# Lecture 4: Quantitative Spatial Economics

## Economics 552

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- Economic activity is highly unevenly distributed across space, as reflected in the existence of cities
- The delicate balance between agglomeration and dispersion forces that underlie these concentrations of economic activity is central to a range of economic phenomena
  - incomes of mobile and immobile factors
  - the magnitude of residential amenities
  - investments,
  - and city and aggregate productivity
- The impact of public policy interventions is crucially determined by how these policies affect the equilibrium balance between these centripetal and centrifugal forces in a realistic context
  - transport infrastructure investments
  - local taxation
  - land regulation
  - place-based policies

# Introduction

- Theoretical literature on economic geography has traditionally focused on stylized settings that cannot easily be taken to the data
- More recent research has developed quantitative models of the spatial distribution of economic activity
  - Rich enough to incorporate first-order features of the data
    - ★ Large numbers of locations with heterogenous geography, productivity, amenities, local factors
    - ★ Trade in goods, migration, and commuting
  - Sufficiently tractable as to enable quantitative counterfactuals to evaluate numerically, in a realistic setup, a variety of policies and counterfactual scenarios

# Introduction

- Early theoretical research on *new economic geography* concentrated on formalizing mechanisms for agglomeration and cumulative causation
  - Fujita, et al. 1999, Fujita and Thisse 2002 and Baldwin et al. 2003
- This literature stressed the combination of love of variety, increasing returns to scale and transport costs as a mechanism for agglomeration forces
  - Provided a fundamental theoretical explanation for the emergence of an uneven distribution of economic activity even on a featureless plain of *ex ante* identical locations
    - ⋆ multiple equilibria in location choices
    - ⋆ Alternative was to incorporate externalities
- Theoretical literature stimulated a wave of empirical research, much of this empirical research was reduced-form in nature
  - Mapping from the model to the empirical specification was often unclear
  - Coefficients of these reduced-form relationships need not be invariant to policy intervention (the Lucas Critique)
  - Inability to evaluate welfare effects of policy

# Introduction

- More recent research in economic geography has developed a quantitative framework that connects closely to the observed data
  - Following the introduction of quantitative models of international trade (in particular Eaton and Kortum, 2002)
- Does not aim to provide a fundamental explanation for the agglomeration of economic activity
  - Agglomeration in these models is simply the result of exogenous local characteristics, augmented by endogenous economic mechanisms
- These frameworks can accommodate many realistic features and can be made quite rich
- The same quantitative framework can be derived from an entire class of theoretical models of economic geography

# Introduction

- The close connection between model and data in this quantitative research has a number of advantages:
  - Through accommodating many regions and a rich geography of trade costs, these models provide microfoundations for central features of the data
  - Explain the observed data as an equilibrium of the model
  - Models are typically exactly identified: one-to-one mapping from the observed data and exogenous primitives or structural fundamentals of the model
    - ★ Can be inverted to identify the unique values of the structural fundamentals
    - ★ Observed variation in the data can be decomposed within the model into the contributions of each fundamental

# Introduction

- A central advantage is the ability to undertake counterfactuals for policy interventions or other out of sample changes in model primitives
  - Assuming identified structural fundamentals are stable and invariant to the analyzed policy interventions
- Yield *general equilibrium* predictions for the spatial distribution of economic activity
  - Take full account of all the complex spatial interactions between locations
- Key implication of this analysis is that locations are not independent observations in a cross-section regression, but are rather systematically linked to one another through trade, commuting and migrations flows
- Use of the model's structure makes it possible to compute the counterfactual change in welfare

# A Menu of Quantitative Spatial Models

- All quantitative spatial models implicitly or explicitly makes assumptions about a number of building blocks:

1. Preferences
2. Production Technology
3. Technology for Trading Goods
4. Technology for Idea Flows
5. Technology for the movement of people
6. Endowments
7. Equilibrium

# A Menu of QSM: Preferences

1. Homogeneous versus differentiated goods (love of variety)
2. Single versus multiple sectors
3. Exogenous amenities (e.g scenic views) and/or endogenous amenities (e.g. crime)
   - In the spirit of the seminal work of Rosen (1979) and Roback (1982), amenities are understood as any characteristic that makes a location a more desirable place of residence
4. Fixed local factors in utility (residential land use)
5. Common versus idiosyncratic preferences
   - Idiosyncratic preferences for each location that are typically modelled as being drawn from an extreme value distribution

# A Menu of QSM: Production Technology

1. Constant versus increasing returns
2. Exogenous productivity differences (e.g. mineral resources) and/or endogenous productivity differences (e.g. knowledge spillovers)
   - Quantitative spatial models have typically found it necessary to allow for such exogenous differences across locations in order to rationalize the observed employment and income data
3. Input-output linkages
4. Fixed local factors in production (commercial land use)

# A Menu of QSM: Technology for Trading Goods

1. Variable versus fixed trade costs
   - A widespread assumption for analytical tractability is iceberg variable transport costs, whereby $d_{ni} \geq 1$ units of a good must be shipped from location $i$ to location $n$ in order for one unit to arrive
   - Important to be consistent with the gravity equation (bilateral trade increases with exporter and importer size and declines with distance)
2. Asymmetric versus symmetric transport costs
3. Geographic (e.g. mountains) versus economic frictions (e.g. borders, road and rail networks)
4. Non-traded goods

