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

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Abstract

International trade models typically consider countries exchanging goods/services, while urban models often examine the consequences of domestic trade for city structure. Relatively little known research synthesizes these to allow for shocks propagating domestically with both domestic and international trade. One exception is Autor et al. (2013), who examine how Chinese imports impact US domestic labor markets.

We consider how city-to-city trade and city international exports impact city Gross Domestic Product (GDP) and housing price growth. We develop a theoretical model of trading cities, domestically and internationally, and explore its empirical predictions. We propose and estimate several empirical models. Using instrumental variables (IV), we identify city-level GDP growth impacts on city house price growth. This first equation follows from imposing spatial equilibrium across cities. The second IV equation examines how international exports from a city, transfers, and domestic shipments impact city-level GDP. We also consider a third set of equations, which explores how economic integration, domestic and international, affects city-level GDP growth. In general, our empirical estimation results confirm the signs/magnitudes predicted by the theory, and imply that labor market shocks in trading cities affect city-level GDP, which in turn impacts housing prices. This theoretical approach, synthesis of city-level data, and empirical analysis are completely novel.

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 economies to import goods that are consumed by their 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, and housing prices and rents, as well as 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 in their export industries.

Research on housing markets and prices typically looks either at the housing market alone, or at the housing and labor markets jointly. Other research on international trade, such as Autor, Dorn, and Hanson (2013), considers the relationship between trade and the labor markets. Our research innovates by bringing into the analysis some additional but lesser known sources of data, which are critical for understanding urban economies as open economies. One is the Bureau of Economic Analysis (BEA) data on MSA GDP, which started in 2001 and is 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] Other data from the Brookings Institute also

[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 2002, 2007 and 2012. As Duranton *et al.* (2014) clarify, the CFS divides the continental US into 121 CFS regions, each an aggregation of adjacent counties. The Duranton and Turner

detail MSA exports based on the production location of the exported products. 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 shipments 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, we outline a static 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. The model predicts that there are structural differences across cities of different types in the determination of city GDP on account of intercity trade, and how GDP growth affects the growth of city-level house prices. The paper also estimates the respective structural equation for 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.

Our interpretation of the empirical findings is that since trading cities have more channels through which an employment shock can be absorbed, there is much less of an impact that is passed through to the housing markets and therefore house price growth may be much more insulated. To the best of our knowledge, the paper's approach is completely novel; we are unaware of any previous research that synthesizes the intercity trade data, city-level housing

sample consists of the 66 such regions organized around the core county of a us metropolitan area. CFS cities are often larger 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. In our analysis, we create correspondence between CFS cities in the years 2007 and 2012 with the 2002 CFS city definitions, leading to 68 cities in each of these three years.

price data, and 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 index, in the context of estimating external shocks to a city's economy. There are several later applications of this index, including Hollar (2011), which is a study on central cities and suburbs; Larson (2013), which considers 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, although one drawback of that data source is that it is based on origin of shipments rather than origin of production.

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 industries. 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 focus on measurement and data construction aspects. Braymen *et al.* (2011) examine R&D and exports, using a somewhat limited, firm level database on exports from the Kauffman Foundation, and control for R&D activity in the metro area. Finally, Vachon and Wallace (2013) use the exports data to assess how globalization affects unionization in 191 MSAs.

Finally, a more recent paper by Li (2015) uses a very rudimentary empirical analysis to motivate her theoretical model and simulations for US cities that describes the relationship between house prices and comparative advantage. The theory is the primary focus of that paper.

Given the sparseness of published research integrating theoretical underpinnings with rigorous empirical modelling on house prices, GDP, and exports at the MSA level, together with the limitations of some of the other exports data sources, our understanding of export-oriented cities would benefit from further analytical and empirical attention.

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 increasing returns to scale (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 with 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 $(X, Y, h(\ell))$ are given by Roy's identity:

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

where $j = X, Y$ denotes goods (but all city type, when cities specialize fully).[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:

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

[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.

