Determinants of City Growth in Brazil

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Abstract

In this paper, we examine the determinants of Brazilian city growth between 1970 and 2000. We consider a model of a city, which combines aspects of standard urban economics and the new economic geography literatures. For the empirical analysis, we constructed a dataset of 123 Brazilian agglomerations, and estimate aspects of the demand and supply side as well as a reduced form specification that describes city sizes and their growth. Our main findings are that decreases in rural income opportunities, increases in market potential for goods and labor force quality and reduction in intercity-transport costs have strong impacts on city growth. We also find that local crime and violence, measured by homicide rates impinge on growth. Using the residuals from the growth estimation, we also find that cities who better administer local land use and zoning laws have higher growth. Finally, our policy simulations show that diverting transport investments from large cities towards secondary cities do not provide significant gains in terms of national urban performance.

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1. Background and Motivation

Why are some cities more successful than their peers? Is the ‘success’ of individual cities driven by factors mostly external to any city’s immediate control (location, growth in market potential, being a port in a period of national trade growth, national level decentralization and improved governance), or do individual city policies and politics influence growth and development? Disentangling the relative contribution of regional and local efforts is important for understanding the potential of alternate policy interventions for stimulating growth of cities across the national urban system. At this time, there is very little research examining the effectiveness of local and national policy environments on urban growth in developing countries.

Brazil is a highly urbanized country – 80 percent of its population lives in urban centers and 90 percent of GDP is created in cities. According to estimates by the UN Population Division for Brazil, the entire growth in population that is expected over the next three decades will be in cities where the national urbanization rate is expected to rise to over 90 percent (UN 2003). This will add about 63 million people to Brazil’s cities, and total urban population will be over 200 million. This population growth is occurring across the Brazilian urban system (Table 1; see also Lemos et al. 2003). Of the 123 major urban agglomerations in Brazil, only three were above 2 million people in 1970 versus ten in 2000. In the middle of the size distribution in 2000, there were 52 agglomerations with population between 250,000 and 2 million people compared to 25 in 1970. Thus, not only is the scale of urbanization a major concern, but the distribution of population across the urban hierarchy will also challenge policy makers to devise appropriate policies for cities of different sizes. Across the urban system, there will be need to meet backlogs in infrastructure, service delivery, and amenity provision, as well as accommodate further growth.

In addition to population increases across the urban system, fiscal and administrative decentralization has increased the role of individual cities in attracting investments and in providing services that are responsive to the needs of local residents. Brazil is one the most decentralized among developing countries. The 1988 Constitution established municipalities as the third level of government, and provided states and municipalities with more revenue raising power and freedom to set tax rates. However many local governments have limited administrative and institutional capacity, and have not been able to effectively use their autonomy to improve service delivery or attract new investment. A recent study by the World Bank (World Bank 2002) identifies that maximizing urban competitiveness from agglomeration economies and minimizing congestion costs from negative externalities are key challenges facing national and local governments in Brazil.

Under this backdrop of rapid population growth and decentralization of administrative and fiscal responsibilities, it becomes essential to identify what types of interventions stimulate growth of individual cities. In addition, we want to find out the consequences of favoring investments in secondary cities on aggregate efficiency and economic growth. There is an ongoing debate in Brazil's policy circles that the largest agglomerations have become too big leading to significant negative externalities of crime, social conflict, and high land costs, and policies should be designed to actively stem the growth of these large agglomerations and favor investments in secondary cities.

It is however not clear if net agglomeration economies in large cites can be offset by incentives and other measures to divert growth to smaller cities.

In this paper, we consider a model of a city, which consists of a demand side—what utility levels a city can pay out—and a supply side—what utilities people demand to live in a city. We estimate aspects of the demand and supply side; and then a reduced form equation that describes city sizes and their growth. For the empirical analysis, we construct a dataset of Brazilian agglomerations to examine city growth between 1970 and 2000. Much of the underlying data come from the Brazilian Bureau of Statistics (IBGE) Population Censuses of 1970, 1980, 1991, and 2000. For the estimation, we make use of GMM and spatial GMM techniques to correct for endogeneity in the presence of spatially autocorrelated errors. Our main findings are that increases in local market potential—the changing access of a city to domestic markets—have an enormous impact on differential city growth rates, along with improvements in inter-regional transport connectivity, as well as education attainment of the labor force. For the last, both labor force quality improvements and base period education attainment matter significantly for growth. In terms of local characteristics, we find that local crime and violence lowers the city growth rate, while better management of city property may raise it.

The rest of the paper is organized as follows. Section 2 provides the model and estimation framework of urban demand and population supply models. The models presented in this section combine traditional urban modeling with concepts from the new economic geography literature. In Section 3, we discuss findings from the empirical analysis and focus our attention on identifying main determinants of city growth. Section

4 provides results from simulations that examine if investments in secondary cites stimulate growth. Section 5 concludes.

2. MEASURING CITY GROWTH

In this paper, we examine the local and regional determinants of city growth in Brazil. Urban growth is represented by both individual city productivity growth and city population growth, which are different indicators of city "success" and represent two interconnected dimensions of successful urban growth. However before we can look at any individual city's success, we need to understand the broader context, in which the economy as a whole is changing. Cities from an economic perspective represent the way modern production is carried out in a country and, as such, reflect what is occurring in the country as a whole.

Production composition of cities varies by city size, where different types of goods are best produced in bigger versus smaller cities. If national output composition changes, altered by changing trade demand or domestic demand that changes with economic growth, then demand moves away from goods produced in smaller types of cities and those cities will suffer a setback. Some will falter; others will adjust what they produce and perhaps upgrade, moving up the urban hierarchy. Which ones adjust well may depend on "luck", but it may also depend on observable attributes such as education of the labor force. A better educated labor force may allow for more nimble adjustment and up-scaling of products produced-- what is called the reinvention hypothesis. Similarly the skill composition of the labor force will vary across cities in systematic ways, as output composition and skill needs vary. More generally, national productivity growth comes from productivity growth within cities, which engender the close social-spatial interactions inherent in innovation, knowledge accumulation and technological improvements. To understand individual city success, we need to account for the external, national factors driving urban changes, as well as to understand the sources of local productivity growth.

At the same time we need to be able to measure when cities are being "successful" versus less successful and what drives success. Much of success may be driven by conditions external to the city, as just noted. In addition to demand changes, changes in national institutions, for example providing smaller cities with greater autonomy in local public sector decision making and greater access to fiscal resources may make it easier for smaller cities to finance the infrastructure and public sector services demanded by firms (transport and telecommunications) and by higher skilled workers (e.g., better schools) and compete successfully with bigger cities for certain industries. For terms of city level conditions, better run cities with more efficient use of public sector revenues will be more attractive to both firms and migrants. And better run cities will co-ordinate better with local businesses to help service their needs and make them more productive. So part of measuring city success is measuring what local producer and consumer amenities are valued and what cities are better at providing these amenities.

In related work, Glaeser et al. (1995) examined how urban growth of the U.S. cities between 1960 and 1990 is related to various urban characteristics in 1960, such as their location, initial population, initial income, past growth, output composition, unemployment, inequality, racial composition, segregation, size and nature of government, and the educational attainment of their labor force. They showed income and population growths are (1) positively related to initial schooling, (2) negatively related to initial unemployment, and (3) negatively related to the initial share of employment in manufacturing. Racial composition and segregation are not correlated with later city population growth. Government expenditures (except for sanitation) are also not associated with subsequent growth. However, per capita government debt is positively correlated with later growth.[1]

In a long run analysis, Beeson et al. (2001) examine the location and growth of the U.S. population using county-level census data from 1840 and 1990. They showed access to transportation networks, either natural (oceans) or produced (railroads), was an important source of growth over the period.[2] In addition, industry mix (share of employment in commerce and manufacturing), educational infrastructure, and weather have promoted population growth.