# A Menu of QSM: Technology for Idea Flows

1. Knowledge externalities and diffusion
   - Whenever an economic agent takes an action that affects another economic agent and this effect is not internalized when evaluating the cost and benefits of the action
   - The standard classification of these microfoundations is due to Marshall (1920) and distinguishes between knowledge spillovers, externalities due to thick labor markets, and backward and forward linkages
2. Innovation
   - Level of local productivity can be constant and exogenous, or the result of intentional investments in innovation
   - The incentives to undertake these investments depend on the market size and therefore on the distribution of economic activity
3. Transferability of ideas
   - Extent to which ideas developed in one location can be costlessly transferred to other locations

# A Menu of QSM: Technology for the movement of people

1. Migration costs
2. Commuting and commuting costs
   - Whether agents can separate their workplace and residence by commuting between them
   - Standard in urban but not in regional models
3. Agent heterogeneity
   - Determines the need to track people as they switch locations
4. Congestion in transportation

# A Menu of QSM: Endowments

1. Population and skills
2. Spatial scope and units
   - In most cases, geographically mobile labor is combined with geographically immobile land
3. Capital and infrastructure
   - Other mobile factors of production can be introduced, such as physical capital that is used in a construction sector
   - Incorporating local capital investments over time that do not depreciate fully introduces a dynamic forward looking problem
     - ★ The whole distribution of capital across space is the state variable
     - ★ So far this has proven intractable

# A Menu of QSM: Equilibrium

1. Market structure
   - Constant returns to scale and perfect competition or increasing returns to scale and monopolistic competition
2. General versus partial equilibrium
   - Choice of the level at which these equilibrium conditions are imposed
3. Land ownership and the distribution of rents
   - If land is used for either residential or production purposes it will generate rents to its owners
     - ⋆ Need to specify who are the owners of land in the different locations
   - Simply allowing for a land market where agents can buy and sell land would be ideal
     - ⋆ Entails the difficulty of incorporating location specific wealth effects which makes agents heterogenous
4. Trade balance
   - In any spatial model one has to take a stand on the spatial unit for which trade is balanced

# Criteria for Menu Choice

1. Tractability
   - Results on the existence and uniqueness of equilibrium and for comparative statics
   - Tractably undertaking counterfactuals using the observed initial equilibrium
   - Advances in computing power and computational methods have made it possible to solve large systems of non-linear equations over realistic computational time periods
   - Analytical characterizations of the dynamics of the distribution of economic activity across space
2. Structural assumptions
   - Determine what is assumed to be a structural parameter or fundamental characteristic of locations that is exogenous and invariant to policy interventions
3. Connection between model and data
   - What are the spatial units for which the data is recorded? What types of data are available?
   - Quantitative models typically can be solved using either data on endogenous bilateral flows or data on exogenous trade frictions
   - Over-identification checks

# A Canonical Quantitative Spatial Model

- Outline a canonical quantitative spatial model that corresponds to a multi-region version of the new economic geography model of Helpman (1998)
- From the menu of building blocks outlined above, this model selects:
  - **Preferences:** Love of variety; Single traded sector; No amenities; Residential land use; Common preferences
  - **Production Technology:** Increasing returns to scale; Exogenous productivity; No input-output linkages; No commercial land use
  - **Technology for Trading Goods:** Iceberg variable trade costs; Symmetric trade costs; Economic and Geographic Frictions; No non-traded goods besides residential land use
  - **Technology for the Movement of Ideas:** No knowledge externalities or diffusion; No innovation; No transferability of ideas
  - **Technology for the Movement of People:** Perfectly costless migration; No commuting; Single worker type with no heterogeneity; No congestion in transportation
  - **Endowments:** Homogenous labor; Exogenous land endowments in regions within a single country; No capital
  - **Equilibrium:** Monopolistic competition; General equilibrium with a single country; Land rents redistributed to residents; Trade is balanced in each location

# A Canonical Quantitative Spatial Model

- Consider an economy consisting of a set $N$ of regions indexed by $n$
- Each region is endowed with an exogenous quality-adjusted supply of land ($H_i$)
- The economy as a whole is endowed with a measure $\bar{L}$ of workers that supply one unit of labor
- Workers are perfectly geographically mobile so in equilibrium real wages are equalized across all populated regions
- Regions are connected by a bilateral transport network that can be used to ship goods subject to symmetric iceberg trade costs
  - $d_{ni} = d_{in} > 1$ units must be shipped from region $i$ in order for one unit to arrive in region $n \neq i$, where $d_{nn} = 1$

# A Canonical QSM: Consumer Preferences

- Preferences are defined over goods consumption ($C_n$) and residential land use ($h_n$) as in

$$U_n = \left(\frac{C_n}{\alpha}\right)^{\alpha} \left(\frac{h_n}{1-\alpha}\right)^{1-\alpha}, \qquad 0 < \alpha < 1$$

- The goods consumption index ($C_n$) is defined over consumption ($c_{ni}(j)$) of the endogenous measures ($M_i$) of horizontally differentiated varieties supplied by each region

$$C_n = \left[\sum_{i \in N} \int_0^{M_i} c_{ni}(j)^{\rho} \, dj\right]^{\frac{1}{\rho}}$$

with dual price index ($P_n$) given by

$$P_n = \left[\sum_{i \in N} \int_0^{M_i} p_{ni}(j)^{1-\sigma} \, dj\right]^{\frac{1}{1-\sigma}}$$