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 in each city type, 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 by the agricultural rent, $R_{a,j}$, 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 nominal 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

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

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]. Because of intraurban 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 $\frac{1}{N_j}F(H_c(N_j))$, where $F(\cdot)$ denotes the aggregate production function. 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 $X-$ type 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:

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

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:

$$\Upsilon_j = \gamma_1 S_j + \gamma_2 \mathcal{T}_j + \gamma_3 \, \text{ex}_j. \quad (12)$$

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

[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.

national currency. It readily follows from (7) and (12) that the conditions $\gamma_2 = \gamma_3 = 1$ are 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 inter-city 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 rate of per capita income relative to the growth rate of national per capita income, Υ_{n}:

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

Eq. (12–13) will be taken to the data. Both these equations are derived using a 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, in 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

[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.

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 nonhousing and housing out of their their labor income net of their savings, (C_{1t}, G_{1t}), and consume again when they are old, $(C_{2t+1}, G_{2,t+1})$ 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, Ioannides (2013). 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 rental income may be written, according to (6), in terms of the number of young residents 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 (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, and capital will seek to locate so as to 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

[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 $b_{it}(Z_{Jt})$.

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 type$-X$ 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:

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

[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.

By taking logs we have:

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

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:

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

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 $GR_{t+1,t}(P_j) - GR_{t+1,t}(P_{\mathrm{j,u}})$, the growth rate of the city price index relative to a national average, is predicted to be positive; the coefficient of $GR_{t+1,t}\Upsilon_j - GR_{t+1,t}(\Upsilon_{\mathrm{n}})$, 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, $P_X Q_X$, and $P_Y Q_Y$, 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:

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

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

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

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

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

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, $\hat{\bar{\Xi}}_t$, 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:

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

[13]The TFP function $\hat{\bar{\Xi}}_t$ 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 $\hat{\bar{\Xi}}_t$ with the same exponents as in Ξ_t^*, but the shift factors differ.

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

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

respectively:

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

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

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

The growth equations obtained above, (27) and (28), follow from 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 the growth rate of income per person may be expressed in terms of the *same* (log)linear combination of the TFP growth rates of the city's different industries, $\alpha \ln \bar{\Xi}_{Xt} + (1-\alpha) \ln \bar{\Xi}_{Yt}$, and in addition, the growth rate of the respective effective labor supply, and of the aggregate physical capital in that city. That is:

$$\mathrm{GR}(\Upsilon_{\mathrm{aut},jt}) = \alpha \mathrm{GR}_{t,t+1}(\Xi_X) + (1-\alpha)\mathrm{GR}_{t,t+1}(\Xi_Y) + (\mu\phi + \upsilon)\mathrm{GR}_{t,t+1}(K_{j,t})$$
$$+(\mu(1-\phi) - \upsilon)\mathrm{GR}_{t,t+1}(H_c(N_{jt})). \tag{29}$$

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. We note that whereas in Eq. (27) and (28), K_t denotes aggregate physical capital in the economy, here $K_{j,t}$ denotes physical capital for city j at time t.

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. 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,

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

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. In work currently in progress, we plan to estimate the growth equations by also including data on capital accumulation.

Another question that would require a modification of the growth model would be to consider how anticipated growth rates on housing prices may hamper city growth. Because of varying housing supply restrictions across various US cities, Glaeser and Gyourko (2017) argue that the local and state control of land use regulations may be quite important in this regard and may also be responsible for spatial variation in housing equity accumulation by US households. Doherty (2017) dramatizes this point by invoking Hsieh and Moretti (2015), arguing that local land-use regulations reduce the United States' GDP by as much as $1.5 trillion a year, or about 10%. As we discuss in section 6.2, our model and estimation results are consistent with the arguments proposed Glaeser and Gyourko and Hsieh and Moretti.

4 Overview of Data

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

The following major sources of data are available to us. We combine these into a single data set, using a common city definition (for approximately 100 "cities") based on the 2002 Commodity Flows Survey (CFS) from the U.S. Bureau of Transportation Statistics: -Annual data (purchased from Telestrian, originating from BEA) for MSA GDP, real and nominal, for about 360 MSAs for 2002-2012;

- Data on city-level domestic exports for 2002, 2007, 2012 for approximately 68 cities from the CFS; each year of the CFS has its own city definitions, which necessitated our matching the data for all three years to one common set of city definitions (for 2002).

