across meso regions we take advantage of the structure in the model that generates

[17] Brazil collects some price data. For example, the CPI is collected in 10 cities nationwide. However, these data do not cover the whole country. Appendix B.7 correlates measures of the CPI with other measured proxies for the cost of living.

a closed form for the price index in the location. From Equation 3, the price index in destination n at time t is given by

$$P_{nt} = \gamma \left[\sum_{s \in N} A_{st} (d_{nst} w_{st})^{-\theta} \right]^{-1/\theta}.$$

We log-linearize the price index equation, yielding[18]

$$\Delta \log P_{nt} = \sum_{s \in N} \pi_{sn,t-1} \Delta \log w_{st},$$

where $\pi_{sn,t-1}$ is the share of imports in n from region s at time t. The change in price is a trade-weighted sum of all the wage shocks, which we can compute from observed wages and then the trade shares from solving the model. This lends itself well to an instrument: the trade-weighted sum of the instrument for wages.

4.2.3 Housing supply equation

From the housing supply equation we have

$$\log r_{nt} = \eta_n + \eta_t + \eta(\log w_{nt} + \log L_{nt}) + \psi_{nt}, \tag{14}$$

where η_n accounts for time-invariant determinants of construction and land costs, η_t captures time trends in these costs, and ψ_{nt} is an error term.

4.2.4 System of GMM equations

We estimate a system of equations by generalized method of moments (GMM). The two coefficients of interest are the elasticity of migration to real wages, ϵ, and the elasticity of housing to population, η. We calibrate $\alpha = 0.2$ using the share of rents on total expenditure drawn from the 2008-2009 Survey of Family Budget.[19] We set up the following estimating equation in first differences

$$\Delta \hat{\delta}^{\kappa}_{nt} = \delta^{b}_{t} + \epsilon(\Delta \log \tilde{w}_{nt}) + \varepsilon^{u}_{nt} \tag{15}$$

$$\Delta \log r_{nt} = \delta^{\eta}_{t} + \eta(\Delta \log w_{nt} + \Delta \log L_{nt}) + \varepsilon^{r}_{nt}, \tag{16}$$

[18] For full details see Appendix E.2.

[19] Data available at http://www.ipeadata.gov.br/.

where $\Delta \log \tilde{w}_{nt} = \Delta \log w_{nt} - 0.2\Delta \log r_{nt} - 0.8\Delta \log P_{nt} = \Delta \log w_{nt} - 0.2\Delta \log r_{nt} - 0.8 \sum_{s \in N} \pi_{sn,t-1} \Delta \log w_{st}$.

In this set of equations wages, rents, and labor are endogenous, and prices are unobserved. We create three instruments. First, we generate a Bartik shock, ΔB^w_{nt}, to instrument for wages. The Bartik shock (Bartik, 1991) attributes national industry-level growth to each region, based on the baseline industry composition of employment. We compute the Bartik shock using data at least 500km from the meso region of interest to avoid spatial correlation in labor demand shocks.[20] Second, we generate a labor supply instrument based on the heterogeneity of "labor market access". When migration is costly it is more difficult for labor to respond to higher wages; as a result, labor supply elasticity will be lower in places that are less connected. We create an instrument for labor, $\Delta \log L^z_{nt}$, that uses the exogenous component of migration costs. Third, we create an instrument for prices, $\Delta \log P^z_{nt}$, by taking a trade-weighted average of the Bartik shock. Appendix C describes each instrument in detail.

The vector of instruments is given by

$$\Delta Z_{nt} \in \{\Delta B^w_{nt}, \Delta \log P^z_{nt}, \Delta \log L^z_{nt}\},$$

and the identifying restrictions are

$$E(\Delta Z_{nt} \varepsilon^u_{nt}) = 0,$$
$$E(\Delta Z_{nt} \varepsilon^r_{nt}) = 0.$$

One immediate challenge to this identification strategy is that our model applies to a single industry, yet the instrument uses the variation of multiple industries. Bartelme (2014) provides a consistent microfoundation for Bartik shocks in an aggregate gravity framework that justifies that use of the Bartik shock for models of our type.

We present the results in Table 3. Column (1) displays the baseline results from our model which allows for bilateral costs of migration and preferences to live in one's state of birth (as well as unobserved preference shocks for each region). We estimate a housing supply elasticity of 0.82 and a migration elasticity to wages of 3.4.[21] The migration elastic-

[20] Results are stable over thresholds from 0-1000km; results available on request. We also check for evidence of serial correlation in the shocks by correlating contemporaneous Bartik shocks with lagged outcomes. We plot the effects of the current Bartik shock on current outcomes and on past outcomes in Figure 2. Bartik shocks (2010-1991) are strongly correlated with 2010-1991 changes in wages and rents, but not with 1991-1980 changes.

[21] We estimate the elasticities with and without the price correction term and with and without state of

ity to wages is a parameter that has not been extensively estimated, but we can compare our result to those reported by others in the (predominantly US) literature. Monte et al. (2015) estimate an elasticity of 4.43 using commuters. Diamond (2016) estimates an elasticity of between 2 and 4. Caliendo et al. (2015) estimate an elasticity of 0.2 for a 5-month frequency. Tombe and Zhu (2015) estimate an elasticity of 0.4 from Chinese data. Our estimate of 3.4 is therefore within the range of these estimates.

Next, we contrast the estimated elasticities we obtain to the elasticities we would obtain in a model without bilateral costs of migration, but where individuals still have taste shocks for different locations. Due to data limitations many spatial equilibrium models are estimated based on population allocations rather than population flows, which is equivalent in our model to setting the origin-destination component of migration costs to zero. The existence of migration costs could affect the estimated elasticity of migration to wages: both high migration costs and a low migration elasticity to wage shocks are consistent with a low observed population response to wage shock. Because migration costs stop some members of the population responding to wage shocks, the estimated migration elasticity may be understated when only population data are used. We show that this is indeed the case for our data by re-estimating the elasticities without bilateral migration costs.[22] We show the results in Column (2) of Table 3. Using exactly the same data and the same estimation approach, the estimated migration elasticity is lower in a model that does not include migration costs. We estimate a statistically insignificant, and economically meaningless, elasticity of migration of -0.5, compared to the point estimate of 3.4 when we use the gross flow data.

birth effects. The migration elasticity is smaller (1.9) when the price term is not included and is larger (9.7) when the birth term is not included. We report results in Appendix Table 9.

[22]Without bilateral migration costs, and still assuming Frechet amenity shocks, the probability that an individual will choose to live in n at time t is

$$\lambda_{nt} = \frac{B_{nt} U_{nt}^{\epsilon}}{\sum_{s \in N} B_{st} U_{st}^{\epsilon}}, \tag{17}$$

where λ_{nt} is the share of total population living in n at time t.

This modifies Equation 9 as we now have

$$\log \lambda_{nt} = \delta_t^{n\kappa} + \delta_{nt}^{n\kappa}.$$

The instrument given by Equation 18 is excluded from estimates shown in Column (2) since it makes sense only with bilateral migration costs. The p-value for the test of overidentifying restrictions is missing as the model is exactly identified.

5 Decomposing the effects of roads

We are now ready to answer the main question of this paper, "What is the relative contribution of improved roads to migration and trade?" To estimate the welfare gains we take the estimated trade costs and migration costs, recompute them under counterfactual travel times, and then re-solve the model.

The first counterfactual is the thought experiment of simply deleting all roads in Brazil. To construct the new travel times between all meso-level locations we use a constant speed of traveling across all pixels. This yields the variable $Z_{knt}^{\text{Empty EMST}}$. We then use the IV estimating equation and the first-stage equation to convert this variable into travel time units.

The second counterfactual considers the road network as if the capital city had stayed in Rio. To compute this network we calculate a minimum spanning tree that connects all state capitals to Rio de Janeiro in the least-distance way possible. A picture of the alternative network is given in Appendix Figure 1b.[23] We rerun the fast marching algorithm on this network to generate an instrument $Z_{knt}^{\text{Rio EMST}}$.

There is an important caveat to these counterfactual exercises. Our model is a static model of migration where individuals make a one-time migration decision. If individuals are forward-looking it is reasonable to think that the decision of where to live today will also take expectations of *future* migration into account. We provide an extension of the model to the dynamic case in Appendix E.1. While our estimation strategy is robust to the existence of such dynamic considerations, as the continuation value is captured as part of the amenity term, during the counterfactuals we hold the amenity term fixed at its estimated value. As a result, our counterfactuals may underestimate the cumulative effect of roads by not accounting for the effect of repeated migration decisions.[24]

Table 4 shows the relative migration and trade costs under the two counterfactuals. Compared to the scenario of no roads, Brasilia reduced trade costs by 47% (the 10th percentile is a 69% reduction; the 90th percentile a 9% reduction) and migration costs by 51% (74%/11% for the 10th/90th percentiles, respectively). Compared with keeping the capital in Rio de Janeiro, Brasilia reduced average trade costs by 7% and average migra-

[23] This alternative network bears some similarities to the actual network because the state capital of Goias, Goiania, is located relatively close to Brasilia. The main difference between the two networks is northeastern Brazil: in the current network there is a road that runs from Brasilia to Fortaleza, passing through the northeast quadrant of the country. The predicted road network for Rio de Janeiro does not have this component.

[24] Caliendo et al. (2015) consider this issue explicitly in their study of the dynamic effects for the US of increased Chinese import competition.

tion costs by 7%. However, the reductions are heterogeneous: 10% of pairs experienced a trade cost increase of at least 15% and 10% of pairs experienced a migration cost increase of at least 17%.

5.1 91% of the gains from improved infrastructure are due to reductions in trade costs

Table 5 shows the equilibrium changes in prices, wages, rents, migration, indirect utility, and welfare. The first panel considers the effects of Brasilia compared with there being no roads. The table shows the point estimates and a 95% confidence interval around the point estimate.[25] Overall, welfare is 10.8% higher. The road network caused a decrease in prices (prices are 85% of their initial value), a slight decrease in the nominal wage (97.8% of the initial level), an increase in migration rates (1.57 times the original amount), and an increase in the indirect utility (the bundle of destination goods) of 11.4%. The welfare measures account for the level of destination utility, incurred migration costs, and the unobserved shock.

We next separate the welfare effects of roads into the piece caused by goods market integration and the piece caused by labor market integration. Column (2) of the table shows the equilibrium if only trade costs fell and migration costs stayed the same as the baseline. Not surprisingly, if migration costs do not fall we do not see an increase in migration (migration rates fall to 88% of the initial value), but there are still large reductions in prices. Because fewer people are migrating, the net welfare increase, accounting for migration costs and preference shocks, is much closer to the net gain in indirect utility (which includes neither migration costs nor preference shocks). Overall welfare goes up by 9.8%. Column (3) repeats the exercise by changing migration costs only and keeping trade costs at the initial value. Migration increases (1.76 times its baseline value), but the fact that migration is costly reduces the net welfare benefit. The welfare gain is equivalent to a 0.1% increase in welfare. Overall, the trade benefits account for 91%, and the migration benefits account for 9%, of the total welfare gain brought by having roads.

These results also shed light on a long-researched question about the substitutabil-

[25] We compute the confidence interval by parametric bootstrap (Horowitz, 2001). We bootstrap over the estimated migration cost parameters, the estimated trade cost parameters, the estimated migration elasticity, and the estimated housing elasticity. For each iteration we draw a vector of independent realizations of each parameter, assuming that the parameter comes from a normal distribution with the estimated coefficient as its mean and the estimated standard error as its standard deviation. We compute 200 bootstrap iterations and calculate the confidence interval within this bootstrapped sample.

ity between trade and migration (Mundell, 1957). We find that trade and migration are substitutes. We show in Column (2) of the table that when trade costs decrease, with migration costs staying constant, migration decreases. This is because lower trade costs lead to lower costs of purchasing traded goods, which increases the real wage, and if the real wage is higher then it is not necessary for individuals to migrate towards higher wage locations. Column (3) shows that when migration costs fall, with migration costs staying constant, there is very little change in the price level of traded goods. Individuals instead respond by migrating more often. Migration and trade thus act as substitutes for one another.

