International and Intercity Trade, and Housing Prices in US Cities[1]

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Jeffrey P. Cohen and Yannis M. Ioannides

Abstract

We develop a model of an economy made up of cities engaged in intercity and in international trade and explore predictions it offers for structuring an empirical investigation. We initially propose a set of two equations, the first of which follows from imposing spatial equilibrium across the system of cities; the second of the equations expresses the role of exports, domestic and/or international, in the determination of city GDP. A third set of equations explores the consequences of economic integration, domestic and international, for the growth rates of city GDP per job. We estimate equations for the growth rate of GDP per job for different types of cities. Our empirical estimation results confirm the signs and magnitudes of the parameter estimates that are predicted by the theoretical model. To the best of our knowledge, our approach is completely novel. We are unaware of any previous use of the intercity trade data nor of the international exports data for the purpose of estimating city GDP determination.

1 Introduction

An economy's cities are its vibrant hubs of economic activity and culture. They host a large and indeed ever increasing share of its population. For a city to function its economy must provide non-tradeable goods and services, which are required for each city's survival. Cities also typically produce tradeable goods, which are exported to the rest of the economy as well as to the rest of the world, thus allowing their economy to import goods that are demanded by its population and industries. The production of tradeable and non-tradeable goods and services typically generates demand for imports of intermediate goods, which are supplied by other cities in the economy and the rest of the world. Urban economic activity provides employment and is accommodated by each city's real estate sector. Real estate encompasses housing and non-housing structures. Commercial real estate prices and rents as well as housing prices and rents and land values are all key determinants of the cost of urban production and urban living. Urban economies are profoundly open to domestic and international competition.

Much of the research on housing markets and prices has been typically conducted by looking either at the housing market alone, or at the housing and labor markets jointly. The research reported here innovates by bringing into the analysis some additional but lesser known sources of data, that are quite critical for understanding urban economies as open economies. One is the Bureau of Economic Analysis data on MSA GDP, which start in 2001 and have been reported annually for 381 US MSAs.[4] A second source is little known data on merchandise exports of different US MSAs to the world economy.[5] Furthermore, data on commodity flows from state to state, and within MSA and within state shipments, allow us to estimate the interactions between trade, on one hand, and labor and housing markets on the other at alternative levels of aggregation.[6] The data also detail MSA to regions of the

[4]http://www.bea.gov/newsreleases/regional/gdp_metro/gdp_metro_newsrelease.htm

[5]http://www.trade.gov/mas/ian/metroreport/

[6]Commodity Flow Survey (CFS) is conducted every five years, in years ending in "2" and "7". Thus, the two latest ones are for 2007 and 2012. As Duranton *et al.* (2114) clarify, the CFS divides the continental US into 121 CFS regions, each an aggregation of adjacent counties. The Duranton and Turner sample consists of the 66 such regions organized around the core county of a us metropolitan area. CFS cities are often larger

world exports, and US states to regions of the world exports data as well as the largest 50 international exporters among US MSA's. Adding up the MSA to MSA shipments (including within-MSA), plus the MSA to each region of the world exports would give us an estimate of overall (domestic plus international) MSA-level gross sales of traded goods and services.

Availability of trade data, intercity as well as international exports data, allow us another glimpse at the forces affecting housing costs. For example, a positive shock to international exports of a particular city translates to shocks to the demand for labor and housing in that city. Thus, trade data may be brought to bear as a direct proxy of contemporaneous economic interaction across economic conditions in different cities.

The remainder of this paper is organized as follows. First, the paper outlines a static model of an economy made up of cities engaged in intercity and in international trade and explores predictions it offers for structuring an empirical investigation. The model predicts that there are structural differences across cities of different types in the growth of land prices and the determination of city GDP on account of intercity trade. The paper estimates the respective structural equations for land price growth and GDP determination. The assumption of spatial equilibrium has been used before when analyzing interactions among US cities [c.f. Glaeser *et al.* (2014)]. Yet the structural differences have not been analyzed. A third equation derives from modeling urban growth. The paper next reviews the data and discusses our empirical results. To the best of our knowledge, the paper's approach is completely novel: we are unaware of any previous use of the intercity trade data, of the international exports data, nor of their role in estimation of city GDP.

2 Literature Review

There is relatively little literature that emphasizes empirically the structural implication of intercity trade. Pennington-Cross (1997) focuses on the development of an exports price

than the corresponding (consolidated) metropolitan statistical areas. For instance, Miami–Fort Lauderdale and West Palm Beach–Boca Raton in Florida are two separate metropolitan areas according to the 1999 us Census Bureau definitions but they are part of the same CFS region.

index, in the context of estimating external shocks to a citys economy. There are several later applications of his index, including Hollar (2011), a study on central cities and suburbs, Larson (2013), a study of housing and labor markets in growing versus declining cities, and Carruthers *et al.* (2006) on convergence. Most of these papers use a similar earlier data set on exports from the 1990s from the International Trade Agency (ITA), which was discontinued prior to 2000. A new exports data set has been released by the ITA beginning in 2005, and may be used in future versions of the paper.

A second but smaller strand of literature uses actual export quantities as control variables, with the exports data being the central focus of the paper for only some of these. For others they are not the primary focus of the papers (they are merely used as controls). These include Lewandowski (1998), which considers economies of scale of exports in MSAs, using the earlier exports data set from the ITA. Ferris and Riker (2015) study the relationships between exports and wages, using the more recent data set on exports, but focuses on measurement and data construction aspects. Braymen *et al.* (2011) examine R&D and exports, using firm level data on exports from the Kauffman Foundation database, and control for R&D activity in the metro area. But that paper does not use our exports data source. Finally, Vachon and Wallace (2013) uses the exports data to assess how globalization affects on unionization in 191 MSAs. So, it looks like our understanding of export-oriented cities would benefit from further attention, analytical and empirical.

3 Intercity Trade and the Housing Market

Drawing on standard approaches for modeling interactions among systems of cities [Desmet and Rossi-Hansberg (2015); Ioannides (2013)], the present paper describes an economy as being made up of cities of different types. Types differ according to the number and types of final goods produced, or whether or not they produce only intermediate goods and import all final goods. Ioannides (2013), Chapter 7, develops a variety of rich urban structures in a static context and *ibid.,* Chapter 9, in a dynamic one. Both approaches impose intracity and intercity spatial equilibrium. In the case of the static model, manufactured goods may be either produced locally or imported from other cities. Manufactured goods are produced using raw labor and intermediate goods interpreted as specialized labor, which are themselves produced from raw labor, using IRS technologies. In the case of the dynamic model, manufactured goods are produced using raw labor and intermediate goods interpreted as specialized labor, which are themselves produced from raw labor, using IRS technologies, and physical capital. In either case, those goods are combined locally to produce a final good that may be used for either consumption or investment. Urban functional specialization, rather than sectoral, as articulated by Duranton and Puga (2005), also leads to structural differences. In other words, certain economic functions, like management, research and development and corporate headquarters may be located in different places than manufacturing. With industrial specialization and diversification being important features of urbanized economies, cyclical patterns in urban output differ across cities, and so do patterns in the variations of employment and unemployment [Rappaport (2012); Proulx (2013)].

3.1 A Static Model of an Urban Economy

We start a basic model [Ioannides (2013), Ch. 7] with two types of cities in a static context: cities specialize either in the production of final good X or final good Y. Residents of all cities consume quantities of the two final goods and housing services $h(\ell)$, defined in terms of units of land. Residents have identical preferences, defined by an indirect utility function as follows:

$$U = \beta^{\beta} \left[\alpha^{\alpha}(1-\alpha)^{1-\alpha} P_X^{-\alpha} P_Y^{-(1-\alpha)}\right]^{-(1-\beta)} R(\ell)^{-\beta} \Upsilon(\ell),\ 0 < \alpha, \beta < 1, \tag{1}$$

where P_X, P_Y, and Υ are the price of good X, good Y, and income per person, respectively. $R(\ell)$ is the rent of land at distance ℓ from the city center, and $\Upsilon(\ell) = W(1 - \kappa\ell)$, where W is the wage rate and κ the unit transport cost in terms of time. Spatial equilibrium within each city is defined in terms of the variation of the land rent with distance from the CBD. That is, for spatial equilibrium,

$$R(\ell) = R_0(1 - \kappa\ell)^{\frac{1}{\beta}}, \tag{2}$$

where $R_0 = R(0)$ denotes the rent of land at the CBD. Individuals' demands $Y, Y, h(\ell)$ are given by Roy's identity in the usual way:

$$X_j = \alpha(1-\beta)\frac{\Upsilon}{P_X};\ Y_j = (1-\alpha)(1-\beta)\frac{\Upsilon}{P_Y};\ h(\ell) = \beta\frac{\Upsilon_j(\ell)}{R_j(\ell)}, \tag{3}$$

where $j = X, Y$ denotes city type.[7] The demand for land, in particular, is given by: $h(\ell) = \frac{\beta W}{R_0}(1-\kappa\ell)^{-\frac{1-\beta}{\beta}}$.

Because of the analytical complexity of the model with housing demand being elastic, we simplify by adopting inelastic housing demand.[8] In that case, the indirect utility function becomes simply:

$$U = \alpha^{\alpha}(1-\alpha)^{1-\alpha}P_X^{-\alpha}P_Y^{-(1-\alpha)}\Upsilon.$$

Income per person in each city type is defined as total income per person, which consists of labor income plus land rental income divided by city population, which is denoted by N_X, N_Y for each type of city. For the simpler model, populations N_j, $j = X, Y$, and physical city sizes, $\bar{\ell}_j = \left(\frac{N_j}{\pi}\right)^{\frac{1}{2}}$ imply an expression for net labor supply:

$$H_c(N_j) = \int_0^{\left(\frac{N_j}{\pi}\right)^{\frac{1}{2}}} 2\pi\ell(1-\kappa'\ell)d\ell = N_j(1-\kappa' N_j^{\frac{1}{2}}), \tag{4}$$

where $\kappa' = \frac{3}{2}\pi^{\frac{1}{2}}$. Assuming that the value of land at the fringe of the city is given, $R_{a,j}$, allows us to solve for physical city size. That is, we have:

$$R_j(\bar{\ell}) = R_{a,j} = R_{0,j}\left(1-\kappa'\bar{\ell}\right)W, \tag{5}$$

where W denotes the nomoinal wage rate. From this and the previous equations, we may solve for $R_{0,j}$ and $\bar{\ell}_j$ as functions of $(N_j, R_{a,j})$. Land rental income is given by

$$\mathcal{Y}_{j,\text{land}} = \frac{1}{N_j}\int_0^{\bar{\ell}_j} 2\pi\ell R_j(\ell)d\ell = \frac{1}{2}\kappa' W N_j^{1/2}. \tag{6}$$

[7] The production of each good requires raw labor and intermediate varieties, which are produced with raw labor using increasing returns to scale production functions. See Ioannides (2013), Ch. 7, Eq. (7.15). The preferences assumed here are more general than in Ioannides (2013), Ch. 7, which assumes that population density (lot size) is set equal to 1.