- Data on international exports by 377 MSAs from the Brookings Institution for the following categories of commodities: agriculture; educational services, medical services and tourism; engineering; finance; general business; IT; manufacturing and mining.[14]

[14] We aggregate these 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 Federal Housing Finance Agency (FHFA).

- 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; however, this would dramatically limit the city coverage and lower our sample size, so we chose to utilize regional CPI data for the 4 geographic regions as defined by the U.S. Bureau of Labor Statistics (BLS). For analysis of Eq. 12, we generate estimates of city price indexes by taking the ratio of nominal to real GDP in each city in each year.

- Data describing land availability and quality for housing use are 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 MSAs, were also obtained, their city definitions were merged, and used for instruments in Eq. 24.

- Data on MSA cancer deaths for 1999-2012 for 104 MSAs from the Center for Disease Control (CDC) are also obtained and utilized as instruments for MSA-level GDP growth in Eq. 24.

- We obtain data on highway "rays" - the number of highway segments that pass into and/or out of a central city - and completed miles of highways in each MSA, from Baum-Snow (2007). We utilize the "rays" data and the lagged national highway miles completed net of highway miles completion divided by the lagged national highway miles completion; and the ratio of national population net of local population to national population, as instruments for the domestic shipments variable in Eq. 12.

- Unemployment Insurance receipts data are obtained for 2002, 2007, and 2012 at the

MSA level from the U.S. Bureau of Economic Analysis (BEA). We use this variable ("real" Unemployment Insurance receipts per capita) as an instrument for transfers in Eq. 12. Gruber (1997) also uses unemployment insurance receipts as an instrument for transfers.

- In constructing the transfers variable that we use in Eq. 12, we use the definition that transfers in a city is equal to the city GDP per job minus the land income minus the labor income. Since the Lincoln Institute land values data is only available for 46 MSA's, we construct the land income per job data from Eq. (6) in this paper. Eq. (6) utilizes the commuting time data, the wages data, and the employment data. In constructing the labor income per job data, we consider the effective employment, where we adjust for the fact that commuting time detracts from labor income potential. We multiply the ratio of total wages to total jobs by the inverse of the typical number of hours per year worked (assuming 35 hours per week for 52 weeks) plus the commute time (in minutes) divided by 60 times 260 (which is 5 days per week times 52 weeks per year). This results in an estimate for effective labor income per hour, which is lastly multiplied by 1800 (the number of hours typically worked in a year) to obtain annual effective labor income per job. As explained above, we follow a similar approach as Gruber (1997) and utilize the unemployment insurance claims data as an instrument for transfers.

- Since a city is small relative to the rest of the world, we assume the demand for a city's exports is exogenous to the city.

4.1 International versus Intercity Trade Flows

Here we discuss some features of intercity shipments data for 2002, 2007 and 2012, using the 68 city definitions we generate from the 2002 CFS. We have matched the roughly 377 MSAs with exports data from the Brookings data source. Exports from city j to the rest of the world are obtained from the Brookings Institution[15]. Since there are fewer cities in

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

the CFS than in the Brookings dataset, many of the exporting MSAs have been combined manually in several instances into a number of broader CFS city definitions. This process was tedious and runs into 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 68 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 68 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 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.

The comparison of the ratio of exports to domestic shipments across the three different years is interesting. For 2007, the mean value of the ratio is 0.2047 and its standard deviation 0.7704. These values imply a coefficient of variation of 3.76. In contrast, both mean and standard deviation are at 0.2738 and 1.2421, respectively, greater for 2012. However, the coefficient of variation at 4.5357 is also greater, and the range of values has widened. In other words, it appears as if U.S. cities on average have become more international export driven over time. There is also a greater spread in cities' export ratio. Some have become much more export intensive while others have become much less export intensive, where the shift is somewhat greater on the higher end of the distribution.

4.2 Descriptive Statistics

Table 1a presents descriptive stats for the data used in the regressions for equations 7 an 12. In Table 1a, the average GDP per job is approximately \$47,900, with the average transfer equal to about \$117,000 and the average domestic sales per job approximately \$59,000. In Table 1b, during the period 2002-2012, the average 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%. In Table 1c, the average annual MSA-level GDP growth rate per job in the years 2003-2012 was about 3.57%, while the average cancer death rate per job was 0.43%. Finally, in Table 1d, the average MSA nominal GDP was approximately \$66.6 billion, with 537,000 "effective" jobs in "large" cities and 61,000 "effective" jobs in "small" cities.