The second panel of the table shows the effect of the Brasilia network compared with that of a hypothetical road network if the capital city had remained in Rio de Janeiro. We find that, in fact, Brasilia has basically the same effect as Rio de Janeiro, with an increase in welfare of only 0.6%. The reason is that, although the road network resulting from the construction of Brasilia lead to lower costs on average that the road network if Rio had remained the capital city, costs actually rose between some of the pairs in the Rio network. Comparing Columns (2) and (3) we find that reducing trade costs only (and holding migration costs constant) would lead to a 0.9% increase in welfare whereas reducing migration costs (and holding trade costs constant) would lead to a 0.3% reduction in welfare.

5.2 It is important to account for costly migration to get the estimated gain from infrastructure correct

Although reduced trade costs largely explain the welfare gains we have reported, this does not mean that costly migration is not important. To demonstrate this point, Column (4) repeats the exercise, assuming that the model lacks bilateral migration costs. The estimated effect of Brasilia is a welfare gain of 8.9%, 18% lower than the estimated effect of the road shock when there is a role for both costly migration and costly trade. That is, in a model where migration also depends on access to infrastructure, the additional benefit raises the estimate of welfare above the baseline calculations. This has implications for any analysis involving optimal road investment: by omitting gains from labor market access, standard estimates understate the net benefits of labor market integration.

5.3 Costly migration induces heterogeneity in the benefits of roads

Finally, we show that in a model with costly migration, utility is no longer equalized across space. This is a key equilibrium condition in standard economic geography models where labor can freely move (but people may have location preferences). Our model includes an equilibrium condition that, *within origin*, all people have the same expected realized utility. Bilateral migration costs induce heterogeneity across people from different origins and so it is no longer the case that utility is equalized across all origins.[26]

Figure 3 shows this graphically. In the model with preference shocks only utility is equalized across space, with all people gaining an increase of 8.4% in utility from the road network. However, in the model with both migration costs and preference shocks, important spatial heterogeneity exists in the incidence of the shock. The average meso region gains 20% in utility, but the interquartile range of gains is 5%-29%.[27] That is, some regions are gaining much less than the average, while others are gaining much more than the average.

This result has direct implications for policy. Migration costs indicate the extent to which a location is "sticky": people are differentially affected by any spatial investment depending on where they live. In many countries, including the US, governments invest resources to develop specific areas, including building infrastructure such as roads, but also making broader investments to encourage job creation or economic growth. When migration is costly there will be heterogeneity in the response to policy for both the regions that are directly affected as well as the regions that are indirectly affected.

6 Conclusion

A large body of literature has studied the effects of roads in facilitating trade. In this paper, we focus on the effects of roads in facilitating the movement of people. Our contribution is to empirically quantify the effects of a large road expansion on both the goods

[26] The result is that expected utility is constant within origin, even though some may choose to migrate to a destination that has relatively higher wages. This is due to the unobserved taste shock. The taste shocks induce sorting across space – the people who are willing to go to places that do not look as appealing do so because they have a high unobserved preference for that location. Under most standard forms of this heterogeneity (notably, the Frechet and Gumbel distributions), the sorting effect exactly offsets the underlying heterogeneity, leaving utility constant across space. This is the same explanation for why the model without origin-destination migration costs will generate constant expected utility across space even though people live in different locations.

[27] These numbers differ from the average gain of 10.8% shown in Table 5 because of weighting. The average meso region is not the average person.

market and the labor market.

The large road expansion we study is the case of Brazil. Brazil relocated its capital city to the interior of the country in 1960 and subsequently built a large highway network connecting the new capital to the state capitals. We generate an instrument for road location based on the straight line connections between the new capital, Brasilia, and state capitals. We first document that states that became more connected by road had increases in the movement of goods and people, compared with states that did not become more connected by road. We then use this exogenous variation in migration and trade costs to estimate counterfactuals in a model of costly trade and costly migration (Eaton and Kortum, 2002; Monte et al., 2015).

We find that the road networks that connected Brasilia to the state capitals decreased migration costs by 51% and trade costs by 47%. Overall, these decreased costs increased welfare by 10.8%, of which 91% was the result of the reduction in trade costs and 9% was due to the reduction in migration costs. Although we find that the reduction in trade costs are the dominant source of welfare gains, we also show that it is important to account for costly migration for three reasons. First, without separating out migration costs from migration returns, researchers will underestimate the migration elasticity, a key input into many spatial equilibrium models. We estimate an elasticity of migration to wages of 3.4; with the same data we estimate an elasticity of -0.57 without accounting for migration costs. Second, the overall estimate of the welfare benefits to improving roads depends on the assumption about how easily people can migrate. We estimate that the road expansion in Brazil increased welfare by 10.8%. Using the same data, we estimate a welfare gain of only 8.9%, 17% lower, if we assume that the only friction to labor migration is due to heterogenous preferences. Third, the spatial equilibrium arbitrage condition, that expected utility is equalized across space, does not hold when migration is costly. Instead, an amended arbitrage equation, that expected utility is equalized within origin, holds in its place. As a result, we show that the spatial gains from any location-specific investment, such as the construction of new roads, depends on an individual's origin. We find that the interquartile range of gains from the improved infrastructure is 5%-29%, compared to uniform gains in the absence of origin-destination costs of migrating.

Our paper shows an important role for infrastructure, to facilitate the movement of labor to where its return is highest, that has not been well studied. If labor is not allocated most productively, then aggregate productivity may decrease, along similar lines to studies examining the misallocation of capital (Hsieh and Klenow, 2009). Likewise, costs

of adjustment of other mobile factors of production such as capital may also hinder the allocation of resources to where it would be most productive. The aggregate effects of this misallocation, particularly for developing countries where infrastructure is poor, is a potentially important mechanism to further explore.

References

Allen, Treb and Costas Arkolakis, "Trade and the Topography of the Spatial Economy," *Quarterly Journal of Economics*, 2014, *129* (3), 1085–1140.

Artuç, E, S Chaudhuri, and J McLaren, "Trade shocks and labor adjustment: A structural empirical approach," *The American Economic Review*, 2010.

Atkin, David, "The Caloric Costs of Culture: Evidence from Indian Migrants," *American Economic Review*, 2016, *106* (4), 1144–81.

Banerjee, Abhijit and A Newman, "Information, the Dual Economy, and Development," *Review of Economic Studies*, 1998, *65* (4), 631–653.

_ , Esther Duflo, and Nancy Qian, "On the Road: Access to Transportation Infrastructure and Economic Growth in China," 2009, pp. 1–22.

Bartelme, Dominick, "Trade Costs and Economic Geography : Evidence from the U.S. ," 2014.

Bartik, Timothy J, "Who Benefits from State and Local Economic Development Policies?," *Books from Upjohn Press*, 1991.

Bird, Julia and Stephane Straub, "Road Access and the Spatial Pattern of Long-term Local Development in Brazil," 2015.

Bryan, Gharad and Melanie Morten, "Economic Development and the Allocation of Labor: Evidence from Indonesia," 2015.

_ , Shyamal Chowdhury, and Ahmed Mushfiq Mobarak, "Under-investment in a Profitable Technology : The Case of Seasonal Migration in Bangladesh," *Econometrica*, 2014, *82* (5), 1671–1748.

Caliendo, Lorenzo, Maximiliano Dvorkin, and Fernando Parro, "The Impact of Trade on Labor Market Dynamics," 2015.

Chein, Flavia and Juliano Assuncao, "How does Emigration affect Labor Markets? Evidence from Road Construction in Brazil.," 2009, pp. 1–32.

de Castro, Newton, "Logistic Costs and Brazilian Regional Development," *mimeo*, 2004.

de Vasconcelos, Jose Romeu, "Matriz do Fluxo de Comércio Interestadual de Bens e Serviços no Brasil 1999," *IPEA DIscussion Paper*, 2001.

Diamond, Rebecca, "The Determinants and Welfare Implications of US Workers' Diverging Location Choices by Skill: 1980-2000," *American Economic Review*, 2016, *106* (3), 479–524.

Donaldson, D, "Railroads and the Raj: Estimating the Economic Impact of Transportation Infrastructure," *American Economic Review (Forthcoming)*, 2016.

Eaton, Jonathan and Samuel Kortum, "Technology, Geography, and Trade," *Econometrica*, 2002, *70* (5), 1741–1779.

Faber, Benjamin, "Trade Integration, Market Size, and Inudstrialization: Evidence from China's National Trunk Highway System," *Review of Economic Studies*, 2014.

Ghani, Ejaz, Arti Grover Goswami, and William R Kerr, "Highway to Success: The Impact of the Golden Quadrilateral Project for the Location and Performance of Indian Manufacturing," *The Economic Journal*, 2014, *126* (March), 317–357.

Harris, John and Michael Todaro, "Migration, Unemployment and Develpment: A Two-Sector Analysis," *The American Economic Review*, 1970, *60* (1), 126–142.

Hassouna, M S and A A Farag, "MultiStencils Fast Marching Methods: A Highly Accurate Solution to the Eikonal Equation on Cartesian Domains," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, 2007, *29* (9), 1563–1574.

Head, Keith and Thierry Mayer, "Gravity Equations: Workhorse, Toolkit, and Cookbook," *Handbook of International Economics*, 2013, p. 63.

Hornung, E, "Immigration and the diffusion of technology: The huguenot diaspora in Prussia," *American Economic Review*, 2014, *104* (1), 84–122.

Horowitz, Joel L., "The Bootstrap," in J J Heckman and E Leamer, eds., *Handbook of Econometrics*, Vol. 5 2001, pp. 3159–3228.

Hsieh, Chang-Tai and Peter J Klenow, "Misallocation and Manufacturing TFP in China and India," *Quarterly Journal of Economics*, 2009, pp. 1–60.

Janvry, Alain De, Kyle Emerick, Marco Gonzalez-navarro, and Elisabeth Sadoulet, "Delinking Land Rights from Land Use : Certification and Migration in Mexico," *American Economic Review*, 2015, *105* (10), 3125–3149.

Jayachandran, S, "Selling labor low: Wage responses to productivity shocks in developing countries," *Journal of Political Economy*, 2006.

Kennan, J, "A Note on Discrete Approximations of Continuous Distributions," 2006.

_ and J Walker, "The Effect of Expected Income on Individual Migration Decisions," *Econometrica*, 2011, *79* (1), 211–251.

Lagakos, David, Moll Benjamin, Tommaso Porzio, and Nancy Qian, "Experience Matters: Human Capital and Development Accounting," 2012.

Mangum, Kyle, "Cities and Labor Market Dynamics," *mimeo*, 2015.

Michaels, G, "The effect of trade on the demand for skill: evidence from the Interstate Highway System," *The Review of Economics and Statistics*, 2008.

Monte, Ferdinando, Stephen Redding, and Esteban Rossi-Hansberg, "Commuting, Migration, and Local Employment Elasticities," 2015, pp. 1–57.

Moretti, Enrico, "Local Labor Markets," *Handbook of Labor Economics*, 2011.

Mundell, Robert, "International Trade and Factor Mobility," *The American Economic Review*, 1957, *47* (3), 321–335.

Munshi, Kaivan and M Rosenzweig, "Networks and Misallocation: Insurance, Migration, and the Rural-Urban Wage Gap," *American Economic Review*, 2015.

Notowidigdo, Matthew, "The incidence of local labor demand shocks," 2013.

Pessino, C, "Sequential Migration Theory and Evidence from Peru," *Journal of Development Economics*, 1991.

Redding, S J, "Goods Trade, Factor Mobility and Welfare," *NBER Working Paper*, 2015.