[8] A more general model with elastic housing demand is fleshed out further below in the paper, section 3.2, in the case of a growing urban economy.

Labor income per person, $\mathcal{Y}_{j,\text{labor}}$ is equal to wage rate times the labor supply net of commuting costs (which are expressed in terms of time), on the supply side, and to the value of sales of the good a city is specializing in, on the demand side, which in turn is spent on both final goods. Thus, allowing for transfers and denoting net transfers per person into city j by $\mathcal{T}_j$, total income per person is equal to labor income per person, $\mathcal{Y}_{j,\text{labor}}$, plus land rental income per person, $\mathcal{Y}_{j,\text{land}}$, plus transfers per person, $\mathcal{T}_j$:

$$\Upsilon_j = \mathcal{Y}_{j,\text{land}} + \mathcal{Y}_{j,\text{labor}} + \mathcal{T}_j. \tag{7}$$

We note that GDP per person is observable and may be used in the place of Υ_j. Transfers account for income that originates outside the particular city, but may depend on city demographics. Also, we experiment with income per employee, which is appropriate because congestion is associated with travel to work.

Because of complexity of analytical expressions, the assumption is often made that land income is redistributed equally among all residents. In such a case, income net of commuting and land costs may be expressed in terms of population and the price of the good in which the city specializes; see below [Ioannides (2013), p. 315]. City output is produced by using labor and other inputs. Following Ioannides (2013), Chapter 7, output is produced by using raw labor and a range of intermediate inputs in the style of Dixit-Stiglitz, which themselves are produced with raw labor using increasing returns to scale technologies. Because of transportation costs, which take the form of time, labor supply, that is available labor minus commuting costs, depends upon the geographic complexity of the city. E.g., with linear commuting costs, assumed above, $\mathcal{K}(\ell) \equiv \kappa\ell$, and inelastic demand for land, net labor supply is given by (4) [*ibid.*, p. 300, eq. (7.2)]. This expression is more complicated in the exact case of our model where housing demand is elastic, or when city geography is more complicated. Thus, GDP supply per person in a city of type j is given by $\frac{1}{N_j} F(H_c(N_j))$. Under the assumptions of Ioannides (2013), Chapter 7, GDP supply per person in city j, gross of transfer income, is given by:

$$\Upsilon_j = B_j P_j N_j^{\frac{1-u_j}{\sigma-1}} (1 - \kappa' N_j^{1/2})^{\frac{\sigma-u_j}{\sigma-1}}, \tag{8}$$

where B_j is a technology parameter, u_j is the elasticity of raw labor in the Cobb-Douglas production function of good j, and σ the elasticity of substitution among the intermediates used in production of either good. This particular result serves to underscore that city geography, and more generally congestion, have complex effects on city GDP supply per person.

For national equilibrium in an economy consisting of n_X cities of type X and n_Y cities of type Y, total population $\bar{N}$ is allocated to all cities,

$$n_X N_X + n_Y N_Y = \bar{N}. \tag{9}$$

In the absence of shipments to the rest of the world (ROW), all exports of good X are purchased by cities of type Y, and all exports of good Y are purchased by cities of type X, the total spending on good Y by all cities is equal to the total spending on good X, where X, Y denote, respectively, the production of good X, good Y by each city of the respective type. That is:

$$(1-\beta)(1-\alpha)n_X X P_X = (1-\beta)\alpha n_Y Y P_Y. \tag{10}$$

Spatial equilibrium among cities is expressed as equalization of utility across cities of different types. Adopting Ioannides (2013), section 7.5, with the expression for income per person in we have that:

$$U_X = C_X \left(\frac{P_X}{P_Y}\right)^{1-\alpha} N_X^{\frac{1-u_X}{\sigma-1}} (1-\kappa' N_X^{1/2})^{\frac{\sigma-u_X}{\sigma-1}}; U_Y = C_Y \left(\frac{P_X}{P_Y}\right)^{-\alpha} N_Y^{\frac{1-u_Y}{\sigma-1}} (1-\kappa' N_Y^{1/2})^{\frac{\sigma-u_Y}{\sigma-1}},$$

where C_X, C_Y are suitably defined constants. Whereas it would be straightforward to work with these utility functions in order to obtain spatial equilibrium conditions, we postpone such an exersise for the more general model we develop next.

Working from (10) we may express aggregate demand in X cities per person in terms of total spending on good X by all other cities per person, which is proxied by shipments per capita S_X from cities of type X to all other cities, $S_X = (1-\beta)\alpha\frac{n_Y}{n_X N_X} Y P_Y$, plus the value of per capita shipments to the ROW, ex_X from a city of type X, plus per capita transfers from the rest of the domestic economy, $\mathcal{T}_X$. That is, respectively for each city type X, Y, we have:

$$\Upsilon_X = (1-\beta)\alpha\frac{n_Y}{n_X N_X} Y P_Y + \mathcal{T}_X + \mathrm{ex}_X; \Upsilon_Y = (1-\beta)(1-\alpha)\frac{n_X}{n_Y N_Y} X P_X + \mathcal{T}_Y + \mathrm{ex}_Y. \tag{11}$$

This will be generalized further below to allow for imports from the ROW. We note that the terms $\frac{n_Y}{n_X N_X} Y P_Y, \frac{n_X}{n_Y N_Y} X P_X$ may be directly proxied by the value of shipments from each city to all other cities.

At a first level of approximation, we may ignore city type[9] and use Eq.'s (11) to motivate a single regression equation for each city that expresses the aggregate demand for GDP per capita in city j in terms of shipments to other cities, S_j, per capita transfers j, $\mathcal{T}_j$, and exports by city j, ex_j, to the rest of the world:

$$\Upsilon_j = \gamma_1 S_j + \gamma_2 \mathcal{T}_j + \gamma_3\, \mathrm{ex}_j. \tag{12}$$

This equation expresses a key feature of the system of cities model: GDP is determined by equilibrium in the goods markets, via the interaction of each city with all other cities, and equilibrium within each city housing market, which enters the definition of Υ_j, aggregate income per person. Each city supplies goods and services to all other cities and buys goods and services from them. Since in an economy like that of the US cities are very open economic entities — in terms of movement of commodities, of people and of knowledge flows — city GDP determination is a critical relationship, much like national income determination of internationally open economies. Here all intercity transactions are expressed as trades in the national currency. It readily follows from (7) and (12) that the conditions $\gamma_2 = \gamma_3 = 1$ testable empirically.

While the model incorporates spatial equilibrium within each city, the urban system is in equilibrium if identical individuals are indifferent among all city locations. Equalizing utility across all cities at all times, the spatial equilibrium condition, and taking first differences allows us to define the growth rate of land value, $R_{0,j}$, for each city relative to a reference urban land value growth rate for the entire system of cities, $R_{0,\mathrm{n}}$, in terms of the growth rate of the price index for city j, P_j, relative to an urban price index, P_{u}, and the growth

[9]City types are hard to assign, because only a small share of city employment may be reliably linked to a city's export industries for most cities. See Ioannides (2013), Chapter 7.

rate of per capita income relative to the growth rate of national per capita income, Υ_{n}:

$$GR_{t+1,t}(R_{0,j}) - GR_{t+1,t}(R_{0,\mathrm{n}}) = \left[GR_{t+1,t}(P_j) - GR_{t+1,t}(P_{\mathrm{u}})\right] + \left[GR_{t+1,t}\Upsilon_j - GR_{t+1,t}(\Upsilon_{\mathrm{n}})\right]. \tag{13}$$

Eq. (12–13) will be taken to the data. Both these equations are derived using a very simplified framework for the purpose of demonstrating the empirical potential of the model. Next we introduce a more general model for individuals' behavior which implies a more complicated spatial equilibrium condition, which which (13) may be nested.

3.2 A Model of Urban Economic Integration, Specialization and Economic Growth

The exposition that follows extends the main model in Ioannides (2013), Chapter 9, in order to allow for international trade.[10] It is a dynamic model that allows for differences across cities in terms of city-specific total factor productivities, $\Xi^*_{i,t}$, and of congestion parameters κ_i. It assumes that individuals are free to move across cities, thus spatial equilibrium is imposed, that is: individuals are indifferent as to where they locate. That is, individuals' lifetime utilities are equalized across all cities. This implies in turn conditions on intercity wage patterns. Similarly, if capital is perfectly mobile, it will move so as pursue maximum nominal returns and in the process equalize them across all cities.

This section aims at obtaining, first, a more general expression for spatial equilibrium and its implications for the growth rate of the price of land (or housing), and second, more general expressions for the growth rate of city GDP for cities engaging in domestic trade as distinct from those engaging in international trade.

A number of individuals $\bar{N}_t$ are born every period and live for two periods. The economy has the demographic structure of the overlapping generations model. WE assume that individuals born at time t work when young, consume their net labor income net of their savings

[10]This main model of Ioannides, Ch. 9, constitutes an original adaptation of Ventura (2005)'s model of global growth to the urban structure of a national economy by building on key features of Ioannides (2013), Ch. 7.

and spending on housing, and consume again when they are old, $(C_{1t}, G_{1t}; C_{2t+1}, G_{2,t+1})$ respectively. WE assume Cobb-Douglas preferences over first- and second-period consumption for the typical individual,

$$U_t = [S^{1-\beta}\beta^{\beta}]^{-S}[(1-S)^{1-\beta}\beta^{\beta}]^{-(1-S)}[C_{1t}^{1-\beta}G_{1t}^{\beta}]^{1-S}[C_{2t+1}^{1-\beta}G_{2,t+1}^{\beta}]^{S},\ 0 < S < 1, \tag{14}$$

where S is a parameter, $0 < S < 1$.