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' CFS. 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 value data at the MSA level for 46 MSA's are available from the Lincoln Institute of Land Policy.[16] However, to broaden our sample we utilize Eq. (6) to develop land value estimates, which is explained in the data section above. We have matched our derived land value MSA-level data with data on unemployment insurance receipts, completed highway miles and per-capita highway "rays" 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 national highway network, which was developed many years ago. For this reason, the size of the highway network outside of a particular city is used as an instrument for domestic shipments; a larger national network outside the city should lead to higher domestic shipments. We use highway rays per-capita as another instrument for domestic shipments, to represent the congestion and/or roads quality within each city. National population relative to local (i.e., city) population is an instrument that controls for the demand for a city's out-of-city shipments. For the transfers variable, Gruber (1997) utilized unemployment insurance claims as an instrument for transfers, and we follow that approach here. 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.

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.[17] The complex dependence of income per person on city geography,

[16]See Davis and Palumbo (2006), Davis and Heathcote (2007), and http://www.lincolninst.edu/subcenters/land-values/metro-area-land-prices.asp

[17]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

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

The spatial equilibrium, Eq. (24), dictates our choice of variables in the empirical analysis. 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,[18] 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 (and these 4 regions encompass all MSAs in the entire US). 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 supply elasticity; and the Wharton Residential Land Use Regulation Index.

temperate zones. The estimated relationship suggests that 1 % higher gross domestic product per capita, 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 for 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.

[18] 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 68 MSA's for which we have sufficient data, for the years 2002, 2007, and 2012; see Table 2. Two is the spatial equilibrium condition, annually for the years 2002 through 2012, 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 "deflate" the data in this estimation equation with a deflator obtained from the ratio of nominal to real GDP. 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. The split-sample estimations are motivated by the trading cities model (equations 27 and 28).

6.1 Determination of MSA GDP Regressions

Our estimation results for Eq. (12) are shown in Table 2. For the domestic shipments variable, in addition to the number of highway "rays planned" per capita, and the share of national population that is outside of the particular city, we use the following as instruments [Baum-Snow (2007)]:

- For the 2002 observations, the share of national completed miles outside of the city, of highways in 1960 passing through all central cities that were in the original plan;
- For the 2007 observations, the share of national completed miles outside of the city, of highways in 1975 passing through all central cities that were in the original plan;
- For the 2012 observations, the share of national completed miles outside of the city, of highways in 1990 passing through all central cities that were in the original plan.

According to Baum-Snow (2007), which pioneered 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. We normalize this rays variable by the population of the city (which varies over time), to obtain our instrument. This normalization is crucial to distinguish between cities with a lot of extra highway capacity versus those that are congested over time relative to the number of people and firms likely using the roads. Note also that the "original plan" for highways was developed in 1947. Also, the lagged national share of completed highways miles outside of a given city will vary across different cities, because this measure excludes the particular city, as an approach to estimate the effect of the highway network in the rest of the nation on a particular city's shipments.

We argue that these highway 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 1940's (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, covering 68 MSA's for which we have suitable data, using Eq. (12), annually for 2002, 2007, and 2012. We put all variables into real terms by using a price deflator that we generate by using the ratio of nominal GDP to real GDP for each city. This is particularly important because the years in our analysis were 2002, 2007, and 2012, which included some boom years and a major recession. In both specifications, the dependent variable is real GDP per job; the estimated coefficients on real domestic shipments per job and on real 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 with the IV estimator. With OLS, the domestic shipments variable is positive but insignificant, the transfers variable is positive and significant, and the exports variable is negative but insignificant. So, the insignificance of the domestic shipments variable naturally leads to the question: does potential endogeneity of domestic shipments cause this shipments coefficient to be biased? Therefore, we place high confidence in our IV estimates, especially since the domestic shipments variable becomes significant with IV. Also, in the IV specification the P-value for the J-Statistic is greater than 0.05, implying the overidentification restrictions are valid. With exports we appeal to their exogeneity to a city, since a city is relatively small with respect to the rest of the world, but the estimated coefficient is negative and highly insignificant. We note, however, that the correct variable in Eq. (12) should be net exports, but we lack reliable city-level data on 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) as 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 $S^{-1}\beta^{-1}$ is the coefficient on the term that expresses a city's GDP growth per capita from that of the national average.