# A Canonical QSM: Production

- Varieties are produced under conditions of monopolistic competition and increasing returns to scale
- The total amount of labor ($l_i(j)$) required to produce $x_i(j)$ units of a variety $j$ in location $i$ is

$$l_i(j) = F + \frac{x_i(j)}{A_i}$$

- Profit maximization and zero profits imply that

$$p_{ni}(j) = \left(\frac{\sigma}{\sigma - 1}\right) d_{ni} \frac{w_i}{A_i}$$

and equilibrium output of each variety is equal to

$$x_i(j) = \bar{x}_i = A_i(\sigma - 1)F$$

and so

$$l_i(j) = \bar{l} = \sigma F$$

- Then, labor market clearing implies that the total measure of varieties supplied by each location is proportional to the endogenous supply of workers $L_i$,

$$M_i = \frac{L_i}{\sigma F}$$

# A Canonical QSM: Price Indices and Expenditure Shares

- The price index can be expressed as

$$P_n = \frac{\sigma}{\sigma - 1}\left(\frac{1}{\sigma F}\right)^{\frac{1}{1-\sigma}}\left[\sum_{i \in N} L_i \left(d_{ni}\frac{w_i}{A_i}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

- The share of location $n$'s expenditure on goods produced in location $i$ is

$$\pi_{ni} = \frac{M_i p_{ni}^{1-\sigma}}{\sum_{k \in N} M_k p_{nk}^{1-\sigma}} = \frac{L_i \left(d_{ni}\frac{w_i}{A_i}\right)^{1-\sigma}}{\sum_{k \in N} L_k \left(d_{nk}\frac{w_k}{A_k}\right)^{1-\sigma}}$$

- The model therefore implies a "gravity equation" for goods trade, where the bilateral trade between locations $n$ and $i$ depends on both "bilateral resistance" (bilateral trade costs $d_{ni}$) and "multilateral resistance" (trade costs to all other locations $k$, $d_{nk}$)
- Hence,

$$P_n = \frac{\sigma}{\sigma - 1}\left(\frac{L_n}{\sigma F \pi_{nn}}\right)^{\frac{1}{1-\sigma}}\frac{w_n}{A_n}$$

# A Canonical QSM: Income and Population Mobility

- Expenditure on land in each location is redistributed lump sum to the workers residing in that location
- Trade balance at each location implies that per capita income in each location ($v_n$) equals

$$v_n L_n = w_n L_n + (1-\alpha) v_n L_n = \frac{w_n L_n}{\alpha}$$

- From the consumer f.o.c.,

$$r_n = \frac{(1-\alpha) v_n L_n}{H_n} = \frac{1-\alpha}{\alpha} \frac{w_n L_n}{H_n}$$

- Population mobility implies that workers receive the same real income in all populated locations, hence

$$V_n = \frac{v_n}{P_n^{\alpha} r_n^{1-\alpha}} = \bar{V}$$

# A Canonical QSM: Income and Population Mobility

- Using the price index, trade balance, and land market clearing in the population mobility condition, real wage equalization implies that

$$\bar{V} = \frac{A_n^{\alpha} H_n^{1-\alpha} \pi_{nn}^{-\alpha/(\sigma-1)} L_n^{-\frac{\sigma(1-\alpha)-1}{\sigma-1}}}{\alpha \left(\frac{\sigma}{\sigma-1}\right)^{\alpha} \left(\frac{1}{\sigma F}\right)^{\frac{\alpha}{1-\sigma}} \left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha}}$$

- Therefore the population share of each location ($\lambda_n \equiv L_n/\bar{L}$) is given by

$$\lambda_n = \frac{L_n}{\bar{L}} = \frac{\left[A_n^{\alpha} H_n^{1-\alpha} \pi_{nn}^{-\alpha/(\sigma-1)}\right]^{\frac{\sigma-1}{\sigma(1-\alpha)-1}}}{\sum_{k \in N} \left[A_k^{\alpha} H_k^{1-\alpha} \pi_{kk}^{-\alpha/(\sigma-1)}\right]^{\frac{\sigma-1}{\sigma(1-\alpha)-1}}}$$

- Each location's domestic trade share ($\pi_{nn}$) summarizes its market access to other locations

# A Canonical QSM: General Equilibrium

- Combining the trade share, price index, and population mobility condition and using that $d_{ni} = d_{ni}$, one can show that the system above reduces to

$$L_n^{\tilde{\sigma}\gamma_1} A_n^{-\frac{(\sigma-1)(\sigma-1)}{2\sigma-1}} H_n^{-\frac{\sigma(\sigma-1)(1-\alpha)}{\alpha(2\sigma-1)}}$$
$$= \bar{W}^{1-\sigma} \sum_{i \in N} \frac{1}{\sigma F} \left( \frac{\sigma}{\sigma - 1} d_{ni} \right)^{1-\sigma} \left( L_i^{\tilde{\sigma}\gamma_1} \right)^{\frac{\gamma_2}{\gamma_1}} A_i^{\frac{\sigma(\sigma-1)}{2\sigma-1}} H_i^{\frac{(\sigma-1)(\sigma-1)(1-\alpha)}{\alpha(2\sigma-1)}}$$

  where the scalar $\bar{W}$ is determined by the requirement that the labor market clear ($\sum_{n \in N} L_n = \bar{L}$) and

$$\tilde{\sigma} \equiv \frac{\sigma - 1}{2\sigma - 1}, \qquad \gamma_1 \equiv \frac{\sigma(1-\alpha)}{\alpha}, \qquad \gamma_2 \equiv 1 + \frac{\sigma}{\sigma - 1} - \frac{(\sigma - 1)(1-\alpha)}{\alpha}$$