Net labor supplied by the young generation in a particular city at t is given by $H_t = N_t\left(1 - \kappa N_t^{\frac{1}{2}}\right)$, with N_t the number of the members of the young generation in a particular city at t, $\kappa \equiv \frac{2}{3}\pi^{-\frac{1}{2}}\kappa'$, and κ' the time cost per unit of distance traveled.

If W_t denotes the wage rate per unit of time, spatial equilibrium within the city obtains when labor income net of land rent is independent of location. This along with the assumption that the opportunity cost of land is 0, and therefore the land rent at the fringe of the city is also equal to 0, yields an equilibrium land rental function as per Chapter 7, section **??**. It declines linearly as a function of distance from the CBD and is proportional to the contemporaneous wage rate, W_t. It is convenient to close the model of a single city and to express all magnitudes in terms of city size. WE again assume that all land rents in a given city are redistributed to its residents when they are young, in which case total rents may be written, according to (**??**), in terms of the number of young residents according to (**??**) as $\frac{1}{2}\kappa W N_t^{\frac{3}{2}}$. This yields first period net labor income per young resident, after redistributed land rentals and net of individual commuting costs, of $\left(1 - \kappa N_t^{\frac{1}{2}}\right)W_t$. With a given wage rate, individual income declines with city size, other things being equal, entirely because of congestion. But, there are benefits to urban production which are reflected on the wage rate.

Let R_{t+1} be the total nominal return to physical capital, K_{t+1}, in time period $t+1$, that is held by the member of young generation at time t. The indirect utility function corresponding to (14) is:

$$R_{t+1}^{S(1-\beta)}P_{G,t}^{-(1-S)\beta}P_{G,t+1}^{-S\beta}\left(1 - \kappa N_t^{\frac{1}{2}}\right)W_t. \tag{15}$$

We assume that capital depreciates fully in one period. The young maximize utility by saving a fraction S of their net labor income. The productive capital stock in period $t+1$,

K_{t+1}, is equal to the total savings of the young at time t. Therefore, previewing our growth models, we have: $K_{t+1} = SN_t\left(1 - \kappa N_t^{\frac{1}{2}}\right)W_t$.

WE develop first the case where all cities are autarkic, that is no intercity trade, and cities produce both manufactured tradeable goods, and use them in turn to produce the composite used for consumption and investment. Each of the manufactured tradeable goods, $J = X, Y$, is produced by a Cobb-Douglas production function, with constant returns to scale, using a composite of raw labor and physical capital, with elasticities $1 - \phi_J$, and ϕ_J, respectively, and a composite made of intermediates. The shares of the two composites are $u_J, 1 - u_J$ respectively. There exists an industry $J-$specific total factor productivity, Ξ_{Jt}. Production conditions for each of two industries J are specified via their respective total cost functions:

$$B_{Jt}(Q_{Jt}) = \left[\frac{1}{\Xi_{Jt}}\left(\frac{W_t}{1-\phi_J}\right)^{1-\phi_J}\left(\frac{R_t}{\phi_J}\right)^{\phi_J}\right]^{u_J}\left[\sum_m P_{Zt}(m)^{1-\sigma}\right]^{\frac{1-u_J}{1-\sigma}} Q_{Jt}, \tag{16}$$

where Q_{Jt} is the total output of good $J = X, Y$, P_{Zt} is the price of the typical intermediate, elasticity parameters u_J, ϕ_J satisfy $0 < u_J, \phi_J < 1$, and the elasticity of substitution in the intermediates composite σ is greater than 1. The TFP term Ξ_{Jt}, summarizes the effect on industry productivity of geography, institutions and other factors that are exogenous to the analysis.

Each of the varieties of intermediates used by industry J are produced according to a linear production function with fixed costs (which imply increasing returns to scale), with fixed and variable costs incurred in the same composite of physical capital and raw labor that is used in the production of manufactured goods X and Y. The shares of the productive factor inputs used are the same as, ϕ_J and $1 - \phi_J$, $J = X, Y$, respectively.[11] The respective total cost function is

$$b_{it}(Z_{Jt}(m)) = \frac{f + cZ_{Jt}(m)}{\Xi_{Jt}}\left[\left(\frac{W_t}{1-\phi_J}\right)^{1-\phi_J}\left(\frac{R_t}{\phi_J}\right)^{\phi_J}\right],$$

and $Z_{Jt}(m)$, the quantity of the input variety m used by industry $J = X, Y$. Its price is determined in the usual way from the monopolistic price setting problem [Dixit and Stiglitz

[11] This may be generalized to allow for input-output linkages by requiring (see also Fujita, *et al.* (1999), Ch. 14), that each intermediate good industry use its own composite as an input. This is accomplished by introducing as an additional term $\left[\int_0^{M_{it}} p_{it}^{1-\epsilon_i}\right]$ on the r.h.s. of the cost function $b_{it}(Z_{Jt})$.

(1977)] and it is equal to marginal cost, marked up by $\frac{\sigma}{\sigma-1}$:

$$P_{Z,J,t} = \frac{\sigma}{\sigma-1}\frac{c}{\Xi_{Jt}}\left(\frac{W_t}{1-\phi_J}\right)^{1-\phi_J}\left(\frac{R_t}{\phi_J}\right)^{\phi_J}.$$

At the monopolistically competitive equilibrium with free entry, each of the intermediates is supplied at quantity $(\sigma-1)\frac{f}{c}$, and costs $\frac{\sigma f}{\Xi_{Jt}}\left(\frac{W_t}{1-\phi_J}\right)^{1-\phi_J}\left(\frac{R_t}{\phi_J}\right)^{\phi_J}$ per unit to produce. Its producer earns zero profits.

We refer to the case where capital and labor are free to move as *economic integration.* With economic integration, industries will locate where industry productivities, the industry-specific TFP functions Ξ_{Jt}'s, are the most advantageous ones, and capital will seek to locate so as maximize its return. Unlike the consequences of economic integration as examined by Ventura, *op. cit.,* where aggregate productivity is equal to the most favorable possible in the economy, here urban congestion may prevent industry from locating so as to take greatest advantage of locational factors. Put differently, free entry of cities into the most advantageous locations may be impeded by competing uses of land as alternative urban sites, at the national level. However, utilities enjoyed by city residents at equilibrium do depend on city populations, and therefore, spatial equilibrium implies restrictions on the location of individuals. We simplify the exposition by assuming that all cities have equal unit commuting costs κ.

We assume that cities specialize in the production of tradeable goods. WE examine the case when each specialized city also produces intermediates that are used in the production of the traded good. Let Q_{Xit}, Q_{Yjt} denote the total quantities of the traded goods X, Y produced by cities i, j, that specialize in their production, respectively. The formulation is symmetrical for the two city types, and therefore, WE work with a city of type X.

The canonical model of an urban economy assumes that capital is free to move. Thus, nominal returns to capital are equalized across all cities. The model assumes that individuals are free to move, which in the context of our two-overlapping generations requires that lifetime utility is equalized across all cities. By using these conditions simultaneously we obtain a relationship between housing prices, consumption good prices and nominal incomes across cities, which may be taken to the data.

3.2.1 Spatial Equilibrium

WE suppress redundant subscripts and write for the nominal wage and the nominal gross rate of return in an $X-$city:

$$W_{Xt} = (1-\phi_X)\frac{P_X Q_X}{H_X},\ R_{Xt} = \phi_X \frac{P_X Q_X}{K_X}, \tag{17}$$

where P_X denotes the local price of traded good X, which is expressed in terms of the local price index, the numeraire, which is equal to one in all cities. WE also assume initially that there are no intercity shipping costs for traded goods. With economic integration, the gross nominal rate of return is equalized[12] across all city types, that is:

$$R_t = R_{Xt} = R_{Yt}.$$

Spatial equilibrium for individuals requires that indirect utility, (15), be equalized across all cities. In view of free capital mobility, spatial equilibrium across cities of different types requires that:

$$P_{G,X,t}^{-(1-S)\beta} P_{G,X,t+1}^{-S\beta} \left(1-\kappa N_{Xt}^{\frac{1}{2}}\right) W_{Xt} = P_{G,Y,t}^{-(1-S)\beta} P_{G,Y,t+1}^{-S\beta} \left(1-\kappa N_{Yt}^{\frac{1}{2}}\right) W_{Yt}. \tag{18}$$

By taking logs we have:

$$\begin{aligned} &-(1-S)\beta \ln P_{G,X,t} - S\beta \ln P_{G,X,t+1} + \ln\left(1-\kappa_X N_{Xt}^{\frac{1}{2}}\right) + \ln W_{Xt} \\ &= -(1-S)\beta \ln P_{G,Y,t} - S\beta \ln P_{G,Y,t+1} + \ln\left(1-\kappa_Y N_{Yt}^{\frac{1}{2}}\right) + \ln W_{Yt}. \end{aligned} \tag{19}$$

Just as in the previous section, this allows us to obtain a condition for spatial equilibrium within each city, which is written directly in terms of labor earnings. Earnings here are expressed in terms of real city output, so we deflate them in terms of a city price index. Thus, spatial equilibrium implies:

$$GR_{t+1,t}(P_{G,j}) - GR_{t+1,t}(P_{G,\mathrm{n}}) = \frac{1-S}{S}\left[GR_{t+1,t}(P_j) - GR_{t+1,t}(P_{\mathrm{j,u}})\right]$$

[12] As Fujita and Thisse (2009), p. 113, emphasize, while the mobility of capital is driven by differences in nominal returns, workers move when there is a positive difference in utility (real wages). In other words, differences in living costs matter to workers but not to owners of capital.

$$+\frac{1}{S\beta}\left[GR_{t+1,t}\Upsilon_j - GR_{t+1,t}(\Upsilon_{\rm n})\right] + \ln\left(1-\kappa_X N_{Yt}^{\frac{1}{2}}\right) - \ln\left(1-\kappa_{\rm n} N_{{\rm n}t}^{\frac{1}{2}}\right). \tag{20}$$

We note that we have imposed spatial equilibrium The last two terms in the right hand side of the above proxy for spatial complexity, regulation, and housing supply factors. Clearly, condition (13), obtained with a simpler behavioral model, may be nested within (20). In particular, the coefficient of $GR_{t+1,t}(P_j) - GR_{t+1,t}(P_{\rm j,u})$, the growth rate of the city price index relative to a national average, is predicted to be positive; the coefficient of $GR_{t+1,t}\Upsilon_j - GR_{t+1,t}(\Upsilon_{\rm n})$, the growth rate of income per capita relative to a national average is predicted to greater than 1.