Sahota, G S, "An Economic Analysis of Internal Migration in Brazil," *The Journal of Political Economy*, 1968.

Schulhofer-Wohl, Sam and Greg Kaplan, "Understanding the Long-Run Decline in Interstate Migration," 2015.

Silva, J M C Santos and Silvana Tenreyro, "The Log of Gravity," *The Review of Economics and Statistics*, 2006, *88* (November), 641–658.

Simonovska, I, M Waugh, and C Welcome, "Elasticity of Trade: Estimates and Evidence," *Journal of International Economics*, 2014, *92* (1).

Sjaastad, L, "The Costs and Returns of Human Migration," *The Journal of Political Economy*, 1962, *70* (5), 80–93.

Tenreyro, Silvana, "Further simulation evidence on the performance of the Poisson pseudo-maximum likelihood estimator," *Economics Letters*, 2009, *44* (0), 1–8.

Tombe, Trevor and Xiadong Zhu, "Trade Liberalization, Internal Migration and Regional Income Differences: Evidence from China," *mimeo*, 2015, pp. 1–42.

Topalova, P, "Factor Immobility and Regional impacts of Trade Liberalization: Evidence on Poverty from India," *American Economic Journal: Applied Economics*, 2010, *2* (4), 1–41.

Tunali, I, "Rationality of Migration," *International Economic Review*, 2000, *41* (4), 893–920.

Figures and Tables

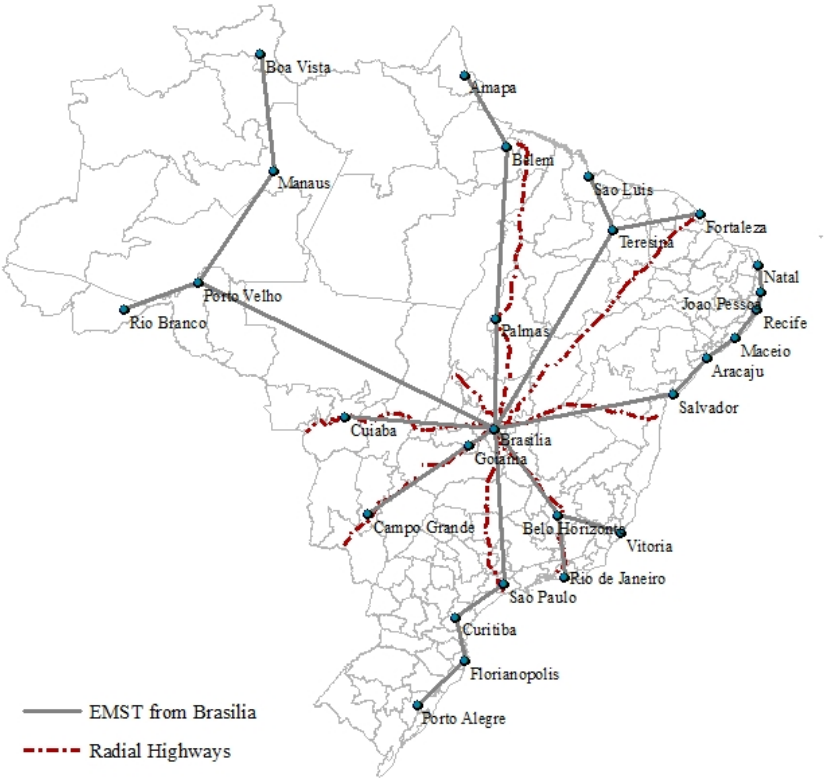
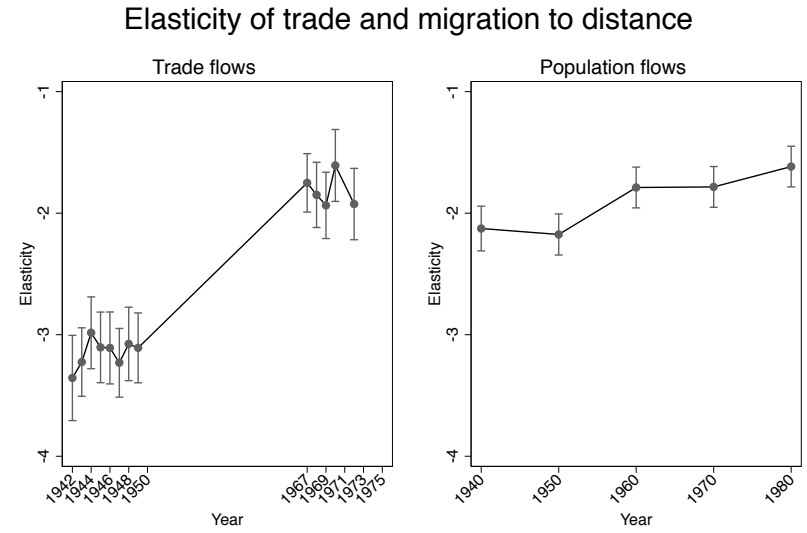
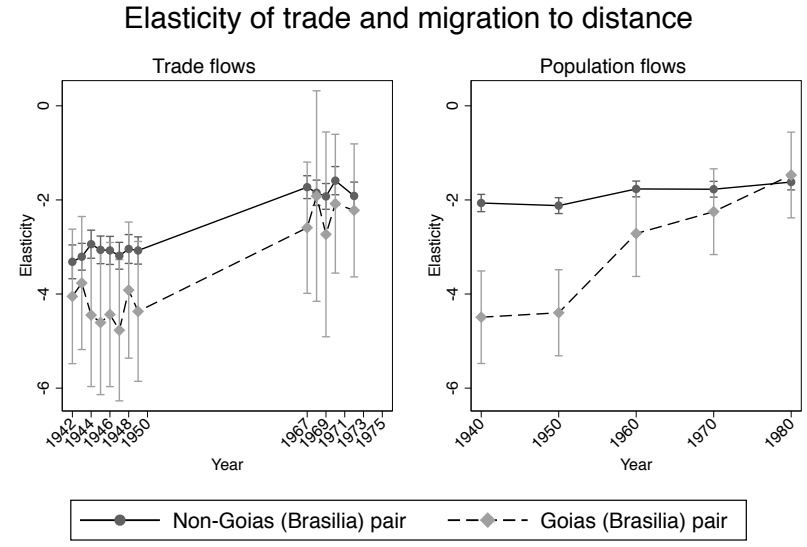


Figure 1: Map of straight line instrument and radial highways

Notes: Figure shows Brasilia and the 26 state capitals. The map shows radial highways out of Brasilia and the straight line instrument for roads. The straight line shows the minimum spanning tree instrument between Brasilia and grouped state capitals. Background of map shows meso region boundaries. Source: Authors' calculations based on maps obtained from the Brazilian Ministry of Transportation.



(a)



(b)

Figure 2: Elasticities to distance

Notes: Figure plots the elasticity of state-to-state trade and migration flows to Euclidean distance, by year. Panel (a) is for all pairs. Panel (b) splits data into pairs where one member is the state of Goias, and then all other pairs. Data dropped if more than 40% of pairs missing for any one year. Source: Brazilian Statistical Yearbooks 1942-1974.

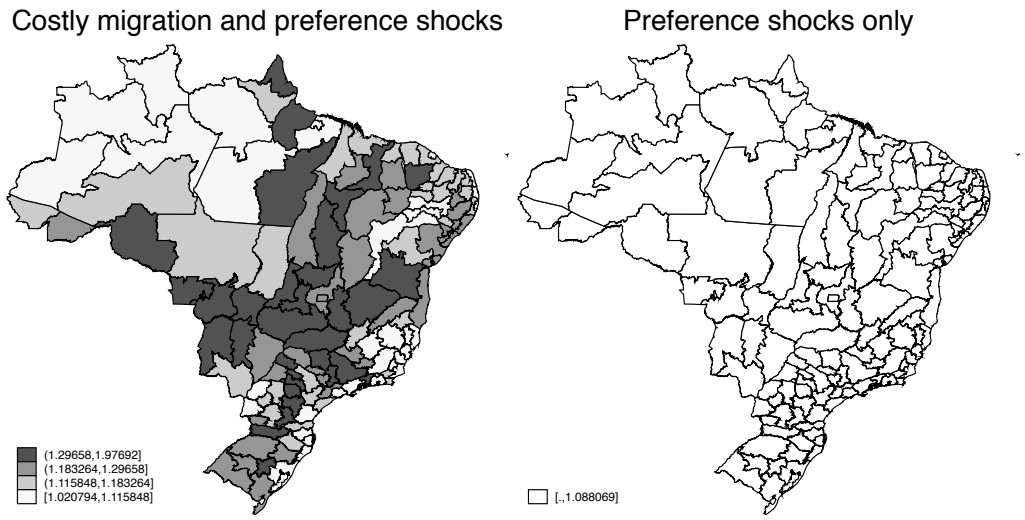


Figure 3: Heterogeneity of impact: Brasilia vs no roads

Notes: Figure shows estimated welfare gains by origin, comparing Brasilia roads vs no roads. Unit of analysis is the meso region. The figure on the left shows estimated welfare for the model with costly migration and preference shocks. The figure on the right shows estimated welfare for the model with preference shocks only. Source: Authors' calculations based on census data.

Table 1: Estimates of gravity equation for interstate trade and migration

	Log trade flow				Log migration flow			
	(1) OLS/level b/se	(2) IV/level b/se	(3) OLS/diff b/se	(4) IV/diff b/se	(5) OLS/level b/se	(6) IV/level b/se	(7) OLS/diff b/se	(8) IV/diff b/se
Log road travel time	-2.37*** (0.28)	-5.81*** (0.54)	-1.65*** (0.32)	-8.26*** (1.17)	-0.49*** (0.12)	-1.26*** (0.19)	-0.26*** (0.090)	-2.30*** (0.36)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OrigxYear FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DestxYear FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pair FE	Yes	Yes	No	No	Yes	Yes	No	No
N	3495	3495	2713	2713	1495	1495	965	965
r2	0.91	0.90	0.48	0.35	0.98	0.98	0.49	0.25

Notes: Gravity for trade estimated from 1942-1949 and 1967-1974 state-to-state value of trade flows. Gravity for migration estimated from 1940, 1960, and 1970 state-to-state population flow using state of birth as origin. Log road travel time computed on actual road networks for 1940, 1960, and 1970 using fast marching algorithm. Instrument is the log road travel time on an empty map for 1940s and on the EMST road network for 1960s and 1970s. Source: Brazilian Statistical Yearbooks 1942-1974.

Table 2: First step estimates: migration costs

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
Dep. variable: Log λ_{knt}	b/se	b/se	b/se	b/se
Log road travel time	-2.74***	-3.70***	-1.48***	-2.22***
	(0.082)	(0.10)	(0.093)	(0.13)
Fixed cost of migrating	-5.32***	-4.20***	-4.38***	-3.61***
	(0.13)	(0.14)	(0.093)	(0.12)
State of birth			1.29***	1.32***
			(0.077)	(0.077)
Year FE	Yes	Yes	Yes	Yes
OrigXYear FE	Yes	Yes	Yes	Yes
DestXYear FE	Yes	Yes	Yes	Yes
No. meso pairs	24,513	24,513	77,054	77,054
No. individuals	12,704,761	12,704,761	12,704,761	12,704,761
Mean migration rate	0.055	0.055	0.055	0.055
Mean distance migrated (km)	675.6	675.6	675.6	675.6
Mean travel time migrated	1.69	1.69	1.69	1.69

Notes: Log λ_{knt} is the share of people from origin k in time t who move to destination n. All pairs involving state capitals are dropped. The maximum number of observations in Cols (1) and (2) is 46,656 (135 origin regions - 27 state capitals = 108 $\times$ 108 destination regions $\times$ 4 years). The maximum number of observations in the specifications which control for state of birth (Cols (3) and (4)) is 1,259,712 (108 $\times$ 108 $\times$ 4 $\times$ 27 states (26 states and the federal district of Brasilia)). Standard errors clustered two-way (origin meso x year and destination meso x year). Source: Brazilian Census data, 1980-2010.