Specifically, In Table 4, when we use OLS with region and year fixed effects, the estimated coefficient for $S^{-1}\beta^{-1}$ is statistically significant but implausible, since it is less than 1. The coefficient on CPI difference is positive but insignificant. But the $S^{-1}\beta^{-1}$ being less than 1 result is implausible, perhaps because the estimate is biased due to omitted variables and/or endogeneity concerns.

Next we estimate the model using instrumental variables, using as instruments the difference between the per job cancer death growth rates at the MSA level and the GDP growth rate at the national level (since the national GDP should be exogenous to an MSA); second, land area that is unavailable for housing; third, the housing supply elasticity; and fourth, the Wharton Regulation Index. We perform the estimations with fixed effects at the region level, and time effects. The results are as follows. The estimates of the key parameters, the coefficients of the regional CPI growth rate minus that of the urban CPI growth rate and of the difference of the MSA GDP per capita growth rate minus the national one, generally agree with the predictions. The estimate of $S^{-1}\beta^{-1}$ is at 4.49 greater than 1, as predicted, and significant, and the $J-$statistic is small ($P-$value=0.1514); the coefficient on CPI difference term is as predicted negative but significant at 7%. If, however, we follow the theory and adopt an one-sided test ($P-$value=0.0385), and the estimate is significant at 5%. A quick calculation shows that the implied parameters are not outrageously implausible. The implied value of S, the savings rate, is about 0.40 and that of β, the elasticity of housing in the utility function, is about 0.56. Both these estimates are too large, though not outside the bounds for those parameters. Specifically, BLS reports[19] that the share of housing in expenditure for urban households was 34.2% in 2011.

Therefore, we are tempted to conclude that the latter instrumental Variables specification with region and year fixed effects is the "preferred" one which controls for endogeneity and omitted variables (through fixed effects). They give us the desired sign, magnitude, and significance on the estimate of $\frac{1-S}{S}$, and the desired sign, magnitude, though not significance of $S^{-1}\beta^{-1}$. The CPI difference term is insignificant; and the $J-$statistic implies the overidentification restrictions are valid since the $P-$value is much 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, since the regional

[19]https://www.bls.gov/opub/btn/volume-2/expenditures-of-urban-and-rural-households-in-2011.htm

level also preserves degrees of freedom with only 4 regions instead of 97. Also, for consistency it makes sense to use the same level of aggregation for the fixed effects as we have for the CPI regions. An implication of these estimates is that the behavioral model helps in addressing another issue. If we were to interpret the price of housing as the user cost of housing, then expected capital gains on housing reduce its user cost. For spatial equilibrium, this is consistent with a lower growth rate of per capita real income in the same city. In other words, and without making a causal claim (but see Glaeser and Gyourko (2017) and Hsieh and Moretti (2015)), expected capital gains in housing are associated with lower real income growth.

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. 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 in terms of which each city's own capital accumulation growth rate is expressed via the model, and on the growth rates of spatial complexity terms for each city type. It also depends on total factor productivity (TFP) growth for integrated cities. Interestingly, the TFP growth rates are the same functions of the TFP growth rates of the representative industries in the economy and differ between integrated and autarkic cities in terms of a constant. Having no measures of city specific TFP growth rates, we use state-level TFP growth rates.