- Wages in turn are implicitly determined by

$$w_n^{1-2\sigma} A_n^{\sigma-1} L_n^{(\sigma-1)\frac{1-\alpha}{\alpha}} H_n^{-(\sigma-1)\frac{1-\alpha}{\alpha}} = \xi$$

  where $\xi$ is a scalar that normalizes wages

# A Canonical QSM: Existence and Uniqueness

- There exists a unique vector $L_n$ that satisfies as long as $\gamma_2/\gamma_1 \in (0,1]$
- Furthermore, if $\gamma_2/\gamma_1 \in (0,1)$ one can also guarantee that a solution can be found by iteration from any initial distribution of populations
- These parameter restrictions amount to imposing conditions that guarantee that congestion forces always dominate agglomeration forces
- A sufficient condition for $\gamma_2/\gamma_1 \in (0,1)$ is $\sigma(1-\alpha) > 1$
  - The higher the elasticity of substitution ($\sigma$), the weaker the agglomeration force
  - The higher the share of land $(1-\alpha)$, the stronger the dispersion force
- Important because it ensures that counterfactuals for transport infrastructure improvements or other public policy interventions have determinate implications

# A Canonical QSM: Model Inversion

- Suppose that a researcher knows values of the model's two key parameters: $\alpha$ and $\sigma$
- Assumed we have parameterized trade costs ($d_{ni}$) and and observe endogenous population, $\{L_n\}$, and nominal wages, $\{w_n\}$
- Then, the model can be *inverted* to recover the unique values of unobserved quality-adjusted land and productivities that rationalize the observed data as an equilibrium outcome of the model
  - Amounts to solving the system of equations for $\{A_n, H_n\}$ given $\{L_n, w_n\}$
  - Solution exists if $\sigma(1-\alpha) > 1$
- For some models and counterfactuals the model can be solved in changes and so solving for a full set of values $\{A_n, H_n\}$ is not necessary
  - As in Dekle, Eaton and Kortum (2005)

# A Canonical QSM: Welfare

- Welfare effects of public policy interventions that change trade costs can be expressed solely in terms of empirically observable sufficient statistics
- Consider a transport infrastructure improvement that reduces trade costs between an initial equilibrium (indexed by 0) and a subsequent equilibrium (indexed by 1)
- Perfect population mobility implies that the transport infrastructure improvement leads to reallocations of population across locations, until real wages are equalized. Hence

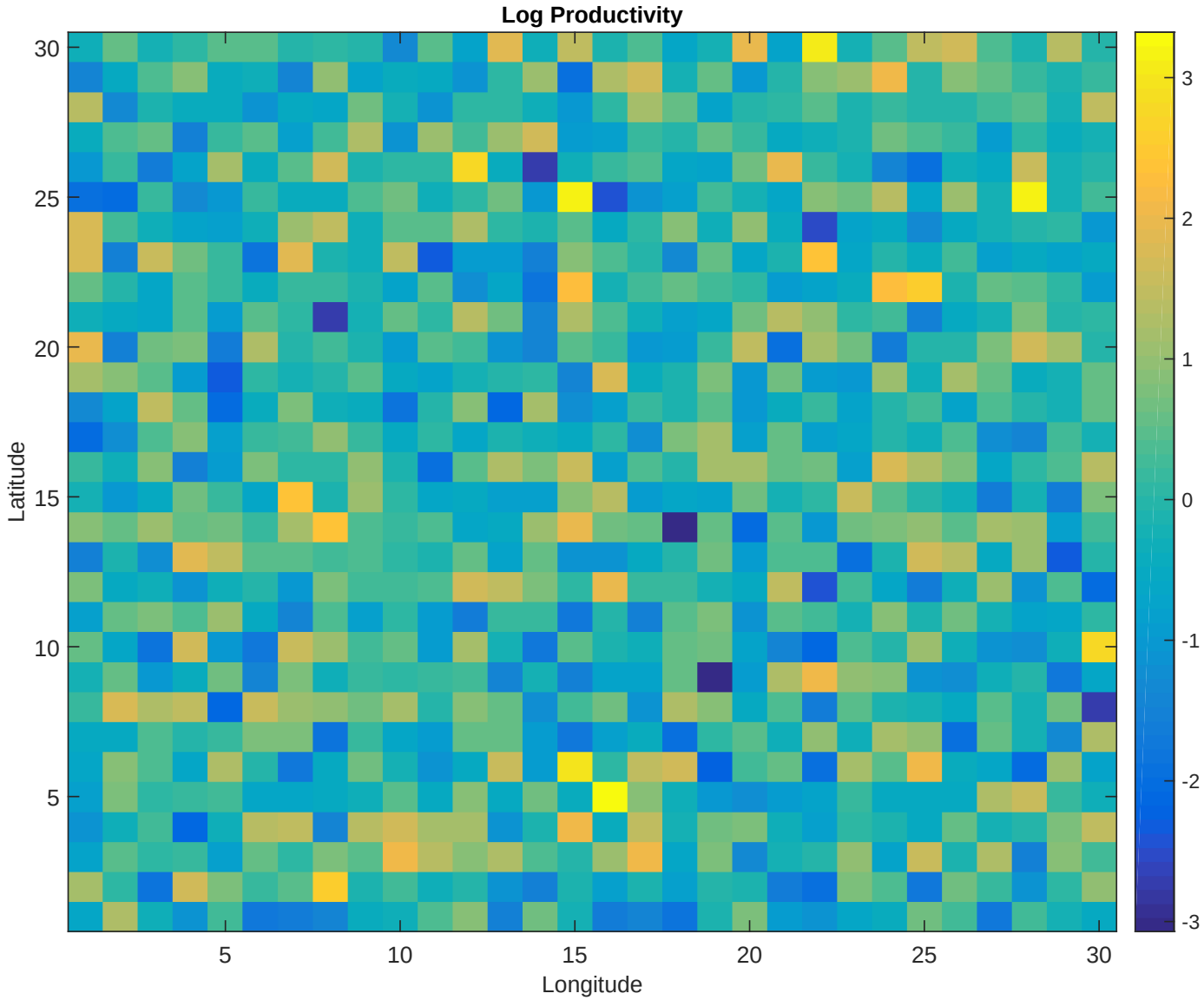
$$\frac{\bar{V}^1}{\bar{V}^0} = \left(\frac{\pi^0_{nn}}{\pi^1_{nn}}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{\lambda^0_n}{\lambda^1_n}\right)^{\frac{\sigma(1-\alpha)-1}{\sigma-1}}$$