Table 3: Structural coefficient estimates

	(1) Mig costs and pref shocks b/se	(2) Pref shocks only b/se
η (housing elasticity)	0.82***	0.95***
	(0.18)	(0.26)
ϵ (migration elasticity)	3.40***	-0.49
	(0.87)	(0.99)
p value	0.53	.

Notes: Estimated using 2010-1991 and 1991-1980 differences. Dependent variable is indirect utility computed from first step estimates with state of birth. Coefficients calculated using two-step GMM. Robust standard errors provided. Overidentification J statistic and p-value provided. Estimates of housing elasticity use population-weighted market access and (own-wage) bartik shocks as instruments for changes in labor income. Estimates of migration elasticity to wages without price adjustments use population-weighted market access and (own-wage) bartik shocks as instruments. Estimates with price adjustment use population-weighted market access and bartik-based price index. Source: Brazilian Census data, 1980-2010.

Table 4: Counterfactual migration and trade costs

	(1) Trade costs mean, p10, p90	(2) Migration costs mean, p10, p90
Relative cost: Brasilia vs no Brasilia	0.53	0.49
	{0.31}	{0.26}
	{0.91}	{0.89}
Relative cost: Brasilia vs Rio	0.93	0.93
	{0.68}	{0.64}
	{1.15}	{1.17}

Notes: Conversion to cost assumes trade elasticity of 4 and migration elasticity of 3.4.

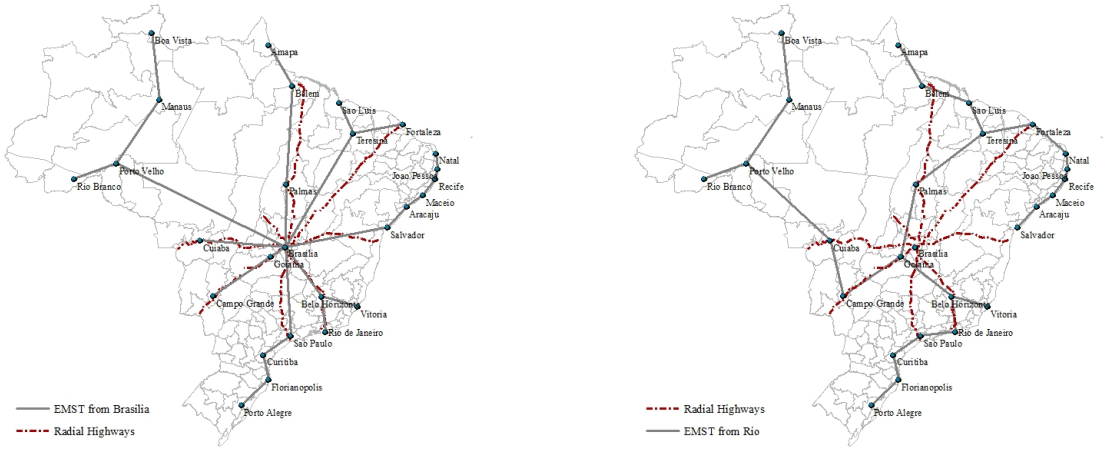
Table 5: Welfare gains of market integration post Brasilia

	Costly migration & preference shocks			Preference shocks only
	(1)	(2)	(3)	(4)
	Both	Trade costs only	Migration costs only	Trade costs
	b/ci	b/ci	b/ci	b/ci
Experiment 1: Brasilia compared to no roads				
Price level	0.853	0.859	0.991	0.882
	[0.827,	[0.831,	[0.972,	[0.858,
	0.876]	0.883]	1.010]	0.916]
Nominal wages	0.986	0.977	1.013	0.967
	[0.957,	[0.954,	[0.989,	[0.948,
	0.992]	0.988]	1.028]	0.997]
Nominal rents	0.991	0.977	1.026	0.874
	[0.935,	[0.912,	[0.990,	[0.820,
	1.012]	0.991]	1.115]	0.929]
Migration rate	1.565	0.883	1.764	1.001
	[1.197,	[0.741,	[1.202,	[1.000,
	2.046]	0.978]	2.626]	1.003]
Utility (V_i)	1.114	1.086	1.033	1.046
	[1.073,	[1.054,	[1.000,	[1.009,
	1.130]	1.112]	1.056]	1.075]
Welfare $(V_{ij}\epsilon_{ij})$	1.108	1.098	1.009	1.089
	[1.086,	[1.076,	[0.999,	[1.069,
	1.289]	1.118]	1.178]	1.108]
Experiment 2: Brasilia compared to Rio EMST				
Price level	0.983	0.981	1.000	0.991
	[0.928,	[0.966,	[0.942,	[0.966,
	1.017]	0.984]	1.044]	1.008]
Nominal wages	0.998	0.997	1.000	1.000
	[0.962,	[0.982,	[0.969,	[0.975,
	1.022]	1.000]	1.027]	1.017]
Nominal rents	0.992	0.995	0.998	0.987
	[0.964,	[0.981,	[0.970,	[0.965,
	1.176]	0.998]	1.208]	1.001]
Migration rate	0.885	0.951	0.937	1.000
	[0.005,	[0.931,	[0.006,	[1.000,
	5.856]	0.970]	5.855]	1.001]
Utility (V_i)	0.999	1.003	0.998	0.998
	[0.905,	[0.997,	[0.900,	[0.994,
	1.131]	1.007]	1.134]	1.001]
Welfare $(V_{ij}\epsilon_{ij})$	1.006	1.009	0.997	1.008
	[0.987,	[1.005,	[0.976,	[1.004,
	1.654]	1.013]	1.636]	1.012]

Notes: Table shows the effect of the counterfactual experiments. All values are relative to a baseline value of 1. Cols (1)-(3) are from the model with both costly migration and unobserved preference shocks. Col (4) sets the origin-destination component of migration cost to zero but retains the unobserved preference shock. Utility is the indirect utility of each location. Welfare is indirect utility, migration cost, and the mean preference shock. 95% confidence interval, computed by 200 parametric bootstrap iterations, reported under coefficient. Source: Authors' calculations from census data.

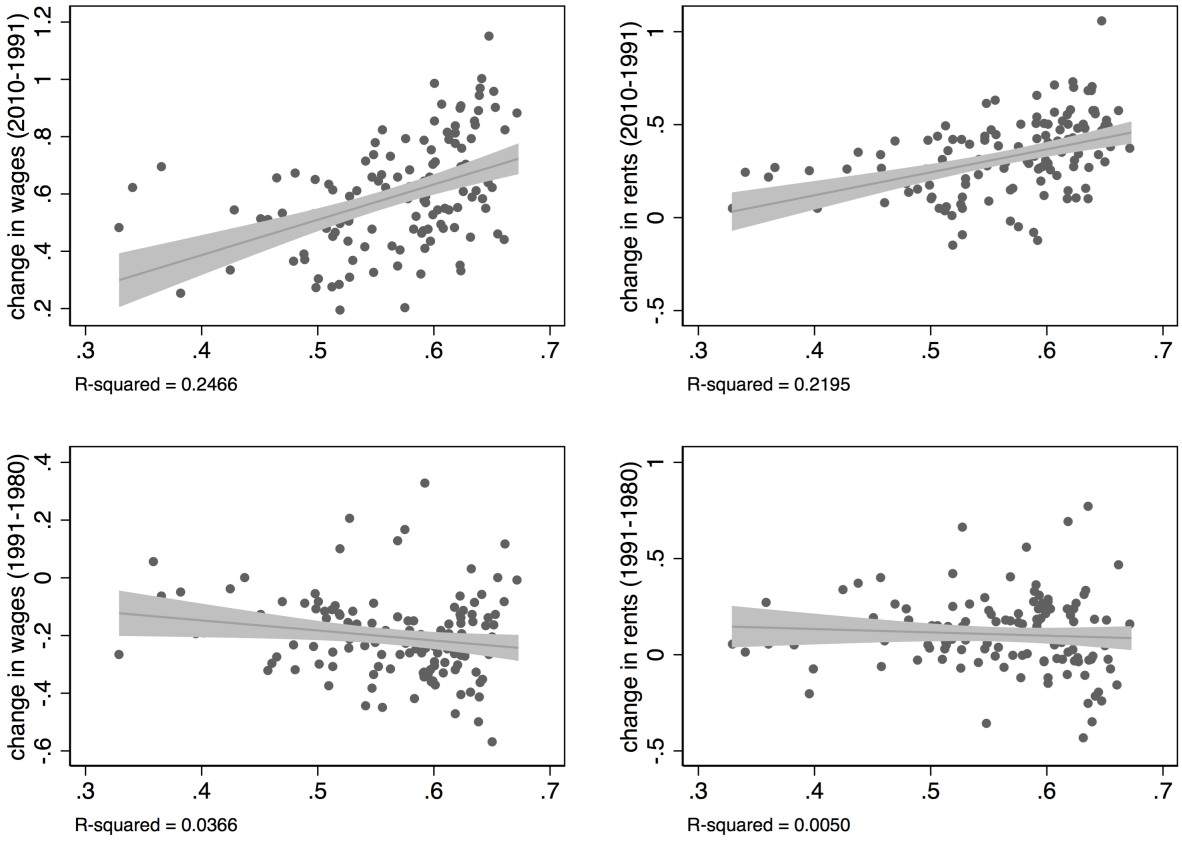
APPENDIX: FOR ONLINE PUBLICATION ONLY

A Appendix Figures and Tables



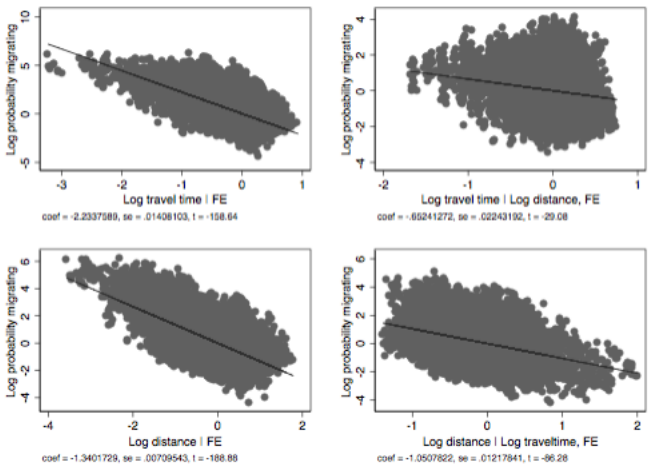
(a) (b)

Notes: Figure shows the EMST for Brasilia (panel A) and the hypothetical EMST if the capital of Brazil had stayed in Rio de Janeiro (panel B).



Appendix Figure 2: Bartik shocks (2010-1991): contemporaneous and lagged changes in wages and rents

Notes: Each dot is a meso region. The graphs at the top plot 2010-1991 Bartik shocks and 2010-1991 changes in wages and rents; the graphs at the bottom plot 2010-1991 Bartik shocks and 1991-1980 changes. Source: Authors' calculations based on census data.



Appendix Figure 3: Bilateral gross migration flows against bilateral distance

Notes: Each dot is a meso-meso pair. The data are pooled for the 1980-2010 period. (Log) travel time is our bilateral measure of travel time computed based on the EMST network. (Log) distance is the Euclidean distance between meso-meso pairs. Measures of travel time and distance are net of origin time year, destination times year, and year fixed effects. Source: Authors' calculations based on census data and maps obtained from the Brazilian Ministry of Transportation.