3.2.2 Intercity Trade and Determination of City GDP

Next we derive expressions for real incomes in different city types in an economy with city specialization in tradeable goods which are combined in every city to produce a composite good which is used for consumption and investment. For a city of type X real income is equal to the value of the output of the good in which that city specializes, P_XQ_X, and P_YQ_Y, for a city of type Y. From the definition of the numeraire, in every city: $P_X = \alpha^\alpha(1-\alpha)^{1-\alpha}\left(\frac{P_X}{P_Y}\right)^{1-\alpha}$. By using the condition for spatial equilibrium, we may obtain an expression for the terms of trade, the price ratio, from which we may obtain an expression for the real income of a type X city:

$$Q_X\alpha^\alpha(1-\alpha)^{1-\alpha}\left(\frac{P_X}{P_Y}\right)^{1-\alpha} = \alpha_X^* Q_X^\alpha Q_Y^{1-\alpha}\left(\frac{N_{Xit}}{N_{Yit}}\right)^{1-\alpha},$$

where $\alpha_X^* = \alpha^\alpha(1-\alpha)^{1-\alpha}\left(\frac{1-\phi_Y}{1-\phi_X}\right)^{1-\alpha}$. The real income of a city specializing in good X, $\mathcal{X}_t$, is expressed in terms of city populations of *both* types of cities, (N_X, N_Y), total capital in the economy, K_t, and parameters as follows:

$$\mathcal{X}_t = \mathcal{N}_X\left(\frac{K_t}{\bar{N}}\right)^{\alpha\mu_X\phi_X + (1-\alpha)\mu_Y\phi_Y}, \tag{21}$$

where the auxiliary variable $\mathcal{N}_X$ is defined as a function of city sizes and parameters:

$$\mathcal{N}_X(N_X, N_Y) \equiv \alpha_X^*\widehat{\Xi}_t N_X^{\alpha\mu_X+1-\alpha}\left(1-\kappa N_X^{\frac{1}{2}}\right)^{\alpha\mu_X(1-\phi_X)} N_Y^{(1-\alpha)\mu_Y-(1-\alpha)}\left(1-\kappa N_Y^{\frac{1}{2}}\right)^{(1-\alpha)\mu_Y(1-\phi_Y)}, \tag{22}$$

and the function $\widehat{\Xi}_t$,[13] defined as a transformation of TFP functions $\bar{\Xi}_{Xt}, \bar{\Xi}_{Yt}$:

$$\widehat{\Xi}_t \equiv \bar{\Xi}_{Xt}^{\alpha}\bar{\Xi}_{Yt}^{1-\alpha}\left(\frac{\phi_X}{1-\phi_X}\right)^{\alpha\mu_X\phi_X}\left(\frac{\phi_Y}{1-\phi_Y}\right)^{(1-\alpha)\mu_Y\phi_Y}\left(\frac{1-\alpha\phi_X-(1-\alpha)\phi_Y}{\alpha\phi_X+(1-\alpha)\phi_Y}\right)^{\alpha\mu_X\phi_X+(1-\alpha)\mu_Y\phi_Y}. \tag{23}$$

The counterpart of (21) for $P_Y Q_Y$, the real income of a city specializing in good Y, is given by:

$$\mathcal{Y}_t = \mathcal{N}_Y\left(\frac{K_t}{\bar{N}}\right)^{\alpha\mu_X\phi_X+(1-\alpha)\mu_Y\phi_Y}, \tag{24}$$

where $\alpha_Y^* = \alpha^\alpha(1-\alpha)^{1-\alpha}\left(\frac{1-\phi_X}{1-\phi_Y}\right)^{\alpha}$,

$$\mathcal{N}_Y(N_X, N_Y) \equiv \alpha_Y^*\widehat{\Xi}_t N_X^{\alpha\mu_X-\alpha}\left(1-\kappa N_X^{\frac{1}{2}}\right)^{\alpha\mu_X(1-\phi_X)} N_Y^{(1-\alpha)\mu_Y+\alpha}\left(1-\kappa N_Y^{\frac{1}{2}}\right)^{(1-\alpha)\mu_Y(1-\phi_Y)}. \tag{25}$$

Eq. (21) and (24) define city income for cities of type X and of Y, respectively, as functions of the economy wide capital per person, $\frac{K_t}{\bar{N}}$, and of $\mathcal{N}_X, \mathcal{N}_Y$, which are functions of populations of both city types, of economy wide TFP, $\widehat{\Xi}_t$, defined in (23) above, and of parameters.

Taking logs of both sides of (21) and (24) and subtracting the second from the first, we have:

$$\ln \mathcal{X}_t - \ln \mathcal{Y}_t = \ln \mathcal{N}_X - \ln \mathcal{N}_Y. \tag{26}$$

By using the definitions of $\mathcal{N}_X, \mathcal{N}_Y$, in (22), (25), the rhs above becomes: $\ln \alpha_X^* - \ln \alpha_Y^* + \ln N_X - \ln N_Y$.

3.2.3 Growth of Integrated Cities

By taking logs and time-differencing, we may express the growth of income of income of a particular city in terms of constants and the difference in the growth rate of a city of a particular type from that of the average city, and of the growth rate of aggregate capital.

[13] The TFP function $\widehat{\Xi}_t$ is the counterpart for the integrated economy of Ξ_t^*, defined in Ioannides (2013), Ch. 9, for the autarkic cities. The industry TFP functions enter $\widehat{\Xi}_t$ with the same exponents as in Ξ_t^*, but the shift factors differ.

That is, we have for growth in per capita income for type$-X$ and type$-Y$ cities,

$$\mathrm{GR}(\Upsilon_{X,t}) = \ln \mathcal{X}_{t+1} - \ln \mathcal{X}_t,\ \mathrm{GR}(\Upsilon_{Y,t}) = \ln \mathcal{Y}_{t+1} - \ln \mathcal{Y}_t$$

respectively:

$$\begin{aligned}
\mathrm{GR}(\Upsilon_{X,t}) &= \mathrm{GR}(\widehat{\Xi}_t) + (\alpha\mu_X + 1 - \alpha)\mathrm{GR}(N_{X,t}) + ((1-\alpha)\mu_Y - (1-\alpha))\mathrm{GR}(N_{Y,t}) \\
&+(\alpha\mu_X\phi_X + (1-\alpha)\mu_Y\phi_Y)\mathrm{GR}(K_t) - (\alpha\mu_X\phi_X + (1-\alpha)\mu_Y\phi_Y)\mathrm{GR}(\bar{N}_t) \\
&-\alpha\mu_X(1-\phi_X)\kappa[N_{X,t+1}^{\frac{1}{2}} - N_{X,t}^{\frac{1}{2}}] - (1-\alpha)\mu_Y(1-\phi_Y)\kappa[N_{Y,t+1}^{\frac{1}{2}} - N_{Y,t}^{\frac{1}{2}}]. \qquad (27)
\end{aligned}$$

$$\begin{aligned}
\mathrm{GR}(\Upsilon_{Y,t}) &= \mathrm{GR}(\widehat{\Xi}_t) + (\alpha\mu_X - \alpha)\mathrm{GR}(N_{X,t}) + ((1-\alpha)\mu_Y + \alpha))\mathrm{GR}(N_{Y,t}) \\
&+(\alpha\mu_X\phi_X + (1-\alpha)\mu_Y\phi_Y)\mathrm{GR}(K_t) - (\alpha\mu_X\phi_X + (1-\alpha)\mu_Y\phi_Y)\mathrm{GR}(\bar{N}_t) \\
&-\alpha\mu_X(1-\phi_X)\kappa[N_{X,t+1}^{\frac{1}{2}} - N_{X,t}^{\frac{1}{2}}] - (1-\alpha)\mu_Y(1-\phi_Y)\kappa[N_{Y,t+1}^{\frac{1}{2}} - N_{Y,t}^{\frac{1}{2}}]. \qquad (28)
\end{aligned}$$

These growth equations may be rewritten in terms of the difference between the growth rate of an individual city from that of the average city.

A number of remarks are in order in taking these equations to the data. First, the assumptions of the model imply that the term $\mathrm{GR}(\widehat{\Xi}_t)$ in the RHS of (27) may be treated as a total factor productivity growth rate, i.e., a Solow residual. Furthermore, it is not city-specific. Second, since the growth rate of the economy's aggregate physical capital, term $\mathrm{GR}(K_t)$, is also common to all cities, it could be instrumented by means of the national nominal interest rate. Third, the coefficient of the aggregate population growth rate, $(\alpha\mu_X\phi_X + (1-\alpha)\mu_Y\phi_Y)$, is the same as that of growth rate of the economy's aggregate physical capital. Therefore, by following our approach above and expressing growth in income per person relative to the economy's average, where as before for a city of type X the terms associated with cities of type Y serve as proxies for the average economy, the only remaining of the growth rate terms is the growth rate of a city's population relative to the national average. The other remaining terms express the evolution of a city's spatial complexity, relative to the economy's average. It is these predictions that we take to the data.

3.2.4 Growth of Autarkic Cities

This result is due to the assumption of national economic integration and specialization. To see this we may contrast with growth in autarkic cities. Working from Eq. (9.15), Ioannides (2013), p. 414, we have that that growth rate of income per person may be expressed in terms of a linear combination of the TFP growth rates of the city's different industries and of the respective effective city population growth rate:

$$\mathrm{GR}(\Upsilon_{\mathrm{aut},t}) = \alpha\mu_X \mathrm{GR}_{t,t+1}(\Xi_X)+(1-\alpha)\mu_Y \mathrm{GR}_{t,t+1}(\Xi_Y)+(\mu(1-\phi)-\upsilon)\mathrm{GR}_{t,t+1}(H_c(N_t)). \quad (29)$$

We note that this result predicts that other than the presence of a linear combination of the TFP growth rates of the city's different industries the coefficient of the remaining term, $\mathrm{GR}_{t,t+1}(H_c(N_t))$ the city's effective population growth rate, is predicted to be positive. See Ioannides (2013), p.417.