- Under our assumption of $\sigma(1-\alpha) > 1$, a larger reduction in a location's domestic trade share must be offset by a larger increase in its population to preserve real wage equalization

# A Canonical QSM: Quantitative Illustration

- Consider a model economy on a $30 \times 30$ latitude and longitude grid
  - Each location has the same quality-adjusted land area ($H_n$) of 100 kilometers squared.
- We assume that this economy consists of two countries, one of which occupies the Western half of the grid (West), and another which takes up the Eastern half of the grid (East)
- We assume that labor is perfectly mobile across locations within each country, but perfectly immobile across countries
- We compute a measure of the lowest cost route effective distance between locations following Donaldson (2016)
  - Normalize the horizontal or vertical distance between neighboring locations to one
- For each location, we draw a realization for productivity $\{A_n\}$ from an independent standard log normal distribution

# A Canonical QSM: Productivity Realization



# A Canonical QSM: Parameter Values

- We choose central values for the model's parameters based on the existing empirical literature:
  - Share of land in residential consumption expenditure $(1-\alpha)$ to 25 percent
    - ⋆ Consistent with housing expenditure share in Davis and Ortalo-Magne (2011)
- Elasticity of substitution $(\sigma)$ equal to 5, which implies an elasticity of trade flows with respect to trade costs of $\sigma - 1 = 4$ that is line with the estimates in Simonovska and Waugh (2014)
- Trade costs are a constant elasticity function of effective distance $(d_{ni} = dist_{ni}^{\phi})$
  - Implies an elasticity of trade flows with respect to effective distance of $(\sigma - 1)\phi$
  - We choose the parameter $\phi$ to match the elasticity of trade flows with respect to distance in gravity equations using inter-regional trade data of $(\sigma - 1)\phi = 1.5$, which implies $\phi = 0.375$