Appendix Table 1: Summary statistics, by census year

Mean/sd	(1) 1980	(2) 1991	(3) 2000	(4) 2010
Demographic				
Age	35.8	36.4	36.8	37.8
	(11.7)	(11.5)	(11.3)	(11.7)
Years schooling	3.80	5.14	6.35	8.09
	(3.97)	(4.36)	(4.37)	(4.37)
Employment				
Equiv. wage (all)	7.32	5.94	7.96	9.01
	(17.8)	(14.1)	(29.3)	(66.9)
Equiv. wage (employee only)	6.88	5.62	6.76	8.25
	(11.2)	(11.3)	(14.9)	(25.8)
Share pop. who are employees	0.65	0.62	0.64	0.70
	(0.48)	(0.49)	(0.48)	(0.46)
Working in agriculture	0.31	0.30	0.23	0.20
	(0.46)	(0.46)	(0.42)	(0.40)
Working in manufacturing	0.18	0.16	0.15	0.14
	(0.39)	(0.36)	(0.35)	(0.35)
Housing				
Mean rent	314.1	309.9		342.7
	(360.9)	(350.9)		(309.7)
Share paying rent	0.22	0.15	0.13	0.17
	(0.42)	(0.35)	(0.34)	(0.37)
Migration				
Municipality migration rate	0.15	0.11	0.11	0.11
	(0.36)	(0.32)	(0.31)	(0.31)
Meso-region migration rate	0.095	0.070	0.061	0.053
	(0.29)	(0.25)	(0.24)	(0.22)
Missing previous meso	0.014	0.0045	0.0070	0.0045
	(0.12)	(0.067)	(0.084)	(0.067)
Number people	5,896,085	3,540,519	3,965,378	4,471,780
Number municipalities	3,658	3,659	3,659	3,659
Number meso regions	135	135	135	135

Notes: Summary statistics calculated from Census microdata. Sample is 20-65 year old males with non-zero earnings in main occupation, pooling 1980, 1991, 2000 and 2010. Young defined as below median age. Low skilled defined as below median years of schooling. Financial values in year 2000 Brazilian reals (BRL). 1USD =2.3 BRL.

Appendix Table 2: Effect of instrument before Brasilia

	Log population			Log agriculture GDP			Log industry GDP		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	Drop capitals	Drop North	All	Drop capitals	Drop North	All	Drop capitals	Drop North
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
Log distance to EMST	-0.021	-0.0047	-0.011	-0.0093	-0.00070	-0.0031	-0.055	-0.020	-0.039
	(0.036)	(0.027)	(0.027)	(0.037)	(0.038)	(0.039)	(0.074)	(0.063)	(0.064)
Log distance to coast	0.064**	0.022	0.036	0.17***	0.14***	0.15***	0.039	-0.013	0.015
	(0.029)	(0.029)	(0.032)	(0.038)	(0.040)	(0.044)	(0.061)	(0.061)	(0.066)
Log dist. to nearest capital	-0.082	0.050	0.058	0.042	0.071	0.085	-0.49***	-0.34***	-0.32**
	(0.060)	(0.056)	(0.057)	(0.070)	(0.075)	(0.077)	(0.13)	(0.13)	(0.13)
Log distance to Brasilia	0.090	0.043	0.12*	-0.29***	-0.36***	-0.27***	-0.26*	-0.43***	-0.27
	(0.065)	(0.063)	(0.068)	(0.084)	(0.088)	(0.096)	(0.15)	(0.15)	(0.16)
N	1900	1848	1776	2848	2770	2663	2697	2622	2533
r2	0.019	0.018	0.023	0.22	0.23	0.24	0.13	0.12	0.12

Notes: Units of observations are the minimum comparable areas (AMC) as of 1920. Population data refer to 1920 and 1940. GDP data refer to 1920, 1939, and 1949. Shortest distances are computed in GIS using the centroids of the geographic units. Cols (1), (4), and (9) include all AMCs. Cols (2), (5), and (10) drop AMCs which contain a state capital. Cols (3), (6), and (9) drop the Northern region. Standard errors clustered at the AMC level. Source: IBGE and IPEA Data.

Appendix Table 3: First stage estimates, Estimates of gravity equation for interstate trade and migration

	Trade		Migration	
	(1)	(2)	(3)	(4)
	Level	First diff.	Level	First diff.
	b/se	b/se	b/se	b/se
Log EMST	0.43***	0.30***	0.45***	0.24***
	(0.032)	(0.034)	(0.049)	(0.028)
Year FE	Yes	Yes	Yes	Yes
OrigxYear FE	Yes	Yes	Yes	Yes
DestxYear FE	Yes	Yes	Yes	Yes
Pair FE	Yes	No	Yes	No
N	3495	2713	1495	965
r2	0.99	0.87	0.98	0.65
F stat log EMST	183.9	80.4	83.8	76.2

Notes: Log road travel time computed on actual road networks for 1940, 1960, and 1970 using fast marching algorithm. Instrument is the log road travel time on an empty map for 1940s and on the EMST road network for 1960s and 1970s. Source: Brazilian Ministry of Transportation 1940, 1960, 1970.

Appendix Table 4: First stage estimates, First step estimates: migration costs

Dep var: log road travel time	(1) b/se	(2) b/se
Log EMST x 1980	0.84***	0.77***
	(0.037)	(0.032)
Log EMST x 1991	0.80***	0.75***
	(0.029)	(0.027)
Log EMST x 2000	0.77***	0.71***
	(0.029)	(0.028)
Log EMST x 2010	0.78***	0.70***
	(0.028)	(0.026)
State of birth		-0.00068
		(0.0044)
Year FE	Yes	Yes
OrigXYear FE	Yes	Yes
DestXYear FE	Yes	Yes
No. meso pairs	24,513	77,054

Notes: Instrument is the log travel time on the EMST network between origin k and destination n. The maximum number of observations in Cols (1) and (2) is 46,656 (135 origin regions - 27 state capitals = 108 $\times$ 108 destination regions $\times$ 4 years). The maximum number of observations in the specifications which control for state of birth (Cols (3) and (4)) is 1,259,712 (108 $\times$ 108 $\times$ 4 $\times$ 27 states (26 states and the federal district of Brasilia)). Source: Brazilian Census data, 1980-2010.

Appendix Table 5: First step estimates: migration costs. Poisson estimates

	IV	OLS		Poisson	
	(1)	(2)	(3)	(4)	(5)
Dep. variable: Log λ_{knt}	b/se	b/se	b/se	b/se	b/se
Log road travel time	-2.22***	-1.48***		-1.34***	
	(0.13)	(0.093)		(0.12)	
Fixed cost of migrating	-3.61***	-4.38***	-3.64***	-5.02***	-4.38***
	(0.12)	(0.093)	(0.096)	(0.12)	(0.14)
State of birth	1.32***	1.29***	1.31***	0.88***	0.88***
	(0.077)	(0.077)	(0.077)	(0.057)	(0.059)
Log EMST x 1980			-1.79***		-1.34***
			(0.095)		(0.12)
Log EMST x 1991			-1.47***		-1.34***
			(0.086)		(0.11)
Log EMST x 2000			-1.30***		-1.33***
			(0.096)		(0.10)
Log EMST x 2010			-1.84***		-1.81***
			(0.081)		(0.12)
Year FE	Yes	Yes	Yes	Yes	No
OrigXYear FE	Yes	Yes	Yes	Yes	Yes
DestXYear FE	Yes	Yes	Yes	Yes	Yes
No. meso pairs	77,054	77,054	77,054	1,098,790	1,098,790

Notes: Log λ_{knt} is the share of people from origin k in time t who move to destination n. The maximum number of observations in the specifications which control for state of birth is 1,259,712 ($108 \times 108 \times 4 \times 27$ states (26 states and the federal district of Brasilia)). Standard errors clustered two-way (origin meso x year and destination meso x year). Source: Brazilian Census data, 1980-2010.

Appendix Table 6: First step estimates: migration costs. IV estimates by year

Dep. variable: Log λ_{knt}	(1) Pooled b/se	(2) 1980 b/se	(3) 1991 b/se	(4) 2000 b/se	(5) 2010 b/se
Log road travel time	-2.22***	-2.93***	-1.85***	-1.60***	-2.34***
	(0.13)	(0.29)	(0.19)	(0.22)	(0.20)
Fixed cost of migrating	-3.61***	-2.60***	-3.83***	-4.02***	-4.05***
	(0.12)	(0.25)	(0.18)	(0.17)	(0.18)
State of birth	1.32***	1.32***	1.30***	1.38***	1.24***
	(0.077)	(0.14)	(0.14)	(0.15)	(0.13)
Year FE	Yes	No	No	No	No
OrigXYear FE	Yes	Yes	Yes	Yes	Yes
DestXYear FE	Yes	Yes	Yes	Yes	Yes
No. meso pairs	77,054	21,678	17,443	18,718	19,215
No. individuals	12,704,761	5,727,814	3,499,540	3,920,757	4,329,368
Mean migration rate	0.055	0.096	0.070	0.061	0.050
Mean distance migrated (km)	675.6	659.0	711.4	694.7	685.4
Mean travel time migrated	1.69	1.94	1.82	1.65	1.56

Notes: Log λ_{knt} is the share of people from origin k in time t who move to destination n. The maximum number of observations in Cols (1) and (2) is 46,656 (135 origin regions - 27 state capitals = 108 $\times$ 108 destination regions $\times$ 4 years). The maximum number of observations in the specifications which control for state of birth (Cols (3) and (4)) is 1,259,712 (108 $\times$ 108 $\times$ 4 $\times$ 27 states (26 states and the federal district of Brasilia)). Standard errors clustered two-way (origin meso x year and destination meso x year). Source: Brazilian Census data, 1980-2010.

Appendix Table 7: Decomposition of net returns to migrating into costs and returns

	Baseline	Incl. state birth	Low Skilled		High Skilled	
	(1)	(2)	(3)	(4)	(5)	(6)
			Young	Old	Young	Old
All possible moves						
Net return to migrating	-2.710	-1.948	-1.575	-1.746	-1.740	-1.716
Observed return	0.000	-0.000	0.000	0.000	0.000	0.000
Unobserved return	0.000	0.000	0.000	0.000	0.000	0.000
Observed cost	-2.710	-1.948	-1.575	-1.746	-1.740	-1.716
Observed cost (% of utility)	0.933	0.857	0.793	0.825	0.824	0.820
Share of observed migration cost						
Fixed	0.456	0.546	0.716	0.685	0.601	0.691
Travel time	0.544	0.454	0.284	0.315	0.399	0.309
State of birth		-0.000	-0.000	0.000	0.000	-0.000
Moves that occurred						
Net return to migrating	0.385	1.186	1.271	1.171	1.246	1.193
Observed return	-0.293	-0.263	-0.183	-0.126	-0.252	-0.182
Unobserved return	2.916	3.165	2.889	2.908	3.038	2.965
Observed cost	-2.238	-1.716	-1.436	-1.611	-1.540	-1.590
Observed cost (% of utility)	0.893	0.820	0.762	0.800	0.785	0.796
Share of observed migration cost						
Fixed	0.552	0.620	0.786	0.742	0.680	0.746
Travel time	0.448	0.443	0.260	0.279	0.379	0.281
State of birth		-0.062	-0.046	-0.021	-0.059	-0.027
Mean migration rate	0.071	0.071	0.094	0.051	0.091	0.054

Notes: Based on the baseline estimates from first step estimation. Table shows logged values. Observed cost (% of utility) is average utility cost of migrating (1 -1/exp(log observed cost)). Values converted using an elasticity of migration to wages of 3.4.

Appendix Table 8: Estimates of gravity equation for trade - 1999 data

	(1) OLS b/se	(2) IV b/se
Log road travel time	-2.91***	-3.26***
	(0.26)	(0.24)
Orig FE	Yes	Yes
Dest FE	Yes	Yes
N	682	682
r2	0.89	0.89

Notes: 1999 state-to-state trade flow data are based on state tax data. We use the 2000 road network to construct road travel time between state pairs. Instrument is the log travel time on the EMST network between origin k and destination n. The maximum number of observations is 702 ($27 \times 27 - 27$). Source: De Vasconcelos (2001).