In a recent paper for developing countries, Au and Henderson (2005b) take a slightly different approach. They model and estimate net urban agglomeration economies for cities in China, which can be postulated by inverted-U shapes of net output or value-added per worker against city employment. They find urban agglomeration benefits are high – real incomes per worker rise sharply with increases in city size from a low level, level out nearer the peak, and then decline very slowly past the peak. The inverted-U shifts with industrial composition across the urban hierarchy of cities. Larger peak sizes are for more service oriented cities, but smaller for intensive manufacturing cities. In

[1] They attributed this correlation to higher expected growth which made it cheaper to borrow, or government invest heavily in infrastructure to serve that growth.
[2] Transportation network is represented by a group of dummy variables indicating ocean, mountain, confluence of two rivers, railroads, and canals.

addition, (domestic) market potential and accumulated FDI per worker have significant and beneficial effects on city productivity, measured by value-added per worker. However, percentage of high school graduates, distances to a major highway and to navigable rivers, and kilometers of paved road per person have no effects, once market potential is controlled for.

We now describe the model and estimation strategy employed in our analysis. The data used for the analysis have been produced through a joint research program between IPEA, Brasilia and the World Bank. Detailed description of the variables and their sources are provided in Appendix C, and a descriptive overview of Brazilian city growth is in da Mata et. al (2005). There is no official statistical or administrative entity in Brazil that reflects the concept of a city or urban agglomeration that is appropriate for economic analysis. Socioeconomic data in Brazil tend to be available for municípios, the main administrative level for local policy implementation and management. Municípios, however, vary in size. In 2000, São Paulo município had a population of more than ten million, while many other municípios had only a few thousand residents. Furthermore, many functional agglomerations consist of a number of municípios, and the boundaries of these units change over time. Our analysis therefore adapts the concepts of agglomerations from a comprehensive urban study by IPEA, IBGE and UNICAMP (2002) resulting in a grouping of municípios to form 123 urban agglomerations (Figure 1). Throughout this paper we refer to these units of analysis as agglomerations, urban areas, or cities.

Model and estimation strategy

The model consists of a demand side—what utility levels a city can pay out—and a supply side—what utilities people demand to live in a city. We estimate aspects of the demand and supply side; and then a reduced from equation that describes city sizes and their growth. In the end the focus is on the last item.

Demand side

The demand side is given by the schedule of utility levels a city can offer workers, as city size increases. A prime determinant of that is income, *I*, which consists of wage income and income from rents and other non-labor sources. In addition in an indirect utility function we also have a vector of items, Q_i, such as commuting costs, housing rents, local taxes, and local public services and amenities, so that

$$U_i^D = U(I_i, Q_i) \qquad (1)$$

For wage income there is a wage rate component and then a work effort component discussed momentarily. The wage rate component comes from value of marginal productivity relationships, where

$$w_i = w(MP_i, r_i, e_i, N_i) \qquad (2)$$

In (2) *r* is the rental rate on capital, *e* is the quality or education level of workers, *MP* is market potential reflecting the demand for a city's output and hence the price it receives, and *N* is a measure of scale, such as city employment. *MP* from the new economic geography and monopolistic competition literature has a specific form with components we can't measure. We make two adjustments. First we use "nominal" market potential, which is simply the distance discounted sum of total incomes of all MCAs in Brazil for city *i* , or

$$MP_i = \sum_{j, j \neq i} \frac{TI_j}{\tau_{ij}} \qquad (3)$$

TI is total income and τ_{ij} represents the transport cost between *i* and *j*.[3] The calculation of market potential is described in Appendix B, where we use distance as the measure of transport costs. However travel times and costs vary by more than distance. Brazil for 1968, 1980 and 1995 has a measure of the transport cost from each city to its state capital. We divide that variable by distance from the city to the state capital to get a city specific measure of local *unit* transport costs which producers in a city face in selling in the local region. The variable "inter-city transport costs", $i\tau_i$, will be determined by intercity road infrastructure investment.

The major items from urban theory affecting worker well-being, apart from the wage rate are rents and commuting costs. Commuting costs are time costs, of which part will be reflected in lost work time or energy for work, and part in out-of-pocket commuting costs. So total wage income is a function of both the wage rate and hours and energy available to work, where the later will be negatively affected by commuting times. Housing costs are tricky, since higher housing rents are also reflected in higher non-labor income earned by landowners.

For demand side estimation, what we know from the data is total income per worker in each city. We model that as a function of the determinants of the wage rate and then factors affecting work time/energy and housing rental income. Both are a function of city size. In sum we estimate:

$$I_i = I^D(MP_i, i\tau_i, e_i, N_i) \qquad (4)$$

[3] The MCAs (Minimum Comparable Areas) are groups of municípios. The detailed description is in Appendix C.

The scale variable, N, captures three things, scale externality effects on wage rates, increasing housing rental incomes, and reduced work time/energy. As such its sign is uncertain—if cities are at a size where the commuting cost aspects of urban living weigh heavily, at the margin increases in scale could detract from incomes. That will be the case in our estimation (which is also good for “stability” given supply curves are upward sloping—being on the rising part of the “demand curve” can be problematical and also makes sign interpretations in the city size equation more difficult as discussed later).

Population Supply

The population supply relationship we estimate has population supplied to a city increasing in utility offered per worker, which we approximate by income per worker. This will tell us the supply elasticity of people to a city. In addition supply is shifted by attributes, Z_i, of the surrounding area—or substitutes of places to work for population in the area. We have supply to a city of population from nearby rural areas. It is decreasing in surrounding rural incomes where we use a gravity measure of surrounding rural incomes, and it is increasing in surrounding rural population supply where again we use a gravity measure of surrounding rural population. The calculation details are in Appendix B.

The supply equation is given by

$$N_i = N^S(U^s(I_i), Z_i), \text{ where } \partial N^S / \partial I > 0,\ \partial N^S / \partial Z > 0 \qquad (5)$$

Note the inverse we will use later is

$$I_i = I^S(N_i, Z_i) \text{ where } \partial I^S / \partial N > 0,\ \partial I^S / \partial Z < 0. \qquad (6)$$

City Size Level and Growth Equations

The final estimating equations come from equating income demand and supply equations in (4) and (6) and solving for N to get

$$N_i = N(MP_i, i\tau_i, e_i, Z_i) \text{ where } \partial N/\partial MP > 0, \partial N/\partial i\tau < 0, \partial N/e > 0, \partial N/\partial Z > 0. \quad (7)$$

By differentiating (4) and (6) we can interpret coefficients of (7), where

$$\begin{aligned} dN = & \frac{-(\partial I^S/\partial Z)}{\partial I^S/\partial N - \partial I^D/\partial N} dZ + \frac{(\partial I^D/\partial MP)}{\partial I^S/\partial N - \partial I^D/\partial N} dMP \\ & + \frac{(\partial I^D/\partial i\tau)}{\partial I^S/\partial N - \partial I^D/\partial N} di\tau + \frac{(\partial I^D/\partial e)}{\partial I^S/\partial N - \partial I^D/\partial N} de \end{aligned} \quad (8).$$

Note $(\partial I^S/\partial Z)$<0. And $\partial I^S/\partial N - \partial I^D/\partial N$ >0 for "stability", where that is helped by the fact that empirically in Table 2 (discussed momentarily) $\partial I^D/\partial N$ <0.

Equation (7) gives an equation describing the "long run" equilibrium city size values as observed every 10 years. While we estimate this equation, we focus more on a growth version, which doesn't require imposition of long run equilibrium. If cities were operating in long run equilibrium, we would simply estimate (7) in differenced form, with the implied interpretation of the coefficients as written in (8). A growth, as opposed to a levels version of model in (7) has the advantage in estimation of differencing out time invariant variables that affect city size levels. However we make two adjustments to the specification in (8). First, differencing allows us to separate out labor force quality improvements from the effect of education on technology (knowledge accumulation spillovers). The latter is inferred from the effect on city growth of base period education levels, in a common specification in the growth literature. Second a growth formulation allows us conceptually to move beyond the long run equilibrium allocation framework, to incorporate adjustment processes, as in Rappaport (2005). City populations may be responding (non-instantaneously) to changes in local conditions, but response rates depend on base period conditions such as initial size (allowing for mean reversion) and base period industrial base. For initial size, cities that in the base period are large (say, were lucky in their base period error drawing) may respond by less than expected to any improved observed conditions. For industrial composition, if the national economy is continuing to industrialize (as is the case for Brazil over the time period), cities that start with a solid industrial base, may respond more favorably than expected to any improved observed conditions.