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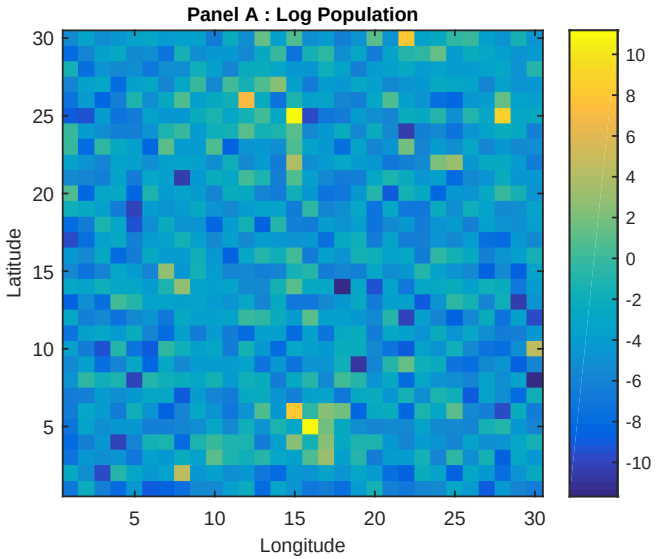
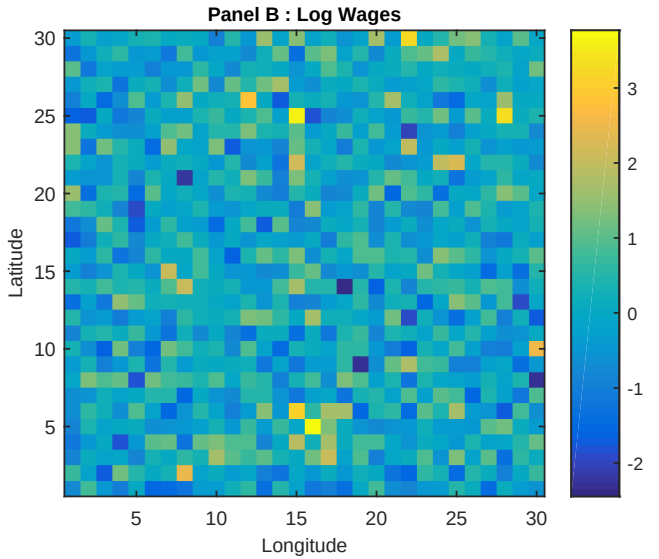
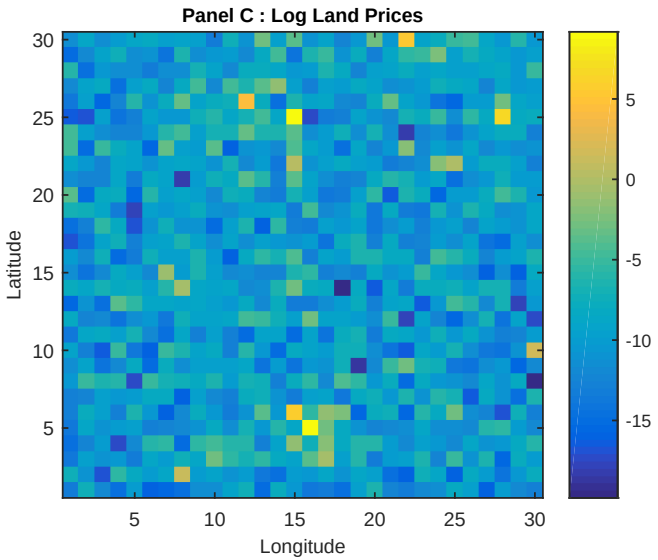
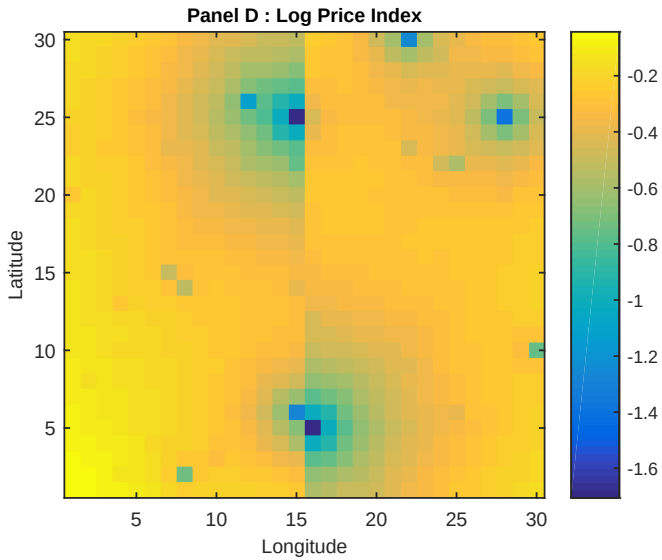
- Elasticity of substitution $(\sigma)$ equal to 5, which implies an elasticity of trade flows with respect to trade costs of $\sigma - 1 = 4$ that is line with the estimates in Simonovska and Waugh (2014)
- Geographic trade costs are a constant elasticity function of effective distance $(d_{ni} = dist_{ni}^{\phi})$
  - Implies an elasticity of trade flows with respect to effective distance of $(\sigma - 1)\phi$
  - We choose the parameter $\phi$ to match the elasticity of trade flows with respect to distance in gravity equations using inter-regional trade data of $(\sigma - 1)\phi = 1.5$, which implies $\phi = 0.375$
- Economic trade costs:
  - Proportional internal tax on trade with other locations of 100 percent $(\tau^{\text{in}} = 2)$
  - Proportional external tax on trade between the two countries of 100 percent $(\tau^{\text{out}} = 2)$
  - Revenue wasted, so modeled as real resource cost