Appendix Table 9: Structural coefficient estimates: with and without adjustment for price

	Nominal				Real			
	(1) Cost b/se	(2) Cost/birth b/se	(3) No cost b/se	(4) No cost/birth b/se	(5) Cost b/se	(6) Cost/birth b/se	(7) No cost b/se	(8) No cost/birth b/se
η (housing elasticity)	0.84***	0.84***	0.95***	0.95***	0.84***	0.82***	0.95***	0.95***
	(0.19)	(0.19)	(0.26)	(0.26)	(0.18)	(0.18)	(0.26)	(0.26)
ϵ (migration elasticity)	5.00***	1.93***	-0.071	-0.66	9.71***	3.40***	0.26	-0.49
	(1.14)	(0.51)	(0.30)	(0.58)	(2.17)	(0.87)	(0.52)	(0.99)
p value	0.0096	0.29	.	.	0.086	0.53	.	.

Notes: Estimated using 2010-1991 and 1991-1980 differences. Coefficients calculated using two-step GMM. Robust standard errors provided. Overidentification J statistic and p-value provided. Columns (1)-(4) depict parameters estimates for the model that does not adjust wages for price of tradeables. Columns (5)-(8) present estimates that are adjusted for price. Estimates of housing elasticity use population-weighted market access and (own-wage) bartik shocks as instruments for changes in labor income. Estimates of migration elasticity to wages without price adjustments use population-weighted market access and (own-wage) bartik shocks as instruments. Estimates with price adjustment use population-weighted market access and bartik-based price index. Source: Brazilian Census data, 1980-2010.

B Data Appendix

B.1 Municipality Level Database

B.1.1 Geographic Units

Municipality boundaries change over time. In order to analyze the same geographical area, we use data aggregated to two geographical regions. The first are the minimum comparable areas (*areas minimas comparaveis*) constructed by the Institute of Applied Economic Research in Brazil. We refer to these units as AMCs, or municipalities for short hand. There are 3659 AMCs in Brazil in the period 1970 to 2000. The second unit of analysis are meso-regions. Meso-regions are statistical regions constructed by the Brazilian Institute of Geography and Statistics (IBGE). The 3659 were grouped into 137 meso-regions; we merge two of these meso regions together because of overlapping municipality boundaries. This leaves us with a final sample of 135 regions.

We construct a regional database of migration, wages and roads at the municipality level between 1970-2010. Summary statistics for the regional database are presented in Appendix Table 1). The primary datasource is the individual data files from the Brazilian Census, 1970-2010, collected by the Brazilian Institute of Geography and Statistics (IBGE). Our sample of interest is males aged 20-65 who report non-zero earnings in their main occupation. All nominal variables are converted into constant 2010 prices; the exchange rate between the USD and Real is approximately 1 USD = 2.3 BRL. [28]

B.1.2 Employment and wages

Wage data are sourced from the census. The census asks both the average earnings per month in the main occupation,[29] as well as the usual hours worked. We use earnings from main occupation and the hours worked to construct an equivalent hourly wage rate. This wage rate is 7.6 BRL on average. This average wage matches well to GDP estimates. Assuming a

[28] We constructed a modified consumer price index that accounts for changes in the Brazilian currency that occurred within the period under analysis. All nominal variables were converted to 2010 BRL. See http://www.ipeadata.gov.br/ for the factors of conversion for the Brazilian currency.

[29] The exception is 1970, where only total earnings, rather than earnings in the main occupation, is asked.

standard 2000 hour work year, the annual wage of 7.3 BRL in 1970 and 9.0 BRL in 2010 would be equivalent to annual incomes of $3000 and $7800. The per capita GDP figures for Brazil are $2400 in 1970 and $5600 in 2010 (World Development Indicators).

Nearly 65% of the population report being employees rather than self-employed. The share working in agriculture is about 26%. The high proportion of self-employed people, particularly in agriculture, may generate concerns that the wage we compute does not accurately reflect actual income. To check for this issue, we use detailed municipality level agriculture input and output data collected in agricultural censuses to show that self-reported income in the population census is highly correlated at the municipality level with agricultural profits (For details, see Appendix B.6).

B.1.3 Migration

The current location of the individual is coded to the municipality level. From 1980 location 5 years ago is also coded to the municipality level. We are able to match the previous location at the municipality for 99.2% of the population (96% of people who report living in a different municipality 5 years ago.)[30] The inter-municipality migration rate is 12% in our sample. Of these moves, 60% (i.e. a migration rate of 7.2%) were between meso-regions.

A focus of our paper is to examine the spatial equilibrium of migration in a model with many locations. This is important because internal migration is more complex than simply rural-urban migration: using these data, 16% of all migrants are rural-rural migrants in 1980; 41% are urban-urban migrants; 35% are rural-urban and 6.8% are urban-rural (numbers not reported in table but available upon request from authors). Our spatial model will capture the heterogeneity in migrant destination by studying the locational choice over N locations.

The relationship between bilateral (gross) migration and bilateral distance is shown in Appendix Figure 3. The first two graphs are plot of the (residual) migration flows against the travel distance. Conditional on destination fixed effects, there is a clear negative relationship between travel

[30]For the other 4%, the location is given at the state, not municipality, level. Fewer than 0.05% of the population report living abroad 5 years previously, so we ignore international migration.

distance and migration. This relationship weakens when we condition on the straight-line distance between origin-destination pairs, but it is still negative. Gross migration flows are also inversely related to straight-line distance, with and without conditioning on travel distance. Overall, the data show that places which are closer and/or more connected through the road network experience larger inflows and outflows of people.

B.1.4 Rental prices

To convert nominal wages into real wages, we need to construct measures of the cost of living across space. Unfortunately, consumer price data is not collected at the municipality level. We instead construct costs of living using the best data sources available: a consumer price index collected at 10 cities in Brazil, and housing prices collected in the population census.

The national consumer price index is a data series collected by IBGE for 10 locations across Brazil. For each AMC, we merge to the closest price collection point. In the analysis, we will make an adjustment sourced from equations linking the ability of a region to trade with other regions and source cheaper products to generate a measure of the change in price indices. Second, we use rental rates from the population census. Approximately 17% of our sample report paying rent to live in their accommodation.

For rental rates we use census data on the rents paid for housing. The mean rental rate for one bedroom is 321 BRL a month, equivalent to 42 hours of work at the mean wage. We show in Appendix B.7 that rental rates are positively correlated with the relative price index. 17% of the population report paying rents for their housing. While this may seem low, the equivalent number for US houses in 2005 is 24%. We run the estimation under several different definitions of the rental variables, including hedonic pricing to impute the cost of non-rented units, and find that the results are robust across definitions of the housing cost variable.

B.2 Historical state-to-state trade and migration flows

We draw state-to-state trade flow data from the statistical yearbooks produced by the IBGE. These data are available annually, spanning the periods 1942-1949 and 1967-1974. The yearbooks report the value of total ex-

ports of each state to other states across the country. The data was sourced by the Technical Council of Economics and Finance.

Data on state-to-state migration flows are also available from the statistical yearbooks on a decennial basis for the years 1940-1980. The books report the number of residents in all states by state of birth. Therefore, we are able to construct these flows for origin of birth. The data come from the decennial Censuses conducted by the IBGE.

For the year 1999, interstate bilateral trade flow data are derived from information on state tax on the movement of goods and services (*Imposto sobre Circulacao de Mercadorias e Servicos*). We use the study produced by de Vasconcelos (2001) as a data source.

B.3 Road data

Our geographic data come from two sources. We obtained vector-based maps from the highway network for the period 1940 to 2000 from the Brazilian Ministry of Transportation. These maps were constructed based on statistical yearbooks from the Ministry's Planning Agency, previously known as GEIPOT. We used the ArcGIS software to georeference the maps to match real-world geographic data. The geographic coordinate system applied to the maps is the SIRGAS 2000.

The second source of data is the IBGE, which provides municipality boundaries maps in digital format. We use the municipality boundaries from 2000 and apply the crosswalk that maps the municipalities that existed in 2000 into AMCs. We then aggregate the AMCs up to meso regions. Due to overlap with AMC boundaries, we need to combine two sets of two meso regions, creating 135 adjusted meso regions. This will be our primary unit of analysis for the spatial component. [31]

Similar to the road data, we applied the coordinate system SIRGAS 2000 to the AMC and meso-region boundaries. Finally, in order to compute geographic distances in kilometers, we projected the maps using the Brazil Mercator projection.

[31] The crosswalk file can be obtained from http://www.ipeadata.gov.br/. For cases where is overlap between the AMC and the meso region we assign the AMC to the meso region which has the largest number of 2010 component municipalities. We then group together Madeira-Guapore and Leste Rondoniense (both in Rondnia) and Sul de Roraima with Norte de Roraima (two meso regions in Roraima).

B.4 Bilateral road travel time

To construct measures of the distance between origin-destination pairs taking into account the actual road coverage we use the fast marching algorithm, following the approach used in Allen and Arkolakis (2014).The fast marching algorithm finds the solution to the Eikonal equation used to characterize the propagation of wave fronts. The algorithm uses a search pattern for grid points in computing the arrival times (distances) that is similar to the Dijkstra shortest path algorithm (Hassouna and Farag (2007)). However, because the fast marching algorithm is applied to a continuous graph, it reduces the grid bias and generates more accurate bilateral distances.

First, we generate a picture of the road network and the location of the 135 meso-regions. This picture is converted into pixels and a travel speed is assigned to each pixel. Pixels corresponding to a paved road are assigned a travel speed of 100, whereas pixels outside the road network are assigned a travel speed of 10. Essentially, this algorithm finds the shortest route, traveling on roads, between two locations, with the minimum off-road traveled to connect a region without a road to the road network. The outcome is a 135x135 matrix where each entry corresponds to the fastest arrival time between a origin-destination pair. We undertake the same exercise for our predicted highway system (the EMST network) to find an instrument for the actual bilateral cost using the travel time on the exogenous road network.[32]

B.5 Minimum Spanning Tree network

We use ArcGIS to compute the EMST network. First, we use the latitude-longitude coordinates to create point features representing the location of Brasilia and the 26 state capitals. Next, we divide the country into 8 exogenous slices, and consider the optimal network connecting the cities within each slice. We do this to avoid exogenous choice in which capital cities were connected to Brasilia. We proceed by creating an imaginary pie sliced into eight parts and centered around Brasilia. We form eight 45 degree slices starting from North and moving clockwise. Then, we classify the

[32]See Section 2.1 for details on the EMST network.

26 state capitals into eight groups, according to the location of their bearing with respect to Brasilia. We use the Spanning Tree Tool, in Arcmap, to find the minimum spanning tree connecting the states in each of the eight groups.[33]

B.6 Self-reported agricultural income

In the Brazilian census, between 50-70% of the sample who report working in agriculture are self-employed rather than employees.[34] Self-reported income in censuses may not accurately reflect agricultural wage income for at least three reasons: i) self-reported income may be revenues, rather than income, ii) it may contain payments to both labor as well as other factors of production such as capital, or iii) it may be more accurately provided at the household, rather than the individual, level (Lagakos et al. (2012)). In this section we use data from Brazilian agricultural censuses and present evidence that, despite the potential problems, agriculture self-employment income as measured in population censuses highly correlates with agriculture profits computed from agricultural censuses. In addition, we run the reduced form analysis in the paper both including and excluding non-employees, and results are robust.