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. Also, the theory accounts for the dependence of the time costs of commuting on city size. We eschew a very tight parametrization on account of commuting costs and we adjust the number of jobs in each city as follows. The effective number of jobs, $H_c(N_{jt})$ above, is defined as follows by using the reported metro-area specific average daily commuting time in minutes, average commute time$_{jt}$:

$$H_{\text{eff},jt} = \text{total jobs} \times \frac{1800 - 5 \times 52 \times \text{average commute time}_{jt}/60}{1800}.$$

Regarding TFP growth rates, which enter the GDP growth equations, the best that we can do is to proxy them by means of state-level TFP growth rates.[20] Similarly, in the absence of city-specific physical capital, we use state-level physical private capital and state-level public capital, as measured by investment in state highways.[21]

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 on the one hand may be less likely to specialize and to depend on international trade, while on the other hand they may be more likely to export products. We use the growth rate of federal funds interest rate to proxy for the growth rate of aggregate physical capital in equations (27) and (28), in accordance with our theory. For both large and small cities, Table 5 shows that the own average net employment growth rate has a significant and positive (as predicted) coefficient, and that for the other city type negative (as predicted) but the latter is not significant for small cities. The national net employment growth rate is not significant in either regression. The estimated coefficient for the state-level TFP growth rates are both statistically significant positive. However, whereas the one for larger cities is positive, as predicted by the theory, the one for smaller cities is negative. Given that urban growth is known not to be even within US states, this perhaps suggests that state-level TFP growth has detrimental

[20]The state-level TFP growth rates data are from Cardarelli and Lusinyan (2015). We are grateful to them for their generosity in lending us the data. We are aware of only two studies in the literature that involve US metro-area TFP growth rates; these are Hsieh and Moretti (2015) and Hornbeck and Moretti (2015). However, their TFP growth rate computations are not made public as of the time of writing.

[21]The private capital data come from the US Census Annual Survey of Manufactures, geographic area series. The public capital data come from the US Census State Government Finances data series. The data recoding and processing is our own.

effect on smaller cities. In addition, during the period of our study, TFP growth decelerates across US states, as Cardarelli and Lusinyan (2015) demonstrate,[22] which may indeed be associated with asymmetric effects across cities. The growth rates for private capital and for highway capital, which appear as determinants for the smaller cities growth equation, are not significant. The overall fit is quite good for both regressions, with R^2's being quite high at 0.587 and 0.506, for large and small cities, respectively.

7 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. One of the unique facets of our work is analogous to Autor, Dorn and Hanson (2013). They examine how imports from China affect the labor markets in U.S. "commuting zones". Our efforts have the potential to shed some light on transmission of labor market shocks on goods markets in trading cities. In turn, we then demonstrate through a parallel empirical analysis that changes to the city-level goods markets affect local housing prices. In other words, our findings imply that trading cities' labor market shocks can indirectly impact the housing markets through the goods markets, and these effects can vary depending on whether the trading cities are "large" or "small".

It would be interesting to explore the potential of the model to explain housing price dynamics and economic growth in a number of truly global cities, like New York, San Francisco, Vancouver, London, Singapore, Hong Kong, etc. In those cities and many others, it is not only international trade but also foreign investment in housing and real estate that

[22] See also Chart 2, https://blogs.imf.org/2014/09/25/a-tale-of-two-states-bringing-back-u-s-productivity-growth/

plays an important but not well understood role. These issues clearly deserve attention in future research.

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9 Appendix (Not for Publication): 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:

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

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

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

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

10 Tables

- Table 1a, 1b, 1c, 1d, 1e: Descriptive Statistics
- Table 2: Estimation Results for City GDP determination, Eq. (12), for 68 cities, 2002, 2007, 2012
- Table 3: Estimation Results for Spatial Equilibrium, Eq. (13), 26 MSA's, 2003-2012
- Table 4: Estimation Results for Eq. (20), 96 MSA's, 2003–2012
- Table 5: Growth Regressions for Large and Small Cities, Equations (27), (28).

Table 1a: Descriptive Statistics for Variables in Equations 7 and 12, 68 Cities, Annual City-level data for 2002, 2007, 2012

	commute time (minutes)	exports per job ($mill)	GDP per job ($mill)	open highway miles in plan	population	labor income ($ thous)	land income ($)
Mean	34.47	0.00581	0.047893	46.04865	2789082	22.191	32914
Median	25.40	0.00432	0.046835	25	1726759	22.011	24677
Maximum	264.80	0.12322	0.092465	564	19837753	43.355	197212
Minimum	15.80	0.00030	0.024757	0	71712	13.108	8939
Std. Dev.	33.09	0.01033	0.010309	65.43195	3229233	4.342	28853
Observations	185	185	185	185	185	185	185

	rays per capita	domestic shipments per job ($ mill)	total jobs	total wages ($)	transfers ($)	UI receipts per job ($ thous)
Mean	0	0.058861	1254921	5.97E+10	116936	0.1778
Median	0	0.040539	801840	3.29E+10	60557	0.1491
Maximum	0	1.02524	8267733	5.64E+11	1279991	0.7495
Minimum	0	0.000541	40323	1.41E+09	-118605	0.0276
Std. Dev.	0	0.093542	1385999	8.00E+10	180018	0.1119
Observations	184	185	185	185	185	185