The urban system of a modern market economy contains cities of different types (Ioannides (2013), Ch. 7) which are in varying degrees integrated into the national and the international economy. Therefore, city growth rates could in general be described by (27), with (29) allowing development of over-identifying restrictions.

3.2.5 Intercity and International Trade and the Determination of City GDP

Comparing city output growth for cities engaged in intercity trade, (27), with that for autarkic cities, (29) suggests that modeling specifically cities' trading outside the system of cities with the rest of the world, is likely to yield expressions for the determination of city GDP that differ from those where there is no international trade. This is indeed the case, as we see shortly. We proceed to modify the model of the urban system by postulating that while cities specialize, some of the cities export to, while other import from, the international economy. We modify the urban structure as follows. There are n_X cities that specialize in the production of good X and sell all of their output within the domestic economy producing Q_X each; there are $n_{X,x}$ cities each with population $N_{X,x}$ also specializing in the production of good X that in addition export $Q_{X,ex}$ of their output, producing in total $Q_{X,p}$ each. Similarly, there are n_Y cities that specialize in the production of good Y and sell all of their output Q_Y in the domestic economy; and there are $n_{Y,m}$ cities each with population $N_{Y,m}$ specializing in the production of good Y, producing Y in quantity $Q_{Y,p}$ each, which also import $Q_{Y,im}$. We simplify the derivations by assuming that the quantities of imports and exports are given.

The national population is distributed over all cities, as before:

$$n_X N_X + n_{X,x} N_{X,x} + n_Y N_Y + n_{Y,m} N_{Y,m} = N. \tag{30}$$

Similarly, total capital is allocated to all cities:

$$n_X K_X + n_{X,x} K_{X,x} + n_Y K_Y + n_{Y,m} K_{Y,m} = K. \tag{31}$$

International trade balance requires that the value of the national exports of good X equal the value of the national imports of good Y:

$$n_{X,x} P_X Q_{X,ex} = n_{Y,m} P_Y Q_{Y,im}. \tag{32}$$

Domestic trade balance requires that spending by all X cities on good Y equal spending on good X by all Y cities:

$$(1-\alpha) n_X P_X Q_X + (1-\alpha) n_{X,x} P_X Q_{X,p} = \alpha n_Y N_Y P_X + \alpha n_{Y,m} N_{Y,m} Q_{Y,p}. \tag{33}$$

These conditions along with the conditions for spatial equilibrium and capital market equilibrium across cities of all types allows us to solve for capital allocation and thus for the output by different types of cities, given city populations and numbers by type. A tedious set of derivations (see Appendix) yields the capital allocations to different city types, as fractions of the aggregate capital, with the factors of proportionality being functions of city sizes and numbers and of parameters.

Thus, using the expressions from the Appendix in (42) we obtain expressions for output for each city type X, Y. The counterparts for city types X, x and Y, m, respectively those that export good X and import good Y, are:

$$Q_{X,x} = \bar{\Xi}_{X,x} H_{X,x}^{\mu_X(1-\phi_X)} K_{X,x}^{\mu_X \phi_X}, Q_{Y,m} = \bar{\Xi}_{Y,m} H_{Y,m}^{\mu_Y(1-\phi_Y)} K_{Y,m}^{\mu_Y \phi_Y}, \tag{34}$$

. The corresponding growth rates for city output of each type are obtained by taking logs and first-differencing. That is,

$$\mathrm{GR}(Q_{X,x,t}) = \mathrm{GR}(\bar{\Xi}_{X,t}) + \mu_X \phi_X [\mathrm{GR}(FPK_{X,t}) + \mathrm{GR}(K_t)] + \mu_X(1-\phi_X)\mathrm{GR}(H_{X,x,t}), \quad (35)$$

where $\mathrm{GR}(FPK_{X,t})$ denotes the factor of proportionality in the expression for $K_{X,t}$, and $H_{c,X,x,t}$ is given by (4), for $N_{X,x}(t)$. An expression similar to (35) is obtained for $\mathrm{GR}(Q_{Y,m,t}) = \ln Q_{Y,m,t+1} - \ln Q_{Y,m,t}$.

This model is formulated in terms of two different tradeable goods, which are traded domestically and internationally and are used in each city to produce a non-tradeable good that is used for consumption and investment. The model may be generalized, following Ventura (2005) to the case of many goods. The simplified two-good case makes it clear that the output growth rates for different city types are described by structurally different expressions, that is for autarkic cities, for cities that trade domestically and for cities that export or import internationally. Depending upon data availability, a number of different estimation equations may be obtained.

3.3 Consequences for Growth Regressions

The spatial equilibrium condition, which expresses arbitrage, turns out to have major implications for urban growth equations in the context of economic integration. This follows from a comparison between the growth equation for autarkic cities with no free movement of labor, which is derived here from from Ioannides (2013), Eq. (9.15), as Eq. (29), with the respective one for cities engaged in intercity trade, Eq. (27), and the one for cities engaged in intercity and international trade, Eq. (35). The consequences of spatial equilibrium for urban growth regression has been emphasized recently by Hsieh and Moretti (2015). They show empirically that spatial equilibrium introduces dependence among city growth rates, which makes the contribution of a particular city to aggregate growth differ significantly from what one might naively infer from the growth of the city's GDP by means of a standard growth-accounting exercise. They show that the divergence can be dramatic. E.g., despite some of the strongest rate of local growth, New York, San Francisco and San Jose were only responsible for a small fraction of U.S. growth during the study period. By contrast, almost half of aggregate US growth was driven by growth of cities in the South. This divergence is due to the fact that spatial equilibrium imposes restrictions on city-specific TFP growth rates.

However, to the best of our knowledge, no previous literature has dealt explicitly with international along with intercity trade. The theory outlined here predicts structural differences in growth regressions across cities with different roles in the urban system. This would be critical if we were to perform a classic Solow residual analysis by working from city output in terms of factor inputs, a point forcefully made by Hsieh and Moretti (2015). it is clear from (21) that a portion of the contribution of capital and that of labor in its entirety are subsumed in the auxiliary variables $\mathcal{X}_t, \mathcal{Y}_t)$), defined in (22) and (22) above. This is also confirmed by contrasting with (29), the expression for the growth rate of autarkic cities.

4 Overview of Data

We have assembled data from a variety of sources which we use as comprehensively as possible in investigating the relationship between intercity and international trade, on the one hand, and the local housing market, on the other. We describe these data so as to provide an overall view of the empirical resources we bring on our approach.

The following major sources of data are available to us: Annual data (purchased from Telestrian) for MSA GDP, real and nominal, for about 360 MSAs from the BEA for 2002–2012; Data on city-level domestic exports for 2002, 2007, 2012 for approximately 100 cities from the Commodity Flows Survey, Bureau of Transportation Statistics; Data on international exports by 377 MSAs from Brookings for the following categories of commodities: agriculture; educational services, medical services and tourism; engineering; finance; general business; IT; manufacturing and mining. We aggregate thess industry data to obtain estimates of total international exports for each MSA. Data on average travel time to work, total city jobs and total city wages from 2002-2012 for 364 MSAs were obtained from Telestrian.

Data for house prices are available for 1996-2013, for 363 MSAs from the FHFA. However, our ability to compute real house price growth is limited by the limited geographical detail available in the CPI data. There are data for the four Census regions annually from BLS and annually for 26 MSAs. Data describing land availability and quality for housing use from a number of different sources, including notably the Lincoln Institute's MSA data for approximately 46 MSA's (Davis and Palumbo, 2007), and for 50 states (Davis and Heathcote, 2007); and the Saiz–Wharton data (Saiz, 2010) on unavailable land area, land supply elasticities, and the Wharton regulation index for approximately 250 MSA's, were also obtained. Data on MSA cancer deaths for 1999-2012 for 104 MSAs from the Center for Disease Control are also available.

4.1 International versus Intercity Trade Flows

Here we discuss some features of intercity shipments data for 2002, 2007 and 2012, using the 100 city definitions we generate from the 2007 Commodity Flows Survey (CFS). We have matched the roughly 377 MSA's with exports data from the Brookings data source. Exports from city j to the rest of the world are obtained from the Brookings Institution[14]. Since there are fewer cities in the CFS than in the Brookings one, many of the exporting MSA's have been combined manually in several instances into a number of broader CFS city definitions. This process was tedious and runs up to the difficulty of changing MSA definitions and different numbers of MSAs across the different waves of the data. Because of these issues, we have approximately 100 cities that we are able to use from the CFS, and we match the data from the 2007 and 2012 CFS, with the MSA GDP and exports data, to roughly 100 city definitions in the 2002 CFS.

We note that the ratio of MSA international exports, defined as international shipments, to domestic exports shipments is generally highest in coastal cities, and lower in inland cities. This of course accords with intuition, given that in general water shipping is less costly than other modes. Washington DC is an outlier, because apparently it ships very

[14]http://www.brookings.edu/research/interactives/2015/export-monitor#10420

little domestically (the government services it produces are not tradeable), and also because it has approximately 27% of the educational services, medical services, and tourism industry exports. While it is possible to break down the exports by reported industry, it is not easy to do so for domestic shipments due to sparseness of the data in some locations that caused the Census Bureau not to disclose the data.

It is interesting to compare the statistics of the ratio of exports to domestic shipments across the three different years for which the domestic shipments data are available. For 2007, the mean value of the ratio is 0.164 and its standard deviation 0.602. These values imply a coefficient of variation of 3.67. In contrast, both mean and standard deviation are at 0.212 and 0.944, respectively, greater for 2012. However, the coefficient of variation at 4.45 is also greater, and the range of values has widened. It would be interesting to investigate the source of this increased dispersion.

5 Estimations

For the determination of city GDP, eq. (12), we use per-capita sales data by each city to other domestic cities, which are available for 3 years (2002, 2007, and 2012), from the Bureau of Transportation Statistics' Commodity Flows Survey. We first estimate eq. (12), using as the dependent variable GDP per employee in city j. We also generate the ratio of exports to number of jobs (or per capita) by city j to the rest of the world. Sales by city j to other domestic cities, is normalized by the number of jobs in city j. One advantage of this Brookings database is that the exports data are defined in terms of the location of production, rather than on the origin of shipment. Otherwise, the GDP for port cities with a lot of transhipments would be exaggerated.