# A Canonical QSM: Equilibrium



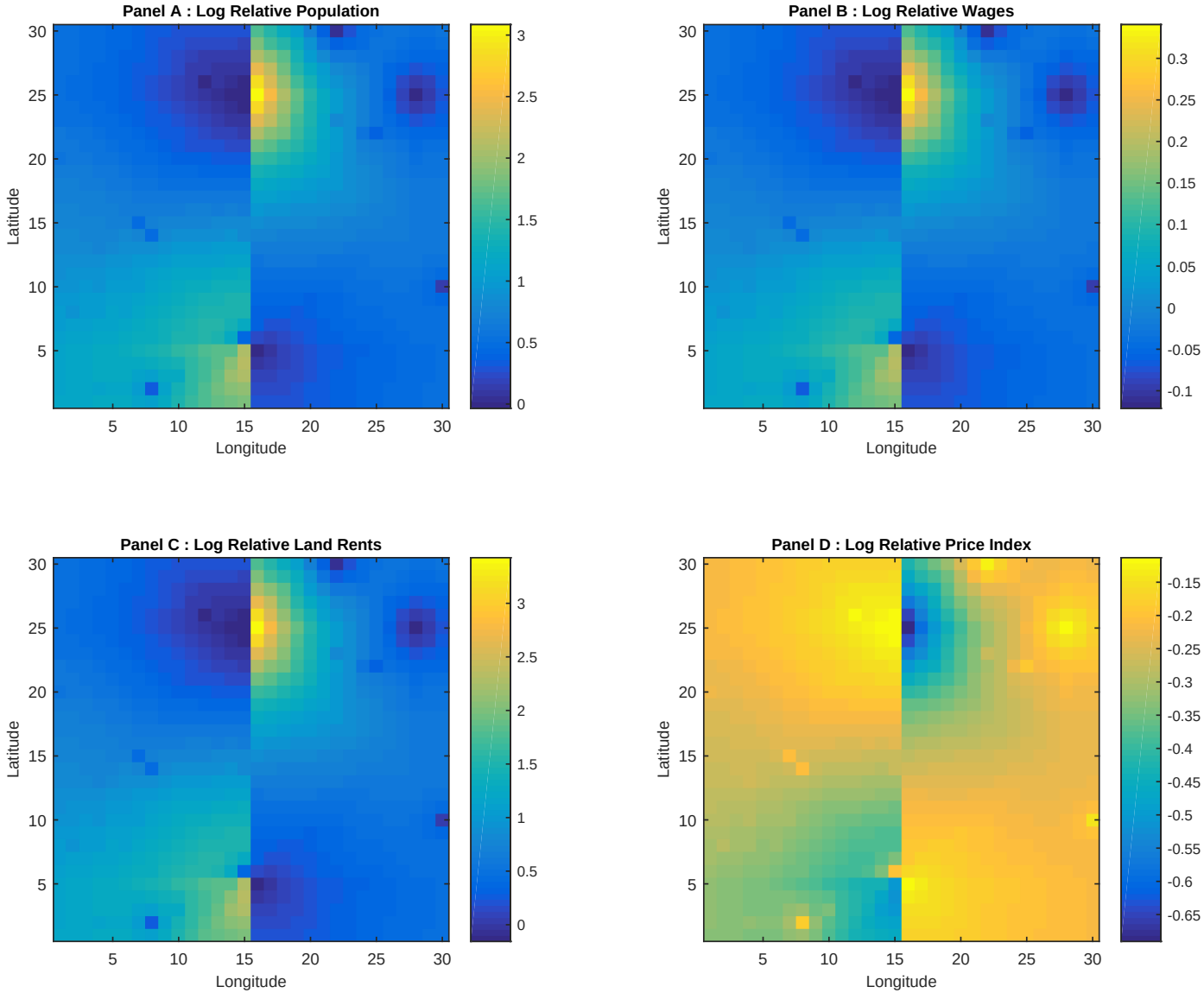



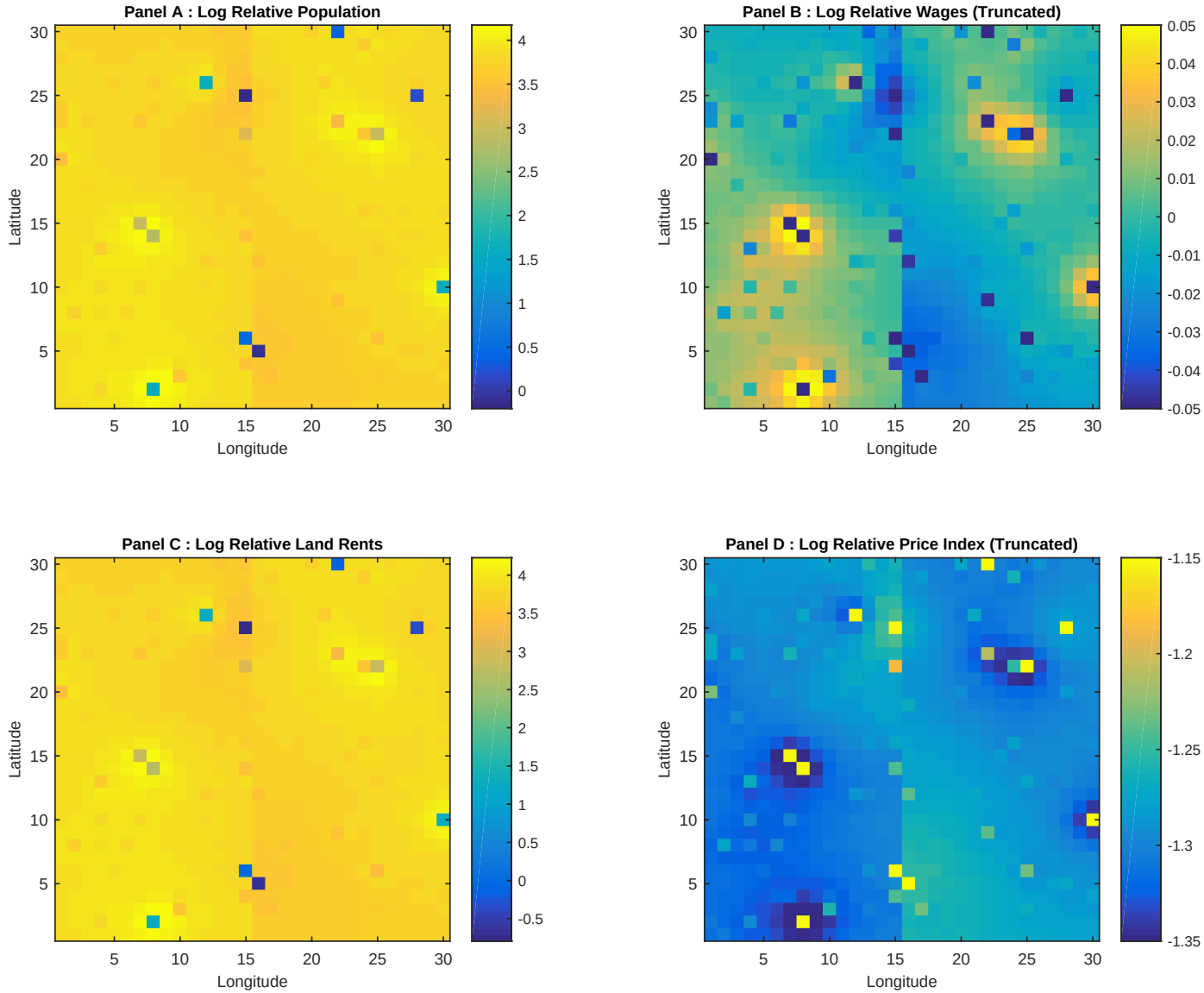
# A Canonical QSM: External Liberalization