* While we have compiled data for 100 "cities" in each of the 3 years, we present data here for 68 cities (although some have missing data for some years).
With the sample of 100 cities, the mean of the domestic shipments per job is higher than the mean of GDP per job, because for the domestic shipments data, many of what we call "cities" include the "remainder of" the domestic shipments in the state that is not included in the other MSAs. But for GDP, the "remainder of" the states only consist of the remaining MSAs among the other MSAs that are not in the state. For some states with relatively few MSAs, this implies that the "remainder of" the domestic shipments in the state can include all of the areas that are not part of an MSA, so that the total (and mean) domestic shipments can be higher than the total (and mean) of GDP. Therefore, we drop the "remainder" cities, leaving us with data for 68 cities that we present in this table and use for our analysis of eq 12.

Table 1b: Descriptive Statistics for Variables in Equation 13, 26 MSA's, 2002-2012

	growth in land value per job MSA	growth in land per job total	growth in GDP per job MSA	growth in GDP per job tot	growth in CPI MSA	growth in CPI "all urban"
Mean	-0.03443627	-0.00616421	0.03782168	0.03720451	0.02363565	0.02394109
Median	-0.02598966	-0.00993421	0.03713319	0.03644239	0.02564788	0.02663043
Max	1.557959	0.1388601	0.1163272	0.05782928	0.05187215	0.0383955
Min	-0.8518781	-0.205807	-0.07548992	0.02066836	-0.02643688	-0.00355778
Std. Dev.	0.2693251	0.1214613	0.01929285	0.0135203	0.01301373	0.01111351
Obs	286	260	286	260	286	286

Table 1c: Descriptive Statistics for Variables in Equation 20, 96 MSA's, 2003-2012

	Growth in CPI (region)	Growth in CPI (MSA)	Growth in GDP per job (MSA)	Growth in GDP per job (nation)	Jobs per capita (nation)	Jobs per capita (MSA)
Mean	0.025275982	0.024520681	0.03566983	0.03622301	0.441852852	0.437501623
Median	0.026948288	0.028339157	0.034661982	0.039357728	0.451738849	0.44866066
Max	0.046546547	0.03785489	0.219547493	0.051632747	0.459386936	0.607012932
Min	-0.004350979	-0.001119453	-0.07355889	0.020502477	0.41812985	0.00000000
Std. Dev.	0.011374057	0.011605292	0.024786624	0.011531386	0.016355196	0.075315113
Obs	970	970	960	970	970	970

	Growth in Cancer deaths per job (MSA)	Growth in Cancer deaths per job (NATION)	Unavailable land share (MSA)	House price elasticity	Wharton Land Use Regulation Index
Mean	0.00430883	0.001036258	0.261474748	1.897750344	0.073577796
Median	0.000415332	-0.008334288	0.192263633	1.668164492	0.034924999
Max	0.205606671	0.055564962	0.796446204	5.453317165	1.892059565
Min	-0.136303455	-0.018477636	0.009316998	0.595266104	-1.23920691
Std. Dev.	0.04312148	0.021239225	0.2091283	0.9204122	0.668382832
				-0.767233036	-0.893310739
Obs	960	970	970	970	970

Table 1d: Descriptive Statistics for Variables in Equation 27, 180 MSA's, 2006-2010

	Nominal GDP ($million)	Large Cities Effective Jobs (net of commute time)	Small Cities Effective Jobs (net of commute time)
Mean	66610.098266	537051	60962
Median	23986	228475	62120
Max	1280307	7584130	62961
Min	9637	47593	57844
Std. Dev.	130187.848132	865517	2025
Obs	865	865	865