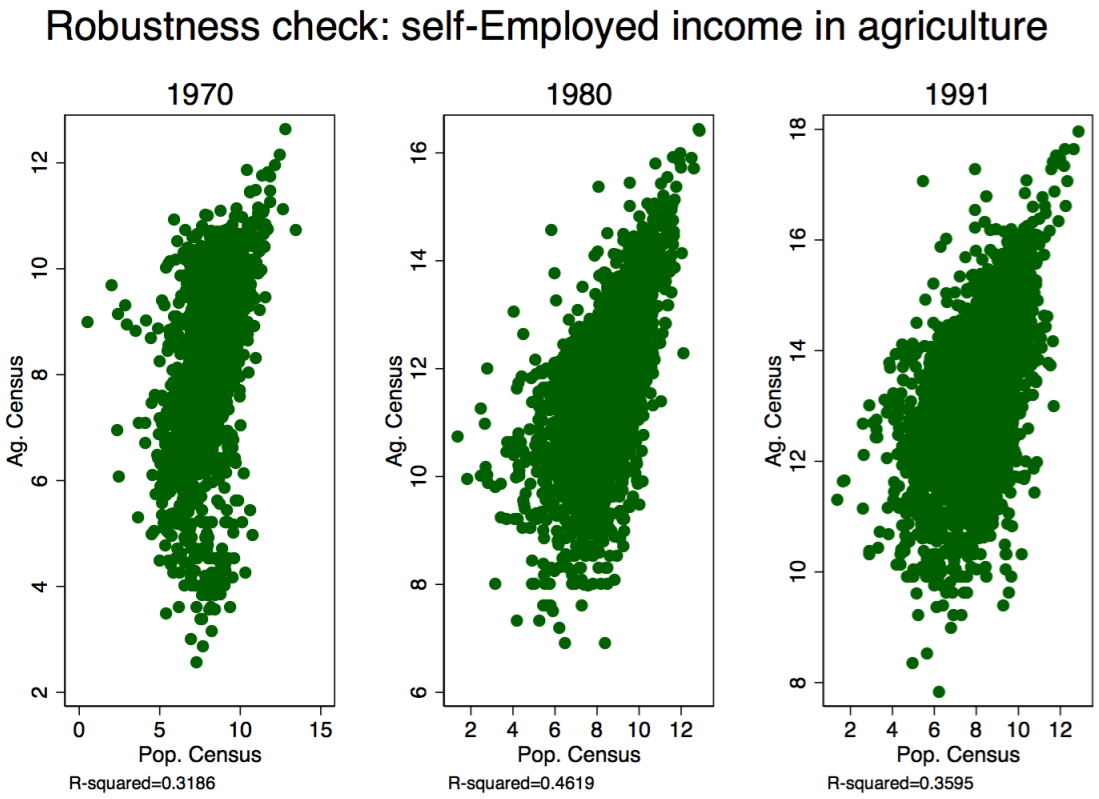
Starting in 1970, the Agriculture Censuses were collected every five years. The agriculture census allows us to measure agricultural income accurately as it covers the universe of agricultural production unities, regardless of their size, output level, or location.[35]It is worth mentioning that home gardens were not considered as agricultural unities for the purpose of data collection. Nonetheless, we believe that we only miss some of the production for own consumption of those who work mainly outside the agricultural sector.

We obtain the series of agriculture revenues and expenses at the AMC level from IPEADATA. Agriculture revenue comprises proceeds from the sale of agricultural products, including final goods produced inside the agricultural unities, as well as revenues from the rental of land and livestock and services rendered to third parts. Agriculture expenses include expenses with wages, rents, other inputs, and operational expenses. Our

[33]The tool uses Prim's algorithm to design the euclidean minimum spanning tree.
[34]The share of the population working in labor force declines from 46% in 1970 to 22% in 2010.
[35]The agricultural censuses include unities located in urban areas.

benchmark measure of AMC-level agricultural income is agricultural profits, as measured by the difference between revenues and expenses. We used the years 1975, 1980, and 1996, which are the closest to the population census years (1970, 1980 and 1991).

Appendix Figure 4 displays the scatterplot of the agriculture (log) profits obtained from the agriculture census against the agriculture self-employment (log) income computed from the population census. The two income measures are positively correlated. The R-squared from regressing the level of agriculture self-employment income on the level of agriculture profits indicates is 0.80.



Appendix Figure 4: Comparison: population and agricultural censuses

Appendix Table 10: Correlation of CPI with other measures of cost of living

Dep var: Relative price index	(1) b/se	(2) b/se
Mean agricultural prices (producer)	0.026**	
	(0.0097)	
Mean rental rate		0.0037
		(0.015)
Year FE	Yes	Yes
N	22	40

Notes: Each observation is a municipality-year. The CPI is collected at 10 locations in Brazil. For each year, we normalize the mean of the index to 1, so the index measures spatial variation in the cost of living. Agriculture prices are available for 1980, 1991 and 2000. Rents are available for 1970, 1980, 1991 and 2010. Standard errors clustered at the municipality level.

B.7 Cost of living

Consumer prices are only collected at 10 cities in Brazil. In this section, we show how the prices correlate with two measures of the cost of living: mean rental rates from the population census, and producer prices at the municipality level computed from the agricultural census. The dependent variable is the price index, normalized each year to have value 1. The agricultural price index is a weighted average of the prices of the 4 main agricultural crops (soy, sugarcane, coffee and corn), sourced from the agricultural census. The rental rate is the mean rental rate per bedroom, sourced from the population census. Table 10 show that both are positively correlated with the relative price index, although the small sample size means that the rental rate is not statistically significant.[36]

[36] Additionally, the CPI is only collected in cities, as a result, there is less variation in rental rates that in the entire sample. The variable of (log) rental rates in the municipalities included in the CPI sample is 0.49, compared with a variance of 0.84 across all municipalities.

C Bartik Shocks

We construct exogenous productivity shocks to instrument for $\Delta \log w_{nt}$. The specific productivity shock we construct is a Bartik shock (Bartik (1991)). These shocks are extensively used in urban economics to generate spatial productivity differences (two recent examples, see Diamond (2016), Notowidigdo (2013).) The Bartik shock takes the national-level growth rate in employment for each industry, and constructs a location specific shock based on a baseline industry specialization of each location. Precisely, we compute the nation-wide increase in wages for each industry between period $t-1$ and period t and then assign a predicted wage shock to location k, based on the baseline composition of industry in location n (empirically, we define this as the composition of employment across industries in 1970). Let the Bartik shock for location n be given by

$$\Delta B_{nt}^{w} = \sum_{\text{ind}} (\Delta \log w_{\text{ind},-n,t}) \frac{L_{\text{ind},n,0}}{L_{n,0}},$$

where $\log w_{\text{ind},-n,t}$ is the average log wage in industry ind in year t, excluding workers in location n, and $L_{\text{ind},n,0}/L_{n,0}$ is the baseline industry composition in location n. The Bartik shocks utilize variation across space in the location of industry.[37]

While ΔB_{nt}^{w} provides an instrument for $\Delta \log w_{nt}$, an instrument for the log-linearized price index (in Equation 20) is

$$\Delta \log P_{nt}^{z} = \sum_{s \in N} \frac{1}{\hat{d}_{sn}} \Delta B_{st}^{w},$$

where $\hat{d}_{sn}$ is the estimate of trade cost obtained from the gravity for trade using 1999 data. This instrument is a bartik-based price index.

Finally, we need an instrument for $\Delta \log L_{nt}$. From the model, we can write labor supply to location n as

$$L_{nt} = \sum_{s \in N} \lambda_{snt} L_{s,t-1}.$$

[37] The employment version of Bartik shocks is computed as

$$\Delta B_{nt}^{L} = \sum_{\text{ind}} (\Delta \log L_{\text{ind},-n,t}) \frac{L_{\text{ind},n,0}}{L_{n,0}}$$

Taking logs and total derivatives yield

$$\begin{aligned}
\log L_{nt} &= \log\left(\sum_{s\in N} \lambda_{snt} L_{s,t-1}\right) \\
\frac{dL_{nt}}{L_{nt}} &= \sum_{s\in N} \lambda_{snt} \frac{L_{s,t-1}}{L_{nt}} \frac{dL_{s,t-1}}{L_{s,t-1}} \\
\Delta \log L_{nt} &= \sum_{s\in N} \mu_{snt} \Delta \log L_{s,t-1}, \qquad (18)
\end{aligned}$$

where μ_{snt} is the proportion of the current labor force in n that migrated from s between $t-1$ and t. Equation (18) motivates the following instrument for $\Delta \log L_{nt}$

$$\Delta \log L^{z}_{nt} = \sum_{s\in N} \frac{1}{\hat{\kappa}_{sn}} \Delta B^{L}_{s,t-1},$$

which is the sum of the lagged employment Bartik across all origins weighted by the inverse of the estimated migration cost (obtained from the first step). This instrument is a population-weighted market access.

D Decomposition of migration costs

With the migration elasticity in hand it is now possible to convert the estimated migration costs into utility-constant terms. To illustrate the magnitudes of the migration cost estimates we decompose the total migration cost estimates into its components in Appendix Table 7. The table has two panels. The first panel shows the cost decomposition over all possible moves. The second panel shows the cost decomposition over moves which actually occur.

Starting with the first panel, the average bilateral migration cost equivalent to 93% of utility. The fixed cost is the dominant component representing 46% of the total cost. The contribution from the bilateral road travel time is 54%. The unobserved extreme value preference shock has the same mean across all locations and so on average the contribution of the unobserved component of the cost is zero.

Migration is more likely to occur between pairs that have lower migration costs and between pairs in which the net unobserved shock an individual receives is large and positive. The overall estimates therefore

overstate the costs of moving. In the second panel of Table 7 we present the decomposition of migration costs for moves that actually *occur* in the data. Observed migration moves are shorter in distance than the average move. This is seen by the level of the observed migration cost falling (2.2 vs 2.7; 89% of utility compated to 93%). We adapt Kennan (2006)'s results to the Frechet distribution, and show the mean unobserved component of the cost for people who choose to move from k to n is given by:[38]

$$\underbrace{\frac{V_{nt}}{V_{kt}}}_{\text{observed return}} \quad \underbrace{\frac{c_{kkt}}{c_{knt}}}_{\text{observed cost}} \quad \underbrace{\frac{E(b_{nt}|\text{choose } n)}{E(b_{kt}|\text{don't choose } k)}}_{\text{unobserved return}} = \frac{1-\lambda_{kkt}}{\lambda_{kkt}^{\frac{1}{\epsilon}} - \lambda_{kkt}}$$

Using this formula, we can separate out the unobserved cost from the observed cost. We do this in the second panel of Table 7. The first thing to note is that the unobserved component on the migration cost is large: it is -1.3 times the total observed cost. We decompose the observed components of the cost in the same way as earlier. Compared to the first panel, moves that occur are those that are closer, and so the fixed cost is a larger component of the total cost (55% vs 46%). The component due to travel time on roads is 45%.

Although the incurred migration cost is negative, this does not mean that migration costs are not important. Rather, the larger the observed component of the migration cost, the larger the unobserved shock will need to be in order to induce someone to move. Pairs with lower bilateral costs of moving will have larger migration flows between them because it is more likely that someone has a large enough preference shock to compensate for the cost incurred, all else equal.

Accounting for the utility people have when they live in their state of birth reduces the migration cost (Column 2): the average cost falls to 86% of utility from 93%, and average incurred cost is 82% compared to 89%. On average, slightly more people move from a region that is in their state of birth to a region that is out of their state of birth than the opposite direction, and so the average incurred cost for the change in birth utility is positive (and many people move from one region in their state of birth to another region also in their state of birth so do not incur any change in their component of their utility, contributing zero for this piece of the

[38] Details on how to compute unobserved costs are in Appendix E.3.

cost). Controlling for utility from living in the state of birth increases the fixed component of the migration cost for moves that incur from 55% to 62%, but the component due to travel time remains stable as the net gain from moving to the birth state compensates for the reduction in fixed cost.