The data for transfer payments per job in city j, which is a regressor in eq. (12), are obtained by solving eq. (7) for transfers per job in terms of GDP per job, land income per land parcel, and labor income per job. Land income data are imputed by assuming that the land value of an average parcel at time 0 is given as the sum of the present discounted value of the expected land income on that average parcel. Assuming the expected land income at time 0 is a constant for all $t = 0, 1, ..., \infty$, then the land value at time 0 is given as $(1+r)/r$ times land income at time 0. This can be solved for land income at time 0 as $r/(1+r)$ times the land value of the average parcel at time 0. Land value data at the MSA level for the 26 MSA's in our sample was obtained from the Lincoln Institute of Land Policy.[15] . We have matched these MSA-level data with state-level land value data (from Davis and Heathcote, 2007) and data on Cancer deaths, highway miles per MSA, and the exports and shipments data. These data are used to estimate the GDP determination equation with an Instrumental Variables procedure. Cities that ship more goods domestically are expected to rely heavily on the highway network, which was developed many years ago. We use highway miles in each city as an instrument for domestic shipments. For the transfers variable, individuals who have recently died from cancer are more likely to have received unemployment benefits, disability payments, etc., and therefore we use cancer deaths as an instrument for transfers. Finally, the demand for a city's international exports is considered exogenous, given that a city is small relative to the rest of the world. We will estimate this GDP determination equation using Instrumental Variables, upon completion of the data compilation.

As we discuss above, GDP for different cities are determined simultaneously, which is to say that their key components are determined simultaneously. Exports other cities make to a particular city reflect their own economic activity, because they themselves import from other cities. In order to select instruments, we recognize that economic activity in each city is responsible for congestion, and air and water pollution, all of which have been shown to be correlated with (and in certain instances causal factors for) the incidence of cancer death rates internationally.[16] The complex dependence of income per person on city geography,

[15]See Davis and Palumbo (2006) and http://www.lincolninst.edu/subcenters/land-values/metro-area-land-prices.asp

[16]See Coccia (2013) who relates breast cancer incidence to per capita GDP. The aim of this study is to analyze the relationship between the incidence of breast cancer and income per capita across countries. The numbers of computed tomography scanners and magnetic resonance imaging are used as a surrogate for technology and access to screening for cancer diagnosis. Coccia reports a strong positive association between breast cancer incidence and gross domestic product per capita, Pearson's r = 65.4 %, after controlling for latitude, density of computed tomography scanners and magnetic resonance imaging for countries in temperate zones. The estimated relationship suggests that 1 % higher gross domestic product per capita,

according to eq. (8), serves to underscore the welfare costs of congestion.

For the estimation of eq. (13), we work with the difference of two terms. The first term is the difference between the housing price growth rate in city j and the national housing price growth rate. The second independent variable is difference between the GDP growth rate per job in city j and the GDP growth rate per job in all MSA's. The city-level growth rate uses the MSA-level GDP and employment data from Telestrian, and the national growth rate is based on the sum of GDP in all 96 MSA's, and the sum of the jobs in all 96 MSA's. The first independent variable in eq. (13) is the difference between the growth rate in city j's Consumer Price Index (CPI) and the growth rate in the national urban CPI. Both of these CPI estimates were obtained from the U.S. Bureau of Labor Statistics,[17], for the years 2002-2012. There are only 26 MSA's for which BLS reports CPI data, and this is why we use the regional CPI measures. Finally, we include two additional covariates — one involving employment per capita in an MSA, and another with the national employment per capita. We include region and year fixed effects. Given that GDP growth is endogenous, we use the following instruments in an Instrumental Variables estimation procedure: the difference between MSA per capital cancer death growth rates and national per capital MSA growth rates; the share of undevelopable land area in the MSA; the land suppy elasticity; and the Wharton WRLURI.

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within the temperate zones (latitudes), increases the expected age-standardized breast cancer incidence by about 35.6 % (p ¡ 0.001). Clearly, wealthier nations may have a higher incidence of breast cancer even when controlling geographic location and screening technology. Grant (2014) emphasizes that researchers generally agree that environmental factors such as smoking, alcohol consumption, poor diet, lack of physical activity, and others are important cancer risk factors for age-adjusted incidence rates for 21 cancers for 157 countries (87 with high-quality data) in 2008. Factors include dietary supply and other factors, per capita gross domestic product, life expectancy, lung cancer incidence rate (an index for smoking), and latitude (an index for solar ultraviolet-B doses). Per capita gross national product, in particular, was found to be correlated with five types, consumption of animal fat with two, and alcohol with one.

[17]http://www.bls.gov/cpi/cpifact8.htm

6 Regressions

We report here estimation results with the two key equations obtained from our theoretical model. One is the condition defining the determination of city GDP, Eq. (12) but only for the 100 MSA's for which we have sufficient data, for the years 2002, 2007, and 2012; see Table 2. Two is the spatial equilibrium condition in two versions using data for the 26 MSA's for which we have CPI data for the years 2002 through 2012: first in terms of land prices, Eq. (13), reported in Table 3, and second in terms of housing prices, Eq. (20), reported in Table 4. The estimation of urban GDP determination requires information for domestic shipments from city j to all cities, the availability of which is limited to those 3 years. We also use a larger sample of MSAs using regional CPI data for approximately 100 MSAs. Finally, we report another set of estimations along the lines of the specific predictions of the growth model, Eq. (27), for the one-half of the sample of cities with larger GDP, (28), for the one-half of the sample of cities with lower GDP, (29), and for all cities; see Table 6.

Tables 1a, 1b, and 1c presents descriptive stats for the data used in the regressions for equations 16, 17, and 19, respectively. In Table 1a, the average GDP per job is approximately \$114,000, with the average transfer equal to about \$59,000 and the average domestic sales per job approximately \$91,000. In Table 1b, during the period 2002-2012, the annual land rent growth per job is negative for both the MSA level and the overall urban total, with the MSA level being more negative than the overall. This negative average may be attributable to the Great Financial Crisis that began in late 2007. The GDP growth rate is approximately 3.7% annually during this period of 2002-2012, while the CPI growth rate is approximately 2.3%. Finally, in Table 1c, the average annual GDP in the years 2002, 2007, and 2012 was about \$123 billion, while the average annual domestic shipments was approximately \$116 billion. The average cancer death rate was slightly lower than 4300.

6.1 Determination of MSA GDP Regressions

Our estimation results for equation (12) are shown in Table 2. For the domestic shipments variable, we use the following as instruments [Baum-Snow (2007)]:

- For the 2002 observations, 100 times the number of highway "rays planned" times the ratio of completed miles of highways in 1960 passing through the central city that were in the original plan divided by the completed miles of highways in 1990 passing through the central city that were in the original plan;
- For the 2007 observations, 100 times the number of highway rays planned times the ratio of completed miles of highways in 1975 passing through the central city that were in the original plan divided by the completed miles of highways in 1990 passing through the central city that were in the original plan;
- For the 2012 observations, 100 times the number of highway rays planned times the ratio of completed miles of highways in 1990 passing through the central city that were in the original plan divided by the completed miles of highways in 1990 passing through the central city that were in the original plan.

According to Baum-Snow (2007), which launched the use of these instruments, a ray is a highway segment that connects to the central city. If a highway segment passes through a central city (into and out of the city only once), it counts as 2 rays. Note also that the "original plan" for highways was developed in 1947.

We argue that these highway ray instruments are highly correlated with domestic shipments (which we have confirmed empirically). But they are expected to be uncorrelated with shocks to city-level GDP because we are looking at past plans for highway rays and past completed highway miles that were in the original plan (from the 1940's). Shocks to GDP between 22 and 42 years later should be uncorrelated with the original plans and previous highway completions that were in the original plans. Our focus on highways that were in the original plan enables us to avoid the complications of new plans for highway construction, which more likely would be considered to be correlated with "shocks" to GDP. For instance, while a new decision to build another highway would be expected to be correlated with a city's domestic shipments, it also can be considered a shock to a city's current output if the new plan is unexpected. Therefore, focusing on highways that were in the original plan from the 1940s (opposed to more recent plans) leads to a credible instrument for current domestic shipments.

Table 2 reports OLS and instrumental variable estimation results in columns 1 and 2, respectively, for 100 MSA's, for which we have suitable data, including using regional CPI data using Eq. (12). In both specifications, the dependent variable is GDP per job; the estimated coefficients on domestic shipments per job and on transfers per job (for which we appeal to Gruber (1997) and use the Unemployment Insurance claims data as an instrument for transfers) are positive and highly significant). As about exports we appeal to their exogeneity to a city, but the estimated coefficient is negative and highly insignificant. We note, however, that the correct variable in (12) should be net exports, but we lack data on city international imports. In an important sense, the reality of modern manufacturing implies that exports and imports are highly correlated, and in this sense exports proxy to some extent for imports.

6.2 Spatial Equilibrium Regressions

We report estimations along the lines of the implications of spatial equilibrium, first in terms of land prices, Eq. (13), shown in Table 3, and second in terms of housing prices, Eq. (20), shown in Table 4. We report estimation results with region fixed effects instead of MSA fixed effects and year fixed effects or a year time trend. We normalize by the number of jobs instead of population and also include the two "spatial complexity" terms at the end of Eq. (20). Recall that the spatial equilibrium condition predicts that $S^{-1}B^{-1}$ is the coefficient on the term that expresses a city's GDP growth per capita from that of the national average.

Specifically, when we use OLS with no fixed effects and no time trend, the estimated coefficient for $S^{-1}B^{-1}$ is statistically significant but implausible, since it is less than 1. The coefficient on CPI difference is also implausible but significant. But the $S^{-1}B^{-1}$ being less than 1 result is implausible, perhaps because the estimate is biased due to omitted variables. Next we added region and time fixed effects, to control for potentially omitted variable bias. This yields $S^{-1}B^{-1} < 1$ and still statistically significant. The respective coefficient on the CPI difference term is negative but insignificant. Therefore, given the implausible result for

$S^{-1}B^{-1} < 1$, perhaps endogeneity is a concern.