3. DETERMINANTS OF GROWTH - DEMAND AND SUPPLY SIDES

Having described the model and estimation strategy in Section 2, we now discuss the main findings from demand, supply, and city growth models. Results from estimating the demand side model (equation 4) are presented in Table 2, pooling three years (1980, 1991, and 2000). We focus on the GMM-IV results in column 1, which are from the two-step efficient GMM in the presence of arbitrary heteroscedasticity and arbitrary within-state correlation.[4] We also give OLS results in column 2. For IV work, in the table here in and in those to follow the instruments are listed. They are typically geographic and historical conditions, with an attempt to use supply conditions as instruments in estimating demand relationships and vice versa, as in classic IV work.[5] Instruments meet informal exclusion restrictions, so for example they are not significant covariates in OLS regressions and don't influence the coefficients of other OLS covariates. Second they

[4] The results are almost identical to 2SLS ones. All the GMM estimations in this paper are the two-step efficient GMM in the presence of arbitrary heteroskedasticity and arbitrary within-state correlation.
[5] Thus in Table 2, instruments are rural supply conditions (including geographic position), consumer amenities (such as weather and infant mortality) that affect location decisions but not productivity, and geographic position which may affect unit transport costs (based on government political allocation rules). We do have historical education attainment, which in a long run equilibrium (as opposed to dynamic growth-adjustment process) is harder to defend.

readily pass Sargan (Hansen J) specification tests suggesting instruments are orthogonal to error terms. For Table 2, GMM results of columns 1 and 3 have good p-values for specification tests. Instruments are strong with average partial R^2's (average partial F's) of .57 and .58 (58.1 and 57.2) respectively.[6]

In Table 2, in columns 1 and 2 the scale measure is total workers in each city. In column 3, population instead of total workers is used to represent urban scale. In column 4, we provide the effects on outcomes of a one standard deviation increase in covariates. All variables have significant impacts on total income per worker. For market conditions, average schooling and ln(market potential), a one standard deviation increase (1.26 and 1.01) raises total income per worker by 33% and 11% respectively. (Of course for covariates in log form we already have elasticities.) For ln(number of workers), we have the classic simultaneity problem where larger cities per se are "more efficient" so we get a positive coefficient in OLS, but in fact we expect negative scale effects at the margin, because we should be on the downward sloping portion of inverted U's (of income against city size).[7] A reduction of one standard deviation (-1.13) in ln(number of workers) increases total income per worker by 18%, with similar results when the size measure is population (column 3). We had no success in estimating a quadratic specification or interacting scale with the manufacturing to service ratio, to examine interactions between city scale and industrial composition.

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[6] Partial R^2 is a squared partial correlation between the excluded instruments and the endogenous regressor in question, and the F-test of the excluded instruments corresponds to this partial R^2.

[7] Theory suggests that, under free migration within a country, if particular cities are not a their peak of inverted U's, they will be to the right of the peak, due to either "stability" conditions in migration-labor markets or conditions on what constitutes a Nash equilibrium in migration decisions (Au and Henderson, 2004; Duranton and Puga, 2004).

Other variables may reflect policy conditions. Cities further from Sao Paulo, over and above declines in market potential, suffer. While this could reflect some aspect of Sao Paulo's huge, modern business service sector market that is critical to access for other cities, it might reflect other items like cost of capital or state provided production amenities that respectively rise and fall as one moves further from the center of the political elites and power in Sao Paulo. The intercity-transport cost variable, reflecting relative investments of transport infrastructure is significant where a reduction of one standard deviation (-.344) increases total income per worker by 3.3%. For intercity-transport costs we use the 1980 value for years 1980 and 1990; and we use the 1995 value for 2000. We give zero values to ln(intercity-transport costs) of state capital cities and insert a dummy for sate capitals. Note the coefficient on state capitals of .16 is much larger than would be expected (.075*.68= .051), if we assigned state capitals mean unit transport costs (.68), given that latter variable has a coefficient of .075. This may suggest state capitals are larger than expected, perhaps favoring themselves (or being favored by the national government) with investment in unobserved production amenities.

Finally, we note that growth or differenced versions of this equation and the population supply one next have very poor IV results, which is mainly due to a weak instrument problem. For the growth specifications, we only focus on the final reduced form specification (Table 5).

Results for population supply are provided in Table 3. Again, for the estimation we pool three years (1980, 1991, and 2000). Columns 1 and 2 give the GMM-IV and then OLS results. The instruments, listed in the footnote of the table, pass specification tests and produce strong first-stage regression results. All terms have strong, expected sign coefficients. In column 1, a 1% increase in a city's total income per capita increases city population by 3%, suggesting an elastic supply curve, but one that is definitely not perfectly (or highly elastic). The gravity measures of surrounding rural population supply and rural income opportunities have the expected opposite effects with similar magnitudes. A 1% increase in surrounding rural population supply increases city population by 7.6%, and a 1% increase in surrounding rural income opportunities decreases city population by 6.9%. Thus, city populations are very sensitive to rural population supply and earning opportunities.

In columns 3-5, we present supply elasticities by year. The point estimates of the income coefficient increases over time, indicating increasing mobility. But as just noted even in 2000, the elasticity, 3.3, is far from a perfect mobility elasticity.[8]

City Size Results

Results for city size from estimating equation (7) are given in Table 4. Column 1 gives GMM-IV results, column 2 OLS, and column 3 the effects of a one standard deviation increase in covariates on city size. For instruments, we use 1970 values and time-invariant variables, as listed in the table. The instruments pass specification tests, but given we are including highly correlated covariates we have a long list of instruments, which are mostly historical conditions. They meet informal exclusion restriction tests and the Sargan value is acceptable, although not great. A problem is that now, for example, we have historical demand conditions instrumenting for current ones which raises two issues. First, if they are valid instruments, that might suggest there are not persistent unobservables driving demand conditions over time (so we are

[8] Under perfect labor mobility, we expect a horizontal population supply curve. All the cities offer the same utility level, and city sizes are only determined by demand-side factors.

instrumenting against just contemporaneous shocks). Second it isn't clear what the rational is for use of historical instruments: why historical values are good instruments for current covariates if we are continually reshuffling the deck with no persistence in unobservables affecting both city size and current and lagged values of covariates. Part of the answer lies in the discussion of adjustment processes and the growth equation which is estimated next. Nevertheless, it is interesting to view the results.

If the reduced form results are indeed from combining demand and supply sides, we expect the coefficient estimates in Table 4 to be consistent with the imputed values from the demand side (Table 2) and the supply side (Table 3). The imputed values can be calculated using (8), such that

$$c_i = \frac{dN}{dQ} = \frac{\partial I^D / \partial Q}{\partial I^S / \partial N - \partial I^D / \partial N} = \frac{b_i}{1/a_1 - b_4}$$
$$c_j = \frac{dN}{dZ} = \frac{-\left(\partial I^S / \partial Z\right)}{\partial I^S / \partial N - \partial I^D / \partial N} = \frac{a_j / a_1}{1/a_1 - b_4}$$

where $\left(c_i, c_j\right)$ are reduced form coefficient estimates in Table 4, b_i the demand side of Table 2, and a_j the supply side of Table 3. The comparison with imputed values, noted in the footnote, confirms a rough consistency between Tables 2 to 4.[9]

Consistent with Tables 2 and 3, Table 4 suggests two things. First, market potential for goods, the rural population supply, and rural income opportunities have

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	Imputed [from Tables 2 (3) and 3 (1)]		Table 4 (1)
Ln(market potential)	$b_1/(1/a_1-b_4)$	0.200	1.967
Ln(inter-city trans. costs)	$b_2/(1/a_1-b_4)$	-0.116	-0.677
Average Schooling	$b_3/(1/a_1-b_4)$	0.537	0.215
Ln(rural pop. supply)	$(a_2/a_1)/(1/a_1-b_4)$	5.311	1.361
Ln(rural income opportunities)	$(a_3/a_1)/(1/a_1-b_4)$	-4.845	-2.688

significant effects on city populations with roughly similar magnitudes. A 1% increase in market potential and rural population increase city size by 2.0% and 1.4% respectively. In comparison, a 1% decrease in rural income opportunities would increase city size by 2.7%. Second, intercity-transport costs and educational attainment (average schooling) are also important as expected.