	"National" Average Effective Jobs, net of commute time	State-level TFP Growth	Federal Funds Rate (National)
Mean	294202	-0.001368826	2.71
Median	298095	-0.00264581	3.94
Max	301586	0.07566632	5.25
Min	284771	-0.07467376	0.11
Std. Dev.	7150	0.025750115	2.19
Obs	865	855	865

Table 1e: Descriptive Statistics for Variables in Equation 28, "Small Cities", 187 MSA's, 2006-2010

	Nominal GDP ($ million)	Small Cities, Eff. Jobs, net of commute	Large Cities, Eff. Jobs, net of commute	Priv. Cap. Stock	Highway Cap. Stock
Mean	5286.855	61049.478	538025.658	357820073	434276838.6
Median	4928.000	55614.069	548378.962	283663386.4	340310012.7
Max	9632.000	130884.309	559979.439	1107558082	1365915125
Min	2251.000	16581.654	502872.571	46138045.3	56172021.33
Std. Dev.	1855.707	21561.809	21994.717	258303293.6	312271143.1
Obs	905	900	905	900	900

	"National" Avg. Eff. Jobs, net of commute	State-level TFP Growth
Mean	294454.150	-0.000666
Median	298094.603	-0.002497
Max	301586.445	0.075666
Min	284770.702	-0.074674
Std. Dev.	7069.461	0.025222
Obs	905	900

Table 2: Estimation Results for Equation 12, for 68 "Cities", Annual City-level Data for 2002, 2007, 2012

Dependent Variable: GDP PER JOB
P-Value in bold

Independent Variables	**OLS**	**Instrumental Variables**
CONSTANT	48804.20	54647.16
	0.0000	**0.0000**
DOMESTIC SALES PER JOB	0.0043	0.0247
	0.1114	**0.0170**
TRANSFERS PER JOB	0.1436	0.4335
	0.0000	**0.0034**
EXPORTS PER JOB	-0.0575	-0.1158
	0.4360	**0.1128**
N	185	184
R-squared	0.1397	-0.4158
J-statistic (P-Value)	-	**0.0906**

Notes:
P-values are based on White Robust standard errors
Sample sizes are less than 204 (68 cities for 3 years) due to missing values for some regressors and/or instruments
Instruments include:

for domestic shipments: "planned highway rays" per-capita;
lagged ratio of highways completed outside the city to all highways completed (inside and outside the city);
share of population outside the city to total national population (a proxy for demand for shipments);
for transfers: real unemployment insurance receipts per capita
exports (real exports per job) 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	IV
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)$^{1/2}$	0.0757	-0.4215
	0.1127	**0.5102**
(National Employment per-capita)$^{1/2}$	-0.0587	0.4718
	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: Nominal GDP Growth Rate **P-Values in bold** Independent Variables	Trading City Model Large cities (eq 27)	Trading City Model Small cities (eq 28)
CONSTANT	0.0362	0.0382
	0.0000	**0.5960**
State-Level Total Factor Productivity Growth	0.2274	-0.2101
	0.0003	**0.0045**
Own-City Net Employment Growth Rate	0.9124	1.2119
	0.0000	**0.0000**
Small-city Average Net Employment Growth Rate	-0.0126	-
	0.0001	-
Large City Average Net Employment Growth Rate	-	-0.0162
	-	**0.2157**
National Net Employment Growth Rate	0.9329	-0.1276
	0.1519	**0.5600**
Interest Rate (federal funds rate) Growth Rate	-0.0585	-
	0.0037	-
State-Level Private Capital Stock Growth	-	0.9517
	-	0.4947
State-Level Highways Capital Stock Growth	-	-0.8373
	-	**0.5320**
Year Dummy for 2007	-0.0283	-0.0098
	0.0000	**0.0125**
Year Dummy for 2008	-0.0208	-0.0025
	0.1077	**0.8199**
Cross Sections (number of cities)	180	187
Years	2006-2010	2006-2010
N	854	894
R-squared	0.5869	0.5064

All regressions estimated by OLS, include cross-sectional fixed effects
Large (small) cities: cities with GDP above (below) the median of all MSA's GDP
Interest Rate: Federal Funds rate, national level estimates
"Net Employment" refers to employment net of commuting time. See the text for an explanation.