Next we try estimating the model using instrumental variables, using as instruments first, the difference between the per job cancer death growth rates at the MSA and national levels, second land area that is unavailable for housing, third the housing supply elasticity, and fourth the Wharton Regulation Index. We perform the estimations with and without fixed effects at the region level, and time effects, and with region fixed effects and a time trend. The results are as follows. Without fixed effects, the estimate of $S^{-1}B^{-1}$ is greater than 1 and significant, but $J-$statistic is large (overidentification restrictions are not valid, P-value=0.0038); the coefficient on CPI difference term is negative but insignificant. With region and time fixed effects, the estimate of $S^{-1}B^{-1}$ is greater than 1 and significant, and the $J-$statistic is small ($P-$value=0.075); the coefficient on CPI difference term is negative but insignificant. With region fixed effects and time fixed effects, the estimate of $S^{-1}B^{-1}$ is greater than 1 and significant, and the $J-$statistic is small ($P-$value   0.15); the coefficient on CPI difference term is negative but insignificant.

Therefore, we are tempted to conclude that the latter Instrumental Variables specification with region and year fixed effects is the "preferred" one which control for endogeneity and omitted variables (through fixed effects). They give us the desired sign, magnitude, and significance on the estimate of $S^{-1}B^{-1}$. The CPI difference term is insignificant; and the $J-$statistic implies the overidentification restrictions are valid since the $P-$value is greater than 0.05 so using conventional levels of significance we can reasonably conclude this is the case. Arguably, we can justify using the region fixed effects instead of the MSA fixed effects, because we aggregate the CPI data to the region level rather than the MSA level (due to the lack of MSA level CPI estimates). So for consistency it makes sense to use the same level of aggregation for the fixed effects as we had for the CPI regions; the regional level also preserves degrees of freedom with only 4 regions instead of 97.

6.3 GDP Growth Rate Regressions

Finally, we report estimations along the lines of the specific predictions of the growth model; see Table 5. Eq. (27) is set in terms of integrated cities of "one type" and (28) is set in terms of integrated cities of the "other type." We estimate the former for the roughly one-half of the sample of cities with GDP above the median, and the latter for the approximately one-half of the sample of cities with GDP below the median. We also estimate (29), which is what the model predicts for autarkic cities, with the data for all cities. Our theory predicts that the GDP growth equations for integrated cities depend on each city's own population growth rate, on that of the other city types and on the national urban population growth rate, on the growth rate of aggregate physical capital, and on the growth rates of spatial complexity terms for each city type. For autarkic cities, our theory predicts that the growth rate depends only on the city's effective population growth rate. TFP growth rates are present on both equations, both having no measures of city specific TFP growth rates, we let them be absorbed by the residuals. We find that for the most part, the signs of the coefficient estimates on these variables are consistent with our expectations, and many of them are statistically significant.

Splitting the sample into large- vs. low-GDP cities is motivated by the commonly obtained prediction of new geography-style of international trade that more highly-integrated cities are more productive. At the same time, larger cities are less likely to be specialized and to depend on international trade. The sample splits we are working with here are of course very tentative. In future work, we aim to estimate such growth equations by splitting the sample into high- vs. low-exporting cities, but we have not yet refined our estimations accordingly.

We use the growth rate of 30-year mortgage interest rate to proxy for the growth rate of aggregate physical capital. The estimate has the predicted negative sign (for both the "small" and "large" city regressions), and the growth rate of the national average employment coefficient implies that higher national employment growth leads to greater city-level GDP growth. For "large" cities, higher job growth leads to significantly higher GDP growth, while for ”small” cities this effect is insignificant. Consistent with our previous estimations, we use GDP per job as well as number of jobs instead of actual populations. Higher employment growth in the other city type has a negative impact on an MSA's GDP growth, which implies that perhaps small cities are competing with large cities for skilled labor in order to enhance their own GDP growth. In sum, other than the “spatial complexity” terms, the coefficients on the regressors of these growth equations generally perform rather well with respect to their signs and significance.

7 Tentative Conclusions

This is the first paper, to the best of our knowledge, which aims at estimating an equilibrium urban macro model that links a city's presence in domestic and international trade to its growth rate performance. We estimate the GDP determination equation, a spatial equilibrium equation, and two sets of growth rate regressions. Our primary empirical findings confirm the comparative statics implications of our theoretical model. In several cases, such as in the spatial equilibrium equation, we have controlled for endogeneity with an Instrumental Variables (IV) approach. In future work, we plan to pursue several robustness checks. For instance, we plan to split the growth rate regressions based on export intensity for the integrated cities. We will also re-estimate the GDP determination equation by IV, and test the hypothesis that the coefficients on the transfers and exports terms are equal to 1. These robustness checks would validate our other empirical estimates as well as confirm that the data uphold the theoretical model implications.

8 Appendix: Derivations of City GDP for the Urban System with International Trade

For the cities that neither export nor import internationally, conditions (9.29–9.31) in Ioannides, *op. cit.,* that follow from the assumptions of capital mobility and spatial equilibrium continue to hold. In addition, the counterpart of (9.29) for cities of type X and X_{ex} yields the counterpart of (9.30), which is implied by spatial equilibrium:

$$\frac{P_X Q_X}{P_X Q_{X,p}} = \frac{N_X}{N_{X,x}}. \tag{36}$$

And similarly for cities of type Y and Y_{im} :

$$\frac{P_Y Q_Y}{P_Y Q_{Y,p}} = \frac{N_Y}{N_{Y,m}}. \tag{37}$$

In other words, the relative share of output by cities of type X, Y are proportional to their respective relative populations. Free capital mobility between X, Y cities implies condition (9.31) in Ioannides, *op. cit.*,

$$\frac{K_X}{K_Y} = \frac{N_X}{N_Y} \frac{\phi_X(1-\phi_Y)}{\phi_Y(1-\phi_X)}, \tag{38}$$

and between X-type cities and X type exporting cities

$$\frac{K_{X,x}}{K_X} = \frac{N_{X,x}}{N_X}, \tag{39}$$

and between Y-type cities and Y type importing cities

$$\frac{K_{Y,m}}{K_Y} = \frac{N_{Y,m}}{N_Y}. \tag{40}$$

These intermediate results will be critical in our derivation of expressions for city output in the presence of international trade.

In each city output of the composite good, which is not traded but is used for consumption and investment is produced by using quantities of tradeable goods X, Y according to

$$Q_X = Q_X^{\alpha} Q_Y^{1-\alpha}.$$

The corresponding (natural) price index is:

$$P \equiv \left(\frac{P_X}{\alpha}\right)^{\alpha} \left(\frac{P_Y}{1-\alpha}\right)^{1-\alpha},$$

which can be normalized and set equal to 1.

The objective of the analysis is to write expressions for real output of different city types, given total capital and total labor in the economy, (K, N), and given the sizes of different city types, $(N_X, N_{X,x}, N_Y, N_{Y,m})$. For example, the real income of a city of type X is $P_X Q_X$, which by using the normalization condition and the spatial equilibrium condition may be written as

$$\alpha^\alpha (1-\alpha)^{1-\alpha} Q_X^\alpha Q_Y^{1-\alpha} \left(\frac{N_X}{N_Y}\right)^{1-\alpha}, \tag{41}$$

where:

$$Q_X = \Xi_X H_X^{\mu_X(1-\phi_X)} K_X^{\mu_X \phi_X}, Q_Y = \Xi_Y H_Y^{\mu_Y(1-\phi_Y)} K_Y^{\mu_Y \phi_Y}, \tag{42}$$

where μ_X, μ_Y may actually be greater or less than 1. The counterparts of these expressions follow for the other types of cities.

We proceed by using the spatial equilibrium conditions among cities of type X, Y, (36) and (37), in the domestic trade balance condition (33) to eliminate $Q_{X,p}, Q_{Y,p}$. We thus have:

$$(1-\alpha)\left[n_X + \frac{N_{X,x}}{N_X}\right] P_X Q_X = \alpha \left[n_Y + n_{Y,m}\frac{N_{Y,m}}{N_Y}\right] P_Y Q_Y.$$

Solving for $\frac{P_X Q_X}{P_Y Q_Y}$ gives:

$$\frac{P_X Q_X}{P_Y Q_Y} = \frac{\alpha}{1-\alpha}\frac{N_X}{N_Y}\,\frac{n_Y N_Y + n_{Y,m} N_{Y,m}}{n_X N_X + n_{X,x} N_{X,x}}. \tag{43}$$

This is a straightforward generalization of the condition in the absence of international trade: if $n_{X,x} = n_{Y,m} = 0$, the spending on good Y by each city of type X is equal to the spending on good X by each city of type Y. From the ratio of the value of output of the typical exporting to importing city follows:

$$\frac{P_X Q_{X,p}}{P_Y Q_{Y,m}} = \frac{\alpha}{1-\alpha}\frac{N_{X,x}}{N_{Y,m}}\,\frac{n_Y N_Y + n_{Y,m} N_{Y,m}}{n_X N_X + n_{X,x} N_{X,x}}. \tag{44}$$

Rearranging the international trade balance condition (32) gives an equation for the terms of trade:

$$\frac{P_X}{P_Y} = \frac{n_{Y,m}}{n_{X,x}}\frac{Q_{Y,im}}{Q_{X,ex}}. \tag{45}$$

Rewriting the labor market condition by using the spatial equilibrium conditions yields:

$$n_X N_X + n_{X,x} N_X \frac{P_X Q_{X,p}}{P_X Q_X} + n_Y N_Y + n_{Y,m} N_Y \frac{P_Y Q_{Y,p}}{P_Y Q_Y} = N.$$

Using it along with the domestic trade balance condition as a simultaneous system of equation allows us to solve for $(n_{X,x}P_XQ_{X,p}, n_{Y,m}P_YQ_{Y,p})$ and obtain:

$$n_{X,x}P_XQ_{X,p} = \frac{\alpha(N - n_XN_X) - (1-\alpha)n_XN_Y\frac{P_XQ_X}{P_YQ_Y}}{(1-\alpha)\frac{N_Y}{P_YQ_Y} + \alpha\frac{N_X}{P_XQ_X}}; \tag{46}$$

$$n_{Y,m}P_YQ_{Y,p} = \frac{(1-\alpha)(N - n_YN_Y) - \alpha n_YN_X\frac{P_YQ_Y}{P_XQ_X}}{(1-\alpha)\frac{N_Y}{P_YQ_Y} + \alpha\frac{N_X}{P_XQ_X}}; \tag{47}$$

Dividing Eq. (47) by Eq. (46) and rearranging allows us to express $\frac{n_{Y,m}}{n_{X,x}}$ in terms of $\frac{P_XQ_X}{P_YQ_Y}$. Then, using Eq. (45) yields an expression for the terms of trade, in terms of $\frac{Q_{Y,im}}{Q_{X,ex}}$, which are given, $(n_X, N_X; n_{X,x}, N_{X,x}; n_Y, N_Y; n_{Y,m}N_{Y,m})$, and parameters:

$$\frac{P_X}{P_Y} = \frac{Q_{Y,im}}{Q_{X,ex}}\frac{N_{X,x}}{N_{Y,m}}\frac{(N - n_YN_Y)(n_YN_Y + n_{Y,m}N_{Y,m}) - n_YN_Y(n_XN_X + n_{X,x}N_{X,x})}{(N - n_XN_X)(n_XN_X + n_{X,x}N_{X,x}) - n_XN_X(n_YN_Y + n_{Y,m}N_{Y,m})}. \tag{48}$$

This solution demonstrates an important role for international trade on the urban structure. It is simplified by solving next below for $n_XN_X + n_{X,x}N_{X,x}, n_YN_Y + n_{Y,m}N_{Y,m}$. The expressions obtained for outputs by different types of cities, namely exporting and non-exporting cities of different types differ depending upon each city type.