Growth Results

Next we turn to growth equations, where we difference the reduced form equation (7). While in principle results should be the same if we are always in long run equilibrium, a differenced equation has four advantages. As noted earlier, a growth formulation allows us (i) to separate out labor force quality improvements from the effect of base period education on local technology (knowledge accumulation spillovers); (ii) to difference out time invariant unobservables affecting city size that are difficult to instrument for; and (iii) to incorporate adjustment processes, where city growth is affected by base period size and industrial composition, as well as changing economic conditions. Finally, (iv), the consideration of adjustment processes provides a rational for instrumenting with historical variables (Au and Henderson, 2005a): cities have accumulation processes for labor with imperfect migration and industrial structures that evolve over time, so historical conditions are related to current changes in covariates in any dynamic adjustment process. The drawback in differencing equations is that the effects of variables which have small changes over time may be poorly estimated, given lack of variation in the data.

Table 5-1 shows the GMM-IV and OLS growth results pooling 1991-1980 and 2000-1991 differenced equation years for equation (7). Covariates are differenced; in addition, before differencing, we now normalize market potential measures with the mean for that year to emphasize how each city's relative conditions are changing over time. For differenced intercity-transport costs, we use the difference between 1995 and 1980 for 2000-1991; and the difference between 1980 and 1968 for 1991-1980. All covariates, except changes in rural population supply have strong and expected sign coefficients. The poor performance of rural population supply is most probably due to the limited variance in relative market potential measures over time and their high degree of correlation (negative between changes in rural income and population supply conditions, as would be expected).

Relative to the levels equation in Table 4, the growth equation coefficients reported in column 1 do differ in magnitude, given in part that we allow for effects of base period conditions-- population and manufacturing to service ratios in the latter specification. As noted above controlling for population allows for dynamic adjustment to steady state levels from the base, and introducing industrial composition allows for adjustment relative to changes in national output composition. Initial city size has a negative coefficient, suggesting either mean reversion or some conditional convergence in population growth across cities, or both. Also, cities with high manufacturing ratios in the base period experience faster growth. We also find that once base period population and industrial composition are controlled for, state capitals are growing faster than other cities, perhaps reflecting favoritism as noted earlier.

For changes in basic demand and supply conditions, we find that decreases in rural income opportunities and increases in market potential of goods and labor force quality (measured by changes in educational attainment) increase the growth rate of city population. As a new effect, educational attainment in the base period increases city population growth rates afterwards, confirming spillover effects of knowledge accumulation. Reductions in intercity-transport costs have a fairly strong effect on city population growth rates: a 10% decrease in intercity unit transport costs increases city population growth by 1.4% over a decade. In the next section we discuss in more detail the magnitudes of effects on growth of different covariates.

In Table 5, columns 3 and 4, we introduce one additional local characteristic to the base specification, the base period homicide rate, an amenity which may affect city growth. Results suggest that higher homicide rates have a detrimental effect on city growth. For example, a 10% increase in base period homicide rates reduces city growth by 1.5% over the next decade.

Decomposing City Growth

In Table 6, we decompose the city population growth results of Table 5, column 1 into contributions of each covariate. We focus on the covariates which are statistically significant. The contribution of each covariate is calculated as a fitted value (the mean value multiplied by the estimated coefficient) relative to the sum of all the fitted values. Column 5 shows the overall contributions for all cities. There is a strong negative effect of city size in base period (-24%). The key positive component to growth comes from increases in market potential (108%); much of what happens to cities is determined by conditions external to them—*demand for their products as driven by what is evolving geographically around them.* Changes in educational attainment (21%), along with base period's educational attainment (10%) which affects local technology growth also matter.

The estimated effects of market potential and technology spillovers support the new economic geography emphasis on local markets and the endogenous growth literature emphasis on human capital accumulation. These results are also consistent with cross country findings in Henderson and Wang (2005).[10] Columns 6 and 7 compare city growth decompositions of large versus small cities. We find no major difference in these effects across city size.

Robustness Tests – Spatial Dependence

Interaction among cities due to trading and technological linkages is likely to influence city growth. In the presence of technology spillovers, copy cat policy adoption, and inter regional transport connectivity, growth in any given city will be related to other cities in the urban system, and the impact of these spillovers is likely to be higher among cities which are geographically close to each other. Much of these interactions however are not observed in the data that we have been able to compile, and thus is relegated to the error specification. In the presence of spatial autocorrelation, standard errors from the city growth estimation are likely to be inaccurate and introduce efficiency problems in the various estimations.

To address this issue, we test whether the clustered estimation results of Tables 2 and beyond are robust to residual spatial dependence. Tests for spatial dependence (Moran's I and Geary's C) show that there is residual spatial autocorrelation in the error terms.[11] To address this issue, we employ the GMM methodology reported by Conley (1999), which uses weighted averages of spatial autocovariance terms to correct the

[10] Henderson and Wang (2005) analyzes how urbanization in a country is accommodated by increases in numbers versus population sizes of cities. Using a worldwide dataset on all metro areas over 100,000 population from 1960-2000, they show market potential, educational attainment, and the degree of democratization strongly affect growth in both city numbers and individual city sizes.
[11] All residuals except Table 4 show spatial autocorrelations.

standard errors of parameter coefficients for possible serial dependence based on location. This approach is robust to misspecification of the degree of spatial correlation among the units. In this nonparametric application, the researcher can specify a cutoff point beyond which spatial dependence is thought to be unimportant. We use latitude and longitude of the agglomeration centroid as coordinate variables. Cutoffs are set to be 1.5 standard deviations of latitude and longitude (10.23, and 8.20), which correspond to 900 miles. Thus, spatial correlation between cities declines linearly and is zero beyond 1.5 standard deviations of latitude and longitude.

Appendix Tables A to D report the two-step spatial GMM and spatial OLS results which correspond to each specification in Table 2 and beyond. In general we find that the GMM results are robust and the spatial GMM results are very similar to the clustered ones.

Decomposition of City Growth Residuals

We now use the residuals from the GMM estimations in Table 5, column 3, and examine if they have any systematic association with time invariant local characteristics. Our main interest is in examining if local management or governance, and inter industry linkages are associated with city growth. In principle, autonomous local government would actively work to provide local public goods for its constituents, and develop policies to stimulate growth and manage externalities. For our analysis, we have two measures of local government efforts: (1) existence of laws to collect property [IPTU] taxes and (2) percentage of population under land zone laws.[12]

[12] Those two measures are as of 1999.

In terms of inter industry linkages; we expect a clustered or densely populated region to provide a rich environment for competition and collaboration among firms and workers in the region, which lead to economic growth. As Saxenian (1994) observed, regional development is more distinct in a region consisting of many small size, more competitive firms than that of a few large firms.[13] We measure the density of economic activities by ln(no. firms relative to workers) = ln(no. formal firms / no. workers in formal firms). We also experimented with the ratio of public industrial to private industrial capital in 1980 (the only year we have it recorded) to see if cities which are more state capitalist are less efficient, or grow more slowly.[14]

The basic estimation results from decomposing the residuals are reported in Table 7. Due to the lack of longitudinal data for local characteristics, the estimation result should be interpreted as associations of contemporary variables rather than a causal relationship. Column 1 is for city growth residuals in (2000-1991) and (1991-1980) regressed against time invariant city characteristics. Column 2 is for (2000-1991) adding to regressors a density measure of economic activities in 1991.[15]

We find that population growth is higher in cities with better enforcement of land use and zoning laws – the estimates suggest that city growth is associated with increases

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[13] Saxenian (1994) examined different regional economic performances between Silicon Valley in California and Route 128 in Massachusetts. Dense social networks and open labor market in Silicon Valley have facilitated informal communication and collaborative practices, and produced a regional network-based industrial system. The Route 128 region, in contrast, is dominated by autarkic (self-sufficient) corporations that internalize a wide range of productive activities. She concluded that this difference in regional socio-economic structure accounts for the divergent prosperity of two regional economies, in spite of their common origins in postwar military spending and university-based research, and even though they enjoyed roughly the same employment levels in 1975.

[14] La Porta and López-de-Silandes (1999) showed privatization in Mexico in 1980s an 1990s led to a significant improvement in firm performance, as profitability increased 24 percentage points and converged to levels similar to those of private firms.