- No tax between countries



# A Canonical QSM: Internal Liberalization

- No tax between regions



# A Canonical QSM: Gains from Trade

| | Welfare Gain West ($\hat{V} = V'/V$) | Welfare Gain East ($\hat{V} = V'/V$) |
|---|---|---|
| External Liberalization | 0.2% | 0.3% |
| Internal Liberalization | 1.4% | 2.3% |

- Link to the Matlab Programs:

`https://www.dropbox.com/sh/ujgdq8xx5ki0zfy/AACXqPflODpXt-DXFftNXfEfa?dl=0`

# Using more Data

- General equilibrium spatial models are typically exactly identified
- We can still use additional data, assumptions or sources of variation to provide
  - Evidence on the mechanisms in these models
  - Test their quantitative predictions (Over-identification tests)
  - Structurally estimate their parameters

# Market Access

- A key implication of quantitative spatial models is that both wages and population depend on market access
- Using CES demand, profit maximization and zero profits , the free on board price ($p_i$) charged for each variety by a firm in each location $i$ must be low enough in order to sell the quantity $\bar{x}_i$ and cover the firm's fixed production costs, so

$$\left(\frac{\sigma}{\sigma-1}\frac{w_i}{A_i}\right)^{\sigma} = \frac{1}{\bar{x}_i}\sum_{n\in N}\left(w_n L_n\right)\left(P_n\right)^{\sigma-1}\left(d_{ni}\right)^{1-\sigma}$$

- Define the weighted sum of market demands faced by firms as *firm market access* ($\text{FMA}_i$) such that

$$w_i = \xi A_i^{\frac{\sigma-1}{\sigma}}\left(\text{FMA}_i\right)^{\frac{1}{\sigma}}, \qquad \text{FMA}_i \equiv \sum_{n\in N}\left(w_n L_n\right)\left(P_n\right)^{\sigma-1}\left(d_{ni}\right)^{1-\sigma}$$

  where $\xi \equiv \left(F\left(\sigma-1\right)\right)^{-1/\sigma}\left(\sigma-1\right)/\sigma$ collects together earlier constants.
- Thus, wages are increasing in both productivity $A_i$ and firm market access ($\text{FMA}_i$)

# Market Access

- Market access also affects the price index , which depends on consumers' access to tradeable varieties.
- Summarize this access to tradeable varieties using the concept of *consumer market access* ($\text{CMA}_n$):

$$P_n = (\text{CMA}_n)^{\frac{1}{1-\sigma}}, \qquad \text{CMA}_n \equiv \sum_{i \in N} M_i (p_i d_{ni})^{1-\sigma}$$

# Market Access

- Redding and Venables (2004) find a strong correlation between wages and these measures of market access
- For counties within the United States, Hanson (2005) finds a similarly strong relationship between wages and market access
- Establishing that these relationships are causal is more challenging
  - Typically studies use instrumental variables
  - Exclusion restriction that the instruments only affects wages through market access is hard to justify
    - ★ Use for example trade liberalizations
- Also use changes in transport infrastructure as in Donaldson (2016) for India's railroads and Donaldson and Hornbeck (2016) for U.S. railroads.
- Redding and Sturm (2008) use the division of Germany after the Second World War as a natural experiment of changes in market access
  - Results are broadly consistent with the model outlined above

# Productivity and Density

- A large empirical literature finds that wages, land prices, productivity, employment and employment growth are positively correlated with population density
- Rosenthal and Strange (2004) report that the elasticity of productivity with respect to the density of economic activity is typically estimated to lie within the range of 3-8 percent
- Establishing that this correlation is indeed causal remains challenging
- Kline and Moretti (2014) provide evidence on the long-run effects of one of the most ambitious regional development programs in U.S. history: the Tennessee Valley Authority (TVA)
  - Manufacturing employment is found to increase well after federal transfers had lapsed, consistent with agglomeration economies
- Bleakley and Lin (2012) find permanent effects of a temporary historical advantage on the spatial distribution of population using variation from portage sites in the United States

# Future Research in QSM

- Most research has continued to be concerned with the production and trade of goods, whereas much economic activity today is concentrated in services, whether tradable or non-tradable
- Most of the main frameworks in the literature are static and abstract from the effect of spatial frictions on the evolution of the spatial distribution of economic activity and growth
- Although there have been several influential studies of the sorting of heterogeneous workers and firms across geographic space, there remains scope for further work
- The economic analysis of the geography of firm and worker networks remains under-explored