Working with the capital mobility conditions (38), (39), and (40) allows us to solving for the capital allocations to different city types and therefore write expressions for real output, the counterparts of (41) for city types that export X and that import Y. This yields:

$$n_XN_X + n_{X,x}N_{X,x} = \frac{\alpha(1-\phi_X)}{\alpha(1-\phi_X) + (1-\alpha)(1-\phi_Y)}N; n_YN_Y + n_{Y,m}N_{Y,m} = \frac{(1-\alpha)(1-\phi_Y)}{\alpha(1-\phi_X) + (1-\alpha)(1-\phi_Y)}N. \tag{49}$$

This solution in turn simplifies (48). It also simplifies (43), which becomes:

$$\frac{P_XQ_X}{P_YQ_Y} = \frac{1-\phi_Y}{1-\phi_X}\frac{N_X}{N_Y},$$

and (44), which becomes:

$$\frac{P_XQ_{X,p}}{P_YQ_{Y,m}} = \frac{1-\phi_Y}{1-\phi_X}\frac{N_{X,x}}{N_{Y,m}}.$$

The allocations of total capital to the different types of cities are:

$$K_X = \frac{N_X\phi_X(1-\phi_Y)}{n_XN_X\phi_X(1-\phi_Y) + n_{X,x}N_{X,x}\phi_X(1-\phi_Y) + n_YN_Y\phi_Y(1-\phi_X) + n_{Y,m}N_{Y,m}\phi_Y(1-\phi_X)}K$$

$$K_{X,x} = \frac{N_{X,x}\phi_X(1-\phi_Y)}{n_X N_X \phi_X(1-\phi_Y) + n_{X,x}N_{X,x}\phi_X(1-\phi_Y) + n_Y N_Y \phi_Y(1-\phi_X) + n_{Y,m}N_{Y,m}\phi_Y(1-\phi_X)}K$$

$$K_Y = \frac{N_Y\phi_Y(1-\phi_X)\phi_X(1-\phi_Y)}{n_X N_X \phi_X(1-\phi_Y) + n_{X,x}N_{X,x}\phi_X(1-\phi_Y) + n_Y N_Y \phi_Y(1-\phi_X) + n_{Y,m}N_{Y,m}\phi_Y(1-\phi_X)}K$$

$$K_{Y,m} = \frac{N_{Y,m}\phi_Y(1-\phi_X)}{n_X N_X \phi_X(1-\phi_Y) + n_{X,x}N_{X,x}\phi_X(1-\phi_Y) + n_Y N_Y \phi_Y(1-\phi_X) + n_{Y,m}N_{Y,m}\phi_Y(1-\phi_X)}K$$

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10 Tables

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Table 1a: Descriptive Statistics for Variables in Equations 7 and 12, 100 Cities, Annual City-level data for 2002, 2007, 2012

	commute time	exports per job	GDP per job	open highway miles in plan	population	rays instrument	shipments per job	total jobs	total wages	transfers	UI receipts per job	labor income	land income
Mean	42.41097	0.008922	0.044558	89.55	2480505	364.9027	0.062243	1098080	4.97E+10	84785.1	0.177564	20.70216	34424.46
Median	24.73333	0.004197	0.043366	28	1659344	200	0.041142	754675	2.81E+10	45812	0.152371	20.06758	16464.25
Maximum	486	0.811691	0.092465	13072	19837753	2700	1.02524	8267733	5.64E+11	1279991	0.749482	43.35488	822704
Minimum	0	0.00011	0.019537	0	0	0	0	0	0	-449227	0.027611	10.70845	0
Std. Dev.	54.44779	0.047758	0.011119	754.5202	2839442	459.1836	0.094344	1204744	6.86E+10	155796	0.104928	4.450402	68269.07
Observations	299	298	297	300	299	224	298	299	299	297	297	298	299

Table 1b: Descriptive Statistics for Variables in Equation 17, 26 MSA's, 2002-2012

	land gr per job MSA	land gr per job total	GDP gr per job MSA	GDP gr per job tot	CPI gr MSA	CPI gr urban
Mean	-3.443627	-0.616421	3.782168	3.720451	2.363565	2.394109
Median	-2.598966	-0.993421	3.713319	3.644239	2.564788	2.663043
Max	155.7959	13.88601	11.63272	5.782928	5.187215	3.83955
Min	-85.18781	-20.5807	-7.548992	2.066836	-2.643688	-0.355778
Std. Dev.	26.93251	12.14613	1.929285	1.35203	1.301373	1.111351
Obs	286	260	286	260	286	286

Table 1c: Descriptive Statistics for Variables in Equation 19, 79 MSA's, 2002-2012

	Shipments (mill$)	GDP (mill$)	Cancer deaths
Mean	116722.4	123303.9	4262.229
Median	77223.5	73903	2872
Max	860095	1151686	35247
Min	0	2996	304
Std. Dev.	129196.9	146855.9	4648.366
Obs	232	211	214

Table 2: Estimation Results for Equation 12, for 100 "Cities", Annual City-level Data for 2002, 2007, 2012

Dependent Variable: GDP PER JOB
P-Value in bold
Independent Variables

	OLS	**Instrumental Variables**
CONSTANT	0.04146822	0.03302751
	0.00000000	**0.00000000**
DOMESTIC SALES PER JOB	0.00761173	0.10577207
	0.22718079	**0.00032336**
TRANSFERS PER JOB	0.00000003	0.00000007
	0.00000000	**0.00000000**
EXPORTS PER JOB	-0.00558097	-0.02424450
	0.65096052	**0.27863920**
N	297	221
R-squared	0.191593234	-0.48742397

Notes:
P-values are based on White Robust standard errors
Sample sizes are less than 300 due to missing values for some regressors and/or instruments
Instruments include:

for domestic shipments: "planned highway rays" times lagged share of highways completed;
for transfers: unemployment insurance receipts
exports is the instrument for itself (since demand for exports assumed exogenous to a city)
constant term is the instrument for itself

Table 3: Estimation Results for Equation 13, 26 MSA's, 2003-2012

Dependent Variable: LAND RENT GROWTH RATE PER JOB DIFFERENCE-GDP GROWTH RATE PER JOB DIFFERENCE
P-Value in bold

Independent Variables	OLS	Fixed Effects
CONSTANT	-3.984608	1.043285
	0.0050	**0.8872**
MSA CPI GROWTH - URBAN CPI GROWTH	5.644318	6.299464
	0.0006	**0.0001**
N	260	260
R-squared	0.044416	0.364512

Table 4: Estimation Results for Equation 20, 96 MSA's, Annual Data, 2003-2012
Spatial Equilibrium Equation
Dependent Variable: MSA House Price Growth Rate - National House Price Growth Rate
P-Values in bold

Independent Variables	OLS	Instrumental Variables
REGIONAL CPI Growth - Urban CPI Growth	-0.3953	-1.4753
	0.2381	**0.0770**
MSA GDP growth per capita - National GDP Growth per capita	0.2951	4.4939
	0.0009	**0.0384**
(MSA Employment per-capita)$^{1/2}$	-0.7573	4.2151
	0.1127	**0.5102**
(National Employment per-capita)$^{1/2}$	-0.5869	4.7178
	0.2361	**0.4745**
N	960	960
R-squared	0.0359	-
J-Statistic	-	0.1514

Note: All models include region and year fixed effects

Instruments for IV Estimation:
Unavailable Land Area; Wharton Regulation Index; House Price Elasticity; MSA Cancer Growth - National Cancer Growth

Table 5: Estimation Results for GDP growth rate regressions, panel data (annual-level, MSA)

Dependent Variable: Real GDP Growth Rate ($2005)

P-Values in bold Independent Variables	Trading City Model Large cities (eq 27)	Trading City Model Small cities (eq 28)	Autarkic City Model All cities (eq 29)
CONSTANT	0.0018	0.0000	-0.0052
	0.3965	**0.9916**	**0.0000**
Net Labor Supply Growth Rate	-	-	0.1890
	-	-	**0.0000**
Own-City Employment Growth Rate	0.2838	-0.0327	-
	0.0024	**0.6833**	-
Small-city Average Employment Growth Rate	-0.0192	-	-
	0.0382	-	-
Large City Average Employment Growth Rate	-	-0.0038	-
	-	**0.0366**	-
Interest Rate Growth Rate	-0.0968	-0.0924	-
	0.0072	**0.0052**	-
National Employment Growth Rate	-0.4920	-0.2102	-
	0.0000	**0.0286**	-
commute costs × difference in (small city employment growth)$^{1/2}$	0.0000	0.0002	-
	0.0000	0.0000	-
commute costs × difference in (large city employment growth)$^{1/2}$	0.0001	0.0000	-
	0.0000	**0.0004**	-
Cross Sections (number of cities)	208	208	353
Years	2006-2012	2006-2012	2007-2012
N	879	882	2114
R-squared	0.4835	0.4872	0.21254695

All regressions estimated by OLS, include cross-sectional fixed effects

Large cities in a particular year are defined as cities with GDP above the median of all MSA's GDP; small cities with GDP below median

Interest Rate based on 30-year mortgage rate, national level estimates