[15] We only have 1991 and 2000 data for ln(no. formal firms / no. workers in formal firms).

in the percentage of city population under land zone laws.[16] However, we do not find any statistically significant association between city growth and existence of laws to collect IPTU (property tax). This is most likely because there is almost no variation in the IPTU collection data – most cities have laws to collect the property tax. A richer set of inter industry linkages is also associated with growth – the OLS coefficient for the number of (formal) firms relative to (formal) workers is statistically significant and has the expected sign. A higher number of firms relative to workers stimulate competition and collaboration among firms and workers in a city, and is associated with higher city growth. The coefficient of public industry capital ratio has a negative sign suggesting a detrimental effect on city growth. However, it is not statistically significant.

4. POLICIES FAVORING SECONDARY CITIES

Using the results from the regressions of city growth, let us consider the following policy experiment. There is considerable policy debate in Brazil that investments need to be directed towards secondary cities to stimulate local economic development and limit the growth of the largest metropolitan areas. However, the impact of these initiatives on overall economic growth and urban efficiency is unclear.

Suppose the Brazilian government invests in transportation infrastructure in order to decrease inter-city transport costs. An issue is whether favoring investments in small cities vis-à-vis large cities increase overall productivity growth, and therefore higher overall economic growth in Brazil. To make the analysis tractable, we first assume that the amount of transportation investment to reduce one unit of inter-city transport cost (per

[16] We can get a similar result when we use a dummy variable indicating more than 50% of population is under land zone laws.

mile) is proportional to city population. So one unit decease in inter-city transport costs for a city of 1 million is assumed to cost the same amount of government expenditure as those for 10 cities of 100,000 people.

In 2000, the largest city, São Paulo, has 17.9 million residents, which is equivalent to the total population of the 88 smallest cities (Table 8). The total population of the 7 largest cities is the same as that of remaining 116 small cities (Our data consist of 123 cities). Our assumption says that total transportation investment needed to decrease one unit of transport costs for São Paulo will also reduce one unit of transport costs for the 88 smallest cities, if invested in those cities.

Table 2 (3) describes the determinants of income per worker, in which average schooling, market potential, city population, and inter-city transport costs affect income per worker. From this equation, we can calculate the total urban income in Brazil, s. t.

$$\begin{aligned}\text{total urban income} &= \sum_{\text{i}=1}^{123} \text{income per worker}_{\text{i}} \times \text{ no. workers}_{\text{i}} \\ &\approx \sum_{i=1}^{123} X_i \hat{b}_{GMM} \times \text{ no. workers}_{\text{i}}.\end{aligned}$$

Now suppose the government invests in transportation infrastructure. In Table 8, we compare the effect on total urban income of investments favoring big cities versus small cities. The first column is the total urban income relative to the baseline income when infrastructure investments favor largest cities, specifically a 1 standard deviation (.8) decrease in inter-city unit transport cost of largest cities. The baseline income is the predicted value of Table 2 (3). The second column is the total urban income when the same amounts are invested in the smallest cities to decrease those cities' transport cost by the same magnitude (.8). We experiment with several combinations of cities in Table 8.

The simulation results show that there are very small differences in total urban income from favoring small cities vis-à-vis large cities. These income differences range around 0.1 ~ 0.5%p of total urban income growth in 2000. The difference is highest when we favor the 104 smallest cities vis-à-vis than the largest two cities (.543%p). These results tell that there are no major gains in terms of overall urban income from diverting investments from the largest cities to secondary cities.

5. Summary and Conclusions

In this paper, we have examined the determinants of Brazilian city growth between 1970 and 2000. For the analysis, we constructed a dataset of 123 agglomerations, and examined factors that influence wages and labor supply. Our main findings are the following. (1) Increases in local market potential are major driver of city growth. (2) Correspondingly inter-regional transport improvements that reduce inter city unit transport costs stimulate growth. (3) Improvements in labor force quality and the spillover effects of knowledge accumulation (measured by initial levels of education attainment) have strong growth impacts as well.

In terms of inter regional transport improvements, the Brazilian government has made significant investments in infrastructure to integrate the national economy and lower business costs in peripheral regions. Most of the improvements in the road network occurred between the 1950s and 1980s, leading to significant reduction in transportation and logistics costs. Castro (2002) measures the benefits of improvements in highway infrastructure from 1970-1995 as the change in equivalent paved road distance from each municipality to the state capital of São Paulo, accounting for the construction of the network as well as the difference in vehicle operating costs between earth/gravel and paved roads. He shows that transport cost reductions were quite significant for the Northern region and Central region state of Mato Grosso, with numbers varying from 5,000 to 3,000 equivalent kilometers of paved road. Average reductions fall to the 1,000 km range in the Central region states of Goiás and Mato Grosso do Sul, the southern states, and the coastal northeastern states. Using this measure, Castro (2002) finds that the reduction in interregional transport costs was one of the major determinants of both the expansion of agricultural production to the central regions of Brazil after the 1960s as well as increases in the country's agricultural productivity

In terms of city level characteristics, we find that local homicide rates have a negative impact on city growth rates. Our decompositions of city growth residuals tentatively show that local land use and zoning enforcement is positively associated with city growth, as is the presence of a diverse set of inter industry linkages. One of the major limitations in our efforts to identify the contribution of local characteristics to city growth has been the lack of longitudinal data, which makes it difficult to draw causal relationships. It would be useful to get better data on historic land use and zoning regulations, as well as local public goods, services, and amenities. In further work, we hope to collect additional data on city level characteristics to better identify their impacts on city growth.

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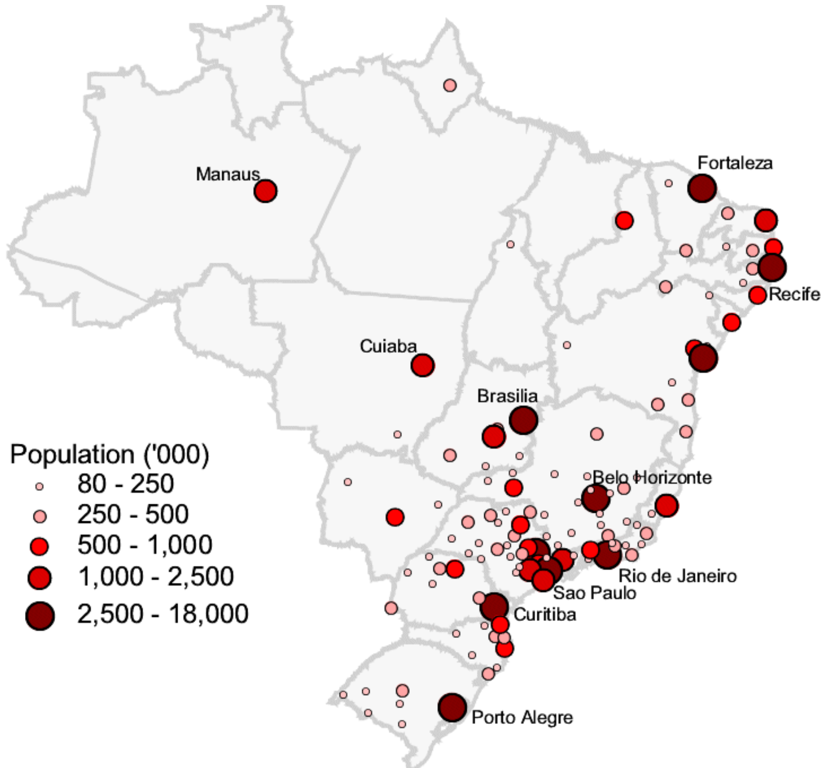

Source: IPEA, IBGE

Figure 1: Urban Agglomerations by population size

Table 1: City Size Distribution

Population size	1970	1980	1991	2000
> 5 million	2	2[1)]	3[2)]	3
2 million - 5 million	1	3	7	7
1 million - 2 million	4	5	5	8
500,000 - 1 million	5	10	15	14
250,000 - 500,000	16	21	23	30
100,000 - 250,000	44	43	44	46
< 100,000	51	39	26	15
Total number of cities	123	123	123	123
Average size	350,857	507,242	657,602	788,222
Min	20,864	41,454	76,816	86,720
Max	8,139,705	12,588,745	15,444,941	17,878,703

1) "São Paulo" and "Rio de Janeiro"
2) "Porto Alegre" is newly added.