The remainder of Table 7 carries out robustness exercises on the migration cost. We first estimate the model separately for different demographic groups.[39] Related literature, mostly in the US, has found that older people and lower skilled people are less likely to migrate (Notowidigdo, 2013; Schulhofer-Wohl and Kaplan, 2015). In Brazil, we find that migration rates are higher for young people, but do not depend on their level of education: the migration rate of younger people (defined as below median, approximately 35 years in the sample) is 9%, compared to the migration rate of older people of 5%. However, the migration rates of low skilled (defined as below-median level of education in each census year) are comparable to the migration rate of high skilled people: young low skilled people migrate at a rate of 9.4%, compared to the migration rate of 9.1% for young high skilled migrants (old low skilled migrate at a rate of 5.1% compared to a rate of 5.4% for old high skilled). Differential migration rates can either be explained by differential costs of moving or differential returns to migrating. The estimated migration costs by demographic group are remarkably stable: from the first panel, these range from 79% of utility for young low-skilled to 83% for old low-skilled (for the moves that actually occur, the range is 76% to 80%).

E Theoretical derivations

E.1 Dynamics

One other important component of the migration decision may be dynamic in nature: a location has benefits both today, but also in the future, given that the individual should be expecting to reoptimize location in the following period. While the main focus of our analysis is through the lens

[39] The spatial equilibrium model we propose assumes homogenous labor force and does not allow for migration costs to be different across demographic groups. A full treatment of heterogeneity in migration responses to changes in moving costs requires extending the spatial equilibrium model to accommodate different types of labor in the local production function. Nonetheless, for estimating differences in the magnitudes of these costs, we do not need to make assumptions about the production function.

of a static model, it is easy to extend the model to incorporate dynamics. Our estimation strategy is robust to the presence of a dynamic component of utility (the "continuation value", below). However, our counterfactuals do not account for any dynamic benefits of roads. In that sense, our counterfactuals are an underestimate of the cumulative effect of roads through repeated migration decisions.

Following Artuç et al. (2010),[40] at a given time t, the (log) utility flow that worker ω living in k and moving to n enjoys is:

$$\log U_{\omega knt} \equiv \tilde{U}_{\omega knt} = \tilde{B}_{nt} + \tilde{w}_{nt} + \tilde{b}_{\omega nt} - \tilde{\kappa}_{knt},$$

[41] where $\tilde{B}_{nt} = \log B_{nt}$, $\tilde{w}_{nt} = \log w_{nt} - \alpha \log P_{nt} - (1-\alpha)\log r_{nt}$ and $\tilde{b}_{\omega nt} = \log b_{\omega nt}$. Since $b_{\omega nt}$ has a Frechet distribution, $\tilde{b}_{\omega nt}$ has a Gumbel distribution. In a dynamic model, workers also take into account the expected future value of living in the destination n given their information set at time t, $\beta E_t V_{n,t+1}$. Therefore, the probability that a worker will migrate from k to n at time t is given by:

$$\lambda_{knt} = \frac{\exp(\tilde{B}_{nt} + \tilde{w}_{nt} + \beta E_t V_{n,t+1} - \tilde{\kappa}_{knt})}{\sum_{s \in N} \exp\left(\tilde{B}_{st} + \tilde{w}_{st} + \beta E_t V_{s,t+1} - \tilde{\kappa}_{kst}\right)}. \tag{19}$$

The estimating equation from this model is exactly the same as Equation (9). The only difference from the original model is the continuation value $\beta E_t V_{n,t+1}$. The continuation value is isomorphic to an amenity value of location n and is included in the fixed effect terms, denoted as $\hat{\delta}^{\kappa}_{nt}$.

$$\log \lambda_{knt} = \hat{\delta}^{\kappa}_{nt} + \hat{\delta}^{\kappa}_{kt} - \epsilon\lambda \log(1 + \text{travel time}_{knt}) + \varepsilon^{\kappa}_{knt}$$

E.2 Log-linearization of price index

The price index in location n is given by:

$$P_n = \gamma \left[\sum_{s \in N} A_{st} (d_{nst} w_{st})^{-\theta} \right]^{-1/\theta}$$

[40] Caliendo et al. (2015) adopts this methodology to study the dynamic effects in the US from increased trade with China.

[41] Artuç et al. (2010) assumes that a worker starting in location k at time t enjoys the real wage at the origin, $\tilde{w}_{kt}$ and then pays the cost of migrating to the destination k. Unlike them, we assume that the worker who chooses to migrate from k to n at time t enjoys the real wages at the destination, $\tilde{w}_{nt}$

We log-linearize the price index using the following steps:

1. Take logs

$$\log P_{nt} = \log \gamma - \frac{1}{\theta} \log \left[\sum_{s \in N} A_{st} (d_{nst} w_{st})^{-\theta} \right]$$

2. First order Taylor expansion around $\log P_{nt-1} = f(w_{1t-1}, w_{2,t-1}, ..., w_{s,t-1})$

$$\log P_{nt-1} + \frac{1}{P_{n,t-1}} (P_{nt} - P_{n,t-1}) = \log \gamma - \frac{1}{\theta} \log \left[\sum_{s \in N} A_{s,t-1} (d_{ns,t-1} w_{s,t-1})^{-\theta} \right] - \sum_{s \in N} \frac{-\theta A_{s,t-1} d_{ns,t-1}^{-\theta} w_{s,t-1}^{-(\theta+1)}}{\theta \left[\sum_{s \in N} A_{s,t-1} (d_{ns,t-1} w_{s,t-1})^{-\theta} \right]} (w_{st} - w_{s,t-1})$$

3. Cancel off $\log P_{n,t-1}$ from both sides, yields:

$$\frac{P_{nt} - P_{n,t-1}}{P_{n,t-1}} = \sum_{s \in N} \frac{A_{s,t-1} (d_{ns,t-1} w_{s,t-1})^{-\theta}}{\left[\sum_{s \in N} A_{s,t-1} (d_{ns,t-1} w_{s,t-1})^{-\theta} \right]} \frac{w_{st} - w_{s,t-1}}{w_{s,t-1}}$$

4. Approximate the percentage growth by a log difference: $\frac{P_{nt} - P_{n,t-1}}{P_{n,t-1}} \sim \Delta \log P_{nt}$. This yields:

$$\begin{aligned} \Delta P_{nt} &\sim \sum_{s \in N} \frac{A_{s,t-1} (d_{ns,t-1} w_{s,t-1})^{-\theta}}{\left[\sum_{s \in N} A_{s,t-1} (d_{ns,t-1} w_{s,t-1})^{-\theta} \right]} \Delta w_{st} \\ &= \sum_{s \in N} \pi_{sn,t-1} \Delta w_{st} \end{aligned} \tag{20}$$

So the change in price is a trade-weighted sum of all the wage shocks. This lends itself well to an instrument: the trade-weighted sum of all the bartik shocks.

E.3 Decomposition of migration costs

From the assumption of Frechet distribution

$$\lambda_{knt} = \frac{(V_{nt}/c_{knt})^{\epsilon}}{\Phi_{kt}},$$

where $V_{nt} = \frac{B_{nt}^{1/\epsilon} w_{nt}}{P_{nt}^{\alpha} r_{nt}^{1-\alpha}}$ and $\Phi_{kt} = \sum_{s \in N} (V_{kt}/c_{kst})^{\epsilon}$. Additionally

$$E(b_{nt}) = \Gamma\left(1 - \frac{1}{\epsilon}\right) = \overline{\Gamma}.$$

This implies that expected utility is the same across all destinations for people from the same origin

$$\begin{aligned} E\left(\frac{V_{nt} b_{nt}}{c_{knt}} | \text{choose } n\right) =& \overline{\Gamma} \frac{V_{nt}}{c_{knt}} \lambda_{knt}^{-1/\epsilon} \\ =& \overline{\Gamma} \frac{V_{nt}}{c_{knt}} \left(\frac{(V_{nt}/c_{knt})^{\epsilon}}{\Phi_{kt}}\right)^{-1/\epsilon} \\ =& \overline{\Gamma} \Phi_{kt}^{1/\epsilon}. \end{aligned}$$

The unconditional expected utility from staying in k at time t is

$$E(\frac{V_{kt} b_{kt}}{c_{kkt}}) = \frac{V_{kt}}{c_{kkt}} E(b_{kt}) = \frac{V_{kt}}{c_{kkt}} \overline{\Gamma}.$$

Additionally,

$$\begin{aligned} E(\frac{V_{kt} b_{kt}}{c_{kkt}}) &= \lambda_{kkt} E(\frac{V_{kt} b_{kt}}{c_{kkt}} | \text{choose } k) + (1 - \lambda_{kkt}) E(\frac{V_{kt} b_{kt}}{c_{kkt}} | \text{don't choose } k) \\ \frac{V_{kt}}{c_{kkt}} \overline{\Gamma} &= \lambda_{kkt} \overline{\Gamma} \Phi_k^{\frac{1}{\epsilon}} + (1 - \lambda_{kkt}) E(\frac{V_{kt} b_{kt}}{c_{kkt}} | \text{don't choose } k) \end{aligned}$$

Therefore

$$E(\frac{V_{kt} b_{kt}}{c_{kkt}} | \text{don't choose } k) = \frac{1}{(1 - \lambda_{kkt})} \frac{V_{kt}}{c_{kkt}} \overline{\Gamma} - \frac{\lambda_{kkt}}{(1 - \lambda_{kkt})} \overline{\Gamma} \Phi_{kt}^{\frac{1}{\epsilon}}.$$

Remember that

$$\lambda_{kkt} = \frac{(V_{kt}/c_{kkt})^{\epsilon}}{\Phi_{kt}} \Rightarrow \frac{V_{kt}}{c_{kkt}} = (\lambda_{kkt} \Phi_{kt})^{\frac{1}{\epsilon}}$$

Then,

$$\begin{aligned} E(\frac{V_{kt} b_{kt}}{c_{kkt}} | \text{don't choose } k) &= \frac{\lambda_{kkt}^{\frac{1}{\epsilon}}}{(1 - \lambda_{kkt})} \overline{\Gamma} \Phi_{kt}^{\frac{1}{\epsilon}} - \frac{\lambda_{kkt}}{(1 - \lambda_{kkt})} \overline{\Gamma} \Phi_{kt}^{\frac{1}{\epsilon}} \\ &= \overline{\Gamma} \Phi_{kt}^{\frac{1}{\epsilon}} \left[\frac{\lambda_{kkt}^{\frac{1}{\epsilon}} - \lambda_{kkt}}{(1 - \lambda_{kkt})}\right] \end{aligned}$$

Now we can decompose the relative gain from migrating to n from k in time t

$$\frac{E(\frac{V_{nt}b_{nt}}{c_{knt}}|\text{choose } n)}{E(\frac{V_{kt}b_{kt}}{c_{kkt}}|\text{don't choose } k)} = \frac{\overline{\Gamma}\Phi_{kt}^{\frac{1}{\epsilon}}}{\overline{\Gamma}\Phi_{kt}^{\frac{1}{\epsilon}}\left[\frac{\lambda_{kkt}^{\frac{1}{\epsilon}}-\lambda_{kkt}}{(1-\lambda_{kkt})}\right]}$$

$$\underbrace{\frac{V_{nt}}{V_{kt}}}_{\text{observed return}} \quad \underbrace{\frac{c_{kkt}}{c_{knt}}}_{\text{observed cost}} \quad \underbrace{\frac{E(b_{nt}|\text{choose } n)}{E(b_{kt}|\text{don't choose } k)}}_{\text{unobserved return}} = \frac{1-\lambda_{kkt}}{\lambda_{kkt}^{\frac{1}{\epsilon}}-\lambda_{kkt}}$$

So, the total migration cost is given by:

$$\frac{c_{knt}}{c_{kkt}}\frac{E(b_{kt}|\text{don't choose } k)}{E(b_{nt}|\text{choose } n)} = \frac{V_{nt}}{V_{kt}}\frac{\lambda_{kkt}^{\frac{1}{\epsilon}}-\lambda_{kkt}}{1-\lambda_{kkt}}$$