Table 2. Demand Side: Determinants of Income Per Worker[a,b,c,d]
(robust standard errors in parentheses)

Dependent variable:	ln(income per capita)			
	(1)	(2)	(3)	(4)
	GMM-IV	OLS	GMM-IV	The effects of 1 s.d. increase in covariates of (1)
Average Schooling	0.263***	0.236***	0.255***	0.331
	(0.018)	(0.025)	(0.017)	
ln(market potential)	0.108***	0.015	0.095***	0.109
	(0.020)	(0.013)	(0.017)	
ln(no. workers)	-0.158***	0.002	-0.141***	-0.179
[ln(population) for (3)]	(0.029)	(0.011)	(0.025)	
ln(inter-city transport costs)	-0.075**	0.034	-0.055**	-0.033
	(0.029)	(0.027)	(0.028)	
state capital dummy	0.158**	0.040	0.169**	
	(0.068)	(0.054)	(0.067)	
ln(distance to São Paulo)	-0.075***	-0.077***	-0.071***	-0.077
	(0.006)	(0.009)	(0.006)	
time dummies	yes	yes	yes	
Observations	369	369	369	
R^2		0.853		
Hansen J statistic (overidentification test)	3.781		3.829	
(p-value)	(0.436)		(0.430)	
Average of Partial R^2	0.572		0.575	
Average of Partial F's	58.10		57.16	

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. The instruments are infant mortality (1970), semi-arid area dummy, ln(average temperature), ln(market pot. agric. land availability, 1970), average years of schooling (1970), ln(rural pop. supply, 1970), ln(rural income opportunities, 1970), ln(distance to state capital), ln(distance to São Paulo), state capital and time dummies.
b. GMM estimates are from the two-step efficient GMM in the presence of arbitrary heteroskedasticity and arbitrary intra-group (within-state) correlation.
c. OLS regressions are with robust cluster standard errors. We assume the observations may be correlated within states, but would be independent between states.
d. Average of Partial R^2 and Partial F's are for average schooling, ln(no. workers), and ln(inter-city transport costs). Market potential is almost completely correlated with those in 1970 (Partial R^2's are around .99).

Table 3. Population Supply[a,b,c]
(robust standard errors in parentheses)

Dependent variable:	ln(population)				
	(1)	(2)	(3)	(4)	(5)
	GMM-IV	OLS	GMM-IV (1980)	GMM-IV (1991)	GMM-IV (2000)
Ln(income per capita)	2.997***	1.813***	2.700***	2.937***	3.335***
	(0.413)	(0.378)	(0.402)	(0.417)	(0.420)
Ln(rural income opportunities:	-6.892***	-4.152***	-7.645***	-6.236***	-6.678***
market potential)	(0.997)	(0.819)	(1.195)	(0.850)	(0.965)
Ln(rural pop. supply market	7.555***	4.878***	8.330***	6.901***	7.325***
potential)	(0.936)	(0.752)	(1.133)	(0.788)	(0.908)
time dummies	yes	yes	yes	yes	yes
Observations	369	369	123	123	123
R^2		0.745			
Hansen J statistic (overidentification test)	1.341		2.401	0.161	2.444
(p-value)	(0.854)		(0.663)	(0.997)	(0.655)
Average of Partial R^2	0.708		0.735	0.693	0.701
Average of Partial F's	47.26		30.14	36.70	41.02

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. The instruments are semi-arid area dummy, ln(average temperature), ln(market pot. agric. land availability, 1970), average years of schooling (1970), ln(per capita capital stock, 1970), manu/service ratio (1970), ln(distance to state capital), and time dummies.
b. GMM estimates are from the two-step efficient GMM in the presence of arbitrary heteroskedasticity and arbitrary intra-group (within-state) correlation.
c. OLS regressions are with robust cluster standard errors. We assume the observations may be correlated within states, but would be independent between states.

Table 4. City Size Equations[a,b,c,d]
(robust standard errors in parentheses)

Dependent variable:	ln(population)		
	(1)	(2)	(3)
	GMM-IV	OLS	The effects of 1 s.d. increase in covariates of (1)
Ln(rural pop. supply)	1.361***	1.216***	1.277
	(0.452)	(0.425)	
Ln(rural income opportunities)	-2.688***	-1.999***	-2.715
	(0.571)	(0.600)	
Ln(market potential)	1.967***	1.426**	1.987
	(0.595)	(0.586)	
Average Schooling	0.215***	0.231**	0.271
	(0.075)	(0.106)	
Ln(inter-city transport costs)	-0.677***	0.081	-0.297
	(0.150)	(0.110)	
State capital dummy	0.433	1.091***	
	(0.282)	(0.170)	
time dummies	yes	yes	
Observations	369	369	
R^2		0.801	
Hansen J statistic (overidentification test)	6.200		
(p-value)	(0.287)		
Average of Partial R^2	0.582		
Average of Partial F's	177.55		

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. The instruments are semi-arid area dummy, ln(average temperature), ln(market pot. agric. land availability, 1970), average years of schooling (1970), ln(industry capital per worker, 1970), ln(rural pop. supply, 1970), ln(rural income opportunities, 1970), ln(distance to state capital), ln(market potential, 1970), manu/service ratio (1970), and state capital and time dummies.
b. GMM estimates are from the two-step efficient GMM in the presence of arbitrary heteroskedasticity and arbitrary intra-group (within-state) correlation.
c. OLS regressions are with robust cluster standard errors. We assume the observations may be correlated within states, but would be independent between states.
d. Average of Partial R^2 and Partial F's are for average schooling and ln(inter-city transport costs). Market potential and gravity measures are almost completely correlated with those in 1970 (Partial R^2's are around .99).

Table 5. City Size Growth Equation[a,b,c,d]
(robust standard errors in parentheses)

Dependent variable:	Δ ln(population)			
	(1)	(2)	(3)	(4)
	GMM-IV	OLS	GMM-IV	OLS
Δ ln(rural pop. supply market	-0.160	0.221**	-0.126	0.272***
potential) / mean	(0.264)	(0.079)	(0.218)	(0.092)
Δ ln(rural income opportunities:	-0.517***	-0.059	-0.672***	-0.098**
market potential) / mean	(0.095)	(0.035)	(0.110)	(0.035)
Δ ln(market potential) / mean	2.874***	0.853***	2.723***	0.694***
	(0.670)	(0.159)	(0.863)	(0.130)
Average schooling (t-1)	0.056***	0.023*	0.093***	0.040***
	(0.020)	(0.012)	(0.019)	(0.011)
Δ Average schooling	0.474***	0.098***	0.432***	0.098***
	(0.100)	(0.032)	(0.120)	(0.033)
Δ ln(inter-city transport costs)	-0.138**	-0.089**	-0.105**	-0.077**
	(0.061)	(0.040)	(0.052)	(0.035)
state capital dummy	0.211***	0.129***	0.150***	0.112***
	(0.048)	(0.036)	(0.031)	(0.030)
ln(population) (t-1)	-0.051***	-0.019*	-0.060***	-0.026***
	(0.009)	(0.010)	(0.009)	(0.009)
Manu / service (t-1)	0.129***	0.101***	0.076*	0.087***
	(0.037)	(0.018)	(0.040)	(0.022)
ln(homicide / pop) (t-1)			-0.150***	-0.093***
			(0.035)	(0.025)
time dummies	yes	yes	yes	Yes
Observations	246	246	245	245
R^2		0.384		0.431
Hansen J statistic (overidentification test)	10.502		8.038	
(p-value)	(0.232)		(0.430)	
Average of Partial R^2	0.469		0.457	
Average of Partial F's	499.0		1160.4	

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. For (1), we use the instruments of Table 4, while dropping ln(industry capital per worker, 1970) and adding ln(population, 1970), ln(income per capita, 1970), manu/service ratio(1970)*ln(population, 1970), manu/service ratio(1970)*ln(income per capita, 1970), manu/service ratio(1970)*ln(market potential, 1970), ln(transport costs to São Paulo, 1968), and ln(transport costs to state capital, 1968). For (3), illiteracy rate (1970) is added to the instruments.
b. GMM estimates are from the two-step efficient GMM in the presence of arbitrary heteroskedasticity and arbitrary intra-group (within-state) correlation.
c. OLS regressions are with robust cluster standard errors. We assume the observations may be correlated within states, but would be independent between states.
d. Average of Partial R^2 and Partial F's exclude those of lagged ln(population), since they are very strongly correlated with those in 1970 (Partial R^2's are around .94).

Table 6. Decomposition of City Size Growth

	Coef. of Table 5 (1), (a_i)	Mean (b_i)[a]			Decomposition of city growth $(a_i \times b_i / c)$, %		
		Total	Large cities[b]	Small cities[b]	Total	Large cities[b]	Small cities[b]
No. cities		123	61	62			
Δ ln(city pop)		0.226	0.264	0.188			
Δ ln(rural income	-0.517	1.000	0.991	1.009	-19.3	-19.0	-19.7
opportunities) / mean							
Δ ln(market potential) /	2.874	1.000	1.003	0.997	107.5	106.9	108.0
mean							
Average schooling (t-1)	0.056	4.568	4.773	4.366	9.6	9.9	9.2
Δ Average schooling	0.474	1.208	1.215	1.201	21.4	21.4	21.5
Δ ln(inter-city transport	-0.138	-0.215	-0.191	-0.239	1.1	1.0	1.2
costs)							
State capital dummy	0.211	0.171	0.344	0.000	1.3	2.7	0.0
ln(population) (t-1)	-0.051	12.339	13.172	11.520	-23.5	-24.9	-22.1
Manu / service (t-1)	0.129	0.406	0.428	0.385	2.0	2.0	1.9
$c = \sum_i a_i \times b_i$		2.674	2.695	2.654			
sum					100.0	100.0	100.0

a. Means are for 2000-1991 and 1991-1980. For average schooling (t-1), it is for 1991 and 1980.
b. We define large (small) cities if they have greater (less) than median city population in each year.

Table 7. Regression of City Growth Residuals[a]
(robust standard errors in parentheses)

Dependent variable:	Residuals of Table 5 (3)	
	OLS	OLS
Laws to collect property tax	0.014	-0.086
	(0.047)	(0.055)
% of population under	0.036*	0.031*
land zone law	(0.020)	(0.017)
Public industry capital /	-0.666	-0.034
total industry capital in 1980	(0.504)	(0.748)
(No. formal firms /		0.955**
No. workers in formal firms) (t-1)		(0.387)
time dummy	Yes	No
Observations	245	122
R-squared	0.017	0.041

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. OLS regression is with robust cluster standard errors. We assume the observations may be correlated within states, but would be independent between states.

Table 8. Policy Simulation: favoring largest cites versus smallest ones
(1 standard deviation decrease in inter-city transport costs in 2000)

Comparison	Total urban income relative to the baseline income (%)		(b-a, %p)
	Favoring largest cities (a)	Favoring smallest cities (b)	
1 largest vs. 88 smallest	102.514	102.809	0.296
2 largest vs. 104 smallest	103.823	104.366	0.543
3 largest vs. 109 smallest	104.951	105.239	0.287
4 largest vs. 112 smallest	105.658	105.987	0.330
5 largest vs. 113 smallest	106.202	106.294	0.091
6 largest vs. 115 smallest	106.560	106.944	0.384
7 largest vs. 116 smallest	107.114	107.408	0.294

Appendix A. Means and Standard Deviations of Variables (N= 369, 123 cities for 3 years)

Variable	mean	Standard deviation
ln (income per worker)	6.53	.279
Average schooling	5.13	1.26
ln (market potential)	27.3	1.01
ln (inter-city trans. costs: excluding state capitals)	.678	.439
ln(no. workers)	11.5	1.13
ln (population)	12.4	1.12
ln(rural pop. supply market potential)	20.2	.938
ln(rural income opportunities: market potential)	12.4	1.01

Appendix B. Market potential measures

(1) Basic Market Potential

Market potential of agglomeration i is defined as the sum of its member MCAs' market potential. Therefore the market potential of agglomeration i in year t is

$$\sum_{k_i \in i}\left(\sum_{j=1}^{3659}\frac{y_j(t)\times pop_j(t)}{\left(Ad_{k_i,j}^{\delta}\right)^{\sigma-1}}\right).$$

where $y_j(t)$ is per capita income of MCA *j* in year *t*, and $pop_j(t)$ population of MCA *j* in year *t*. $d_{i,j}$ is the distance between MCA i and j (100 miles). The distance of own MCA $\left(d_{i,i}\right)$ is the average distance to city center, which is equal to $\frac{2}{3}\sqrt{\frac{area}{\pi}}$. σ is assumed to be 2, δ is 0.3 (0.22 between two port cities), and A is such that $Ad_{i,j}^{0.3}=1$ for the smallest land area city (Au and Henderson, 2004; Hummels, 2001).

(2) Incomes offered in local rural areas competing with own city for local population

The gravity measure of surrounding rural per capita incomes is a market potential measure of agglomeration i in year t, such that

$$\sum_{k_i \in i}\left(\sum_{\substack{j=1 \\ j\notin i}}^{3659}\frac{\text{rural GDP}_j(t)/\text{rural pop}_j(t)}{\left(Ad_{k_i,j}^{\delta}\right)^{\sigma-1}}\right).$$

The MP calculation does not include the rural per capita MCA incomes of the same agglomeration. All parameters are the same as (1). Rural GDPs of (1970, 1980, 1985, and 1996) are assigned to those of (1970, 1980, 1991, and 2000).

(3) Potential supply of people to the city from local rural areas

The gravity measure of surrounding rural population is also a market potential measure of agglomeration i in year t, such that

$$\sum_{k_i \in i}\left(\sum_{\substack{j=1 \\ j\notin i}}^{3659}\frac{\text{rural pop}_j(t)}{\left(Ad_{k_i,j}^{\delta}\right)^{\sigma-1}}\right).$$

The MP calculation is the same as (2).

(4) Market potential measure of agricultural land availability

The agricultural land market potential is calculated in the same way as (1), such that

$$\sum_{k_i \in i}\left(\sum_{j=1}^{3659}\frac{\text{agri land}_j\left(t\right)}{\left(Ad_{k_i,j}^{\delta}\right)^{\sigma-1}}\right)$$

where $\text{agri land}_j\left(t\right)$ is agricultural area of MCA *j* in year *t*. All parameters are the same as previous ones.

Appendix C. Data sources and definitions

There is no official definition of “city” or “agglomeration” in Brazil. The lowest administrative level consists of more than 5000 municípios. However, these vary greatly in size and many functional economic and population agglomerations consist of a number of municípios. In this paper, we therefore follow the example of a study of Brazilian urban dynamics by IPEA, IBGE and UNICAMP (2002). It defined agglomerations based on their place in the urban hierarchy from “World Cities” (São Paulo and Rio de Janeiro) to subregional centers. For each agglomeration, this study identified the municípios that were a functional part of the urban area. The municípios belonging to each agglomeration were then further classified into eight categories according to how tightly they are integrated in the agglomeration, from “maximum” to “very weak”. The main criteria used in these classifications were centrality, function as a center of decision making, degree of urbanization, complexity and diversification of the urban areas, and diversification of services. These were measured by a range of census and other variables such as employed population in urban activities, urbanization rate, and population density. We modified this classification slightly by also including smaller municípios to existing agglomerations if their population exceeded 75,000 population and more than 75 percent of its residents lived in urban areas in 1991, or if they were completely enclosed by an agglomeration.

The agglomeration definitions developed by IPEA, IBGE and UNICAMP (2002) are based on municípios boundaries valid at the time of the Brazilian Population Census of 1991 and the Population Count of 1996, while our study captures dynamics from 1970 to 2000. During this time, many new municípios were created by splitting or re-arranging existing ones. In fact, the number of municípios increased from 3951 to 5501 during these three decades. To create a consistent panel of agglomerations for the 1970 to 2000 period, we therefore used the Minimum Comparable Area (MCA) concept as implemented by IPEA researchers. MCAs group municípios in each of the four census years so that their boundaries do not change during the study period. All data have then been aggregated to match these MCAs. The resulting data set represents 123 urban agglomerations that consist of a total of 447 MCAs.

The sources for the majority of data employed in this paper are the Brazilian Bureau of Statistics (IBGE) Population and Housing Censuses of 1970, 1980, 1991 and 2000. We used the full Brazilian census counts to get information about total population and housing conditions (urbanization rate). Other data were collected only for a sample of households. We used this census sample information for income, industrial composition, education, piped water provision, and electricity availability. The sample sizes varied across census years (1970: *25* percent; 1980: *25*; 1991: *12.5*; 2000: *5*)., but all are representative at the município level, and thus are also reliable at the MCA level employed in this study. Income figures are compiled from monthly data, deflated to 2000 Real (R$).

The transportation cost (proxy for transportation connectivity) between all Brazilian municipalities and the nearest State capital and between all Brazilian municipalities and São Paulo come from Professor Newton De Castro at the Federal University of Rio De Janeiro, and available at www.ipeadata.gov.br.

Existence of Ports and Brazilian Regions dummies are from the Bureau of Statistics (IBGE) Municipalities Profile of 1999. Homicides are from DATASUS / Brazilian Ministry of Health dataset. Local government expenditures are from the Brazilian Treasury dataset of 1991 and 2000. Formal employment data are from RAIS dataset / Brazilian Ministry of Labor. Morandi and Reis (2004) capital stock data employed in our analysis come from Brazilian Economic Censuses of 1970, 1975 and 1980.

Appendix D. Robustness test for spatial dependence

Table A. Demand Side: Determinants of Income Per Worker[a,b]
(standard errors corrected for spatial dependence in parentheses)

Dependent variable:	ln(income per capita)		
	(1)	(2)	(3)
	Spatial GMM	Spatial OLS	Spatial GMM
Average Schooling	0.277***	0.236***	0.262***
	(0.016)	(0.016)	(0.014)
ln(market potential)	0.129***	0.015	0.109***
	(0.027)	(0.013)	(0.021)
ln(no. workers)	-0.176***	0.002	-0.154***
[ln(population) for (3)]	(0.042)	(0.014)	(0.033)
ln(inter-city transport costs)	0.065	0.034*	0.050
	(0.081)	(0.020)	(0.070)
state capital dummy	0.258**	0.040	0.242**
	(0.105)	(0.041)	(0.094)
ln(distance to São Paulo)	-0.072***	-0.077***	-0.069***
	(0.008)	(0.010)	(0.007)
time dummies	yes	yes	yes
Observations	369	369	369
Hansen J statistic (overidentification test)	4.586		4.351

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. The instruments are infant mortality (1970), semi-arid area dummy, ln(average temperature), ln(market pot. agric. land availability, 1970), average years of schooling (1970), ln(rural pop. supply, 1970), ln(rural income opportunities, 1970), ln(distance to state capital), ln(distance to São Paulo), state capital and time dummies.
b. Coordinate variables are latitude and longitude. Cutoffs are 1.5 standard deviations of latitude and longitude (10.23, and 8.20), which correspond to about 900 miles.

Table B. Population Supply[a,b]
(standard errors corrected for spatial dependence in parentheses)

Dependent variable:	ln(population)				
	(1)	(2)	(3)	(4)	(5)
	Spatial GMM	Spatial OLS	Spatial GMM (1980)	Spatial GMM (1991)	Spatial GMM (2000)
Ln(income per capita)	3.051***	1.813***	2.401***	2.971***	3.279***
	(0.559)	(0.359)	(0.464)	(0.393)	(0.601)
Ln(rural income opportunities:	-6.849***	-4.152***	-6.524***	-6.298***	-6.504***
market potential)	(1.407)	(0.830)	(1.453)	(0.992)	(1.398)
Ln(rural pop. supply market	7.500***	4.878***	7.238***	6.951***	7.150***
potential)	(1.364)	(0.788)	(1.415)	(0.970)	(1.342)
time dummies	yes	yes	yes	yes	yes
Observations	369	369	123	123	123
Hansen J statistic (overidentification test)	2.047		2.614	0.185	3.487

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. The instruments are semi-arid area dummy, ln(average temperature), ln(market pot. agric. land availability, 1970), average years of schooling (1970), ln(per capita capital stock, 1970), manu/service ratio (1970), ln(distance to state capital), and time dummies.
b. Coordinate variables are latitude and longitude. Cutoffs are 1.5 standard deviations of latitude and longitude (10.23, and 8.20), which correspond to about 900 miles.

Table C. City Size Equations[a,b]
(standard errors corrected for spatial dependence in parentheses)

Dependent variable:	ln(population)	
	(1)	(2)
	Spatial GMM	Spatial OLS
Ln(rural pop. supply)	2.843***	1.216***
	(0.955)	(0.386)
Ln(rural income opportunities)	-2.679*	-1.999***
	(1.570)	(0.462)
Ln(market potential)	0.527	1.426***
	(2.234)	(0.468)
Average Schooling	0.494***	0.231**
	(0.182)	(0.112)
Ln(inter-city transport costs)	-0.015	0.081
	(0.826)	(0.083)
State capital dummy	0.682	1.091***
	(0.586)	(0.187)
time dummies	yes	yes
Observations	369	369
Hansen J statistic (overidentification test)	4.729	

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. The instruments are semi-arid area dummy, ln(average temperature), ln(market pot. agric. land availability, 1970), average years of schooling (1970), ln(industry capital per worker, 1970), ln(rural pop. supply, 1970), ln(rural income opportunities, 1970), ln(distance to state capital), ln(market potential, 1970), manu/service ratio (1970), and state capital and time dummies.
b. Coordinate variables are latitude and longitude. Cutoffs are 1.5 standard deviations of latitude and longitude (10.23, and 8.20), which correspond to about 900 miles.

Table D. City Size Growth Equation[a,b]
(standard errors corrected for spatial dependence in parentheses)

Dependent variable:	Δ ln(population)			
	(1)	(2)	(3)	(4)
	Spatial GMM	Spatial OLS	Spatial GMM	Spatial OLS
Δ ln(rural pop. supply market	-0.364	0.221***	-0.277	0.272***
potential) / mean	(0.286)	(0.079)	(0.503)	(0.088)
Δ ln(rural income opportunities:	-0.397**	-0.059	-0.435	-0.098***
market potential) / mean	(0.174)	(0.042)	(0.287)	(0.038)
Δ ln(market potential) / mean	3.976***	0.853***	4.098**	0.694***
	(1.075)	(0.158)	(2.047)	(0.135)
Average schooling (t-1)	0.041**	0.023**	0.058	0.040***
	(0.020)	(0.011)	(0.067)	(0.010)
Δ Average schooling	0.510***	0.098***	0.474**	0.098***
	(0.133)	(0.029)	(0.214)	(0.028)
Δ ln(inter-city transport costs)	-0.205***	-0.089***	-0.169	-0.077***
	(0.058)	(0.027)	(0.186)	(0.026)
state capital dummy	0.264***	0.129***	0.202	0.112***
	(0.043)	(0.033)	(0.146)	(0.026)
ln(population) (t-1)	-0.054***	-0.019**	-0.054**	-0.026***
	(0.012)	(0.009)	(0.024)	(0.009)
Manu / service (t-1)	0.157***	0.101***	0.118	0.087***
	(0.038)	(0.018)	(0.112)	(0.019)
ln(homicide / pop) (t-1)			-0.080	-0.093***
			(0.258)	(0.025)
time dummies	yes	yes	yes	yes
Observations	246	246	245	245
Hansen J statistic (overidentification test)	4.812		1.697	

*** significant at 1% level; ** significant at 5% level; * significant at 10% level.

a. For (1), we use the instruments of Table C, while dropping ln(industry capital per worker, 1970) and adding ln(population, 1970), ln(income per capita, 1970), manu/service ratio(1970)*ln(population, 1970), manu/service ratio(1970)*ln(income per capita, 1970), manu/service ratio(1970)*ln(market potential, 1970), ln(transport costs to São Paulo, 1968), and ln(transport costs to state capital, 1968). For (3), illiteracy rate (1970) is added to the instruments.
b. Coordinate variables are latitude and longitude. Cutoffs are 1.5 standard deviations of latitude and longitude (10.23, and 8.20), which correspond to about 900 miles.