Spatial Macroeconomics

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Spatial general equilibrium (SGE) theory and macroeconomic theory have run along parallel lines. SGE theorists have been unconcerned about macroeconomic implications, and macroeconomic theorists have treated the spatial economy as ignorable. This paper explores the macroeconomic implications of SGE theory for GDP in terms of spatial agglomeration theory, spatial spillovers, and spatial heterogeneity in technology. An econometric SGE model for Israel is used to simulate the relation between GDP and gross regional products in terms of spatial shocks in housing, labor and capital markets.

Introduction

Macroeconomists have traditionally ignored the spatial structure of economic activity. This abstraction implicitly treats regions within countries as being homogenous. For example, the macroeconomic effects of productivity shocks are independent of where they occurred. By contrast, international macroeconomists attach importance to the spatial structure of the global economy. The global macroeconomic implications of productivity shocks generally depend on where they occur. The reason for this asymmetry is unclear since national boundaries do not necessarily enclose spatial units that are economically homogeneous. We therefore ask whether the non-spatial tradition in macroeconomics is justifies theoretically and empirically.

Regional economists naturally attach importance to the spatial structure of the economy (Fujita and Thisse 2002, Brakman et al 2009, Combes et al 2008, Prager and Thisse 2012). However, they have been traditionally unconcerned with macroeconomics and GDP. In recent years, however, spatial general equilibrium (SGE) theory has been increasingly concerned with the economic functioning of entire economies. SGE theory has breached the walls between regional economics and macroeconomics. SGE theory began with Roback (1982) who sought to explain the spatial distribution of economic activity by assuming that capital and labor are perfectly mobile within countries. She assumed that product markets are perfectly competitive and treated land as an immobile factor of production. Subsequently, Krugman (1991) developed the New Economic Geography (NEG) model in which intranational trade is costly, product markets are imperfectly competitive, skilled labor and capital are mobile, but unskilled labor is immobile. The market size effect induced by imperfect competition generates pecuniary scale economies and spatial agglomeration. Although Roback and NEG have different positive and normative implications, they are both indirectly concerned with macroeconomics since GDP is the sum of GRPs (gross regional product).

Agglomeration theory dates back to Marshall (1919) who argued that TFP depends on externalities induced by scale. Apart from the role of agglomeration in NEG, agglomeration theory has increasingly focused on social scale economies (Glaeser et al 2001) where the "Consumer City" offers amenities and attractions, which smaller cities cannot provide. There may also be synergisms between these agglomeration effects and agglomeration effects in production. For example, social agglomeration may increase varieties in goods and services, and the greater possibilities of social intercourse may induce technological innovation through "cafeteria" effects (Fu 2007). Agglomeration theory implies that GDP is not independent of the spatial distribution of workers and firms.

Whereas agglomeration theory is based on externalities within spatial units, there may also be spillover effects between spatial units, which also have implications for GDP. In the latter case TFP shocks may be mutually beneficial between spatial units. If so, spatiotemporal feedbacks magnify local TFP shocks across space and over time. Such phenomena do not involve agglomeration, but they have macroeconomic consequences.

We show that provided capital is perfectly mobile within countries spatial heterogeneity in technology does not have macroeconomic consequences. Although such heterogeneity might have consequences for spatial general equilibrium, it (surprisingly) does not matter for GDP.

We begin by recalling theoretical results from Beenstock and Felsenstein (2010) regarding the macroeconomic implications of SGE theory in the presence of agglomeration and spatial spillovers. These results provide the background for an empirical study of the role of space in macroeconomic developments in Israel.

Theory

Externalities play a central role in agglomeration theory. "..an increase in the scale of production…tends to open each business in the industry, whether large or small, access to improved plant, improved methods, and a variety of other external economies." (Marshall 1919, p187). These externalities occur within spatial units; immediate proximity matters. However, there may also be externalities between spatial units if externalities in one unit spillover onto other units. Externalities within spatial units induce agglomeration, as a result of which some spatial units leap forward while other fall behind. We show that even if these externalities are symmetric between spatial units, GDP varies directly with agglomeration. Externalities between spatial units do not induce agglomeration, but they imply that local productivity shocks have national or macroeconomic implications too. In either case, GDP has a spatial dimension because local shocks tend to "snowball" within and between the spatial units that make-up the national economy.

Agglomeration: Intra-spatial Externalities

This section draws on the theory of agglomeration proposed by Beenstock and Felsenstein (2010). There are two regions A and B. Let p denote the proportion of the population residing and working in region A so that 1 – p is the proportion in B. The participation ratio is set to 1, so everybody is employed. A homogenous good is produced with a common Cobb-Douglas technology in A and B, where $\alpha < 1$ denotes the capital exponent. Trade between A and B is frictionless, hence a single price applies in A and B. Capital is perfectly mobile between A and B, so that marginal products of capital are equated ($MPK_A = MPK_B$,), which implies that the relative capital-labor ratio for A varies directly with its relative TFP:

$$\frac{k_A}{k_B} = \left(\frac{TFP_A}{TFP_B}\right)^{1/_{1-\alpha}} \qquad (1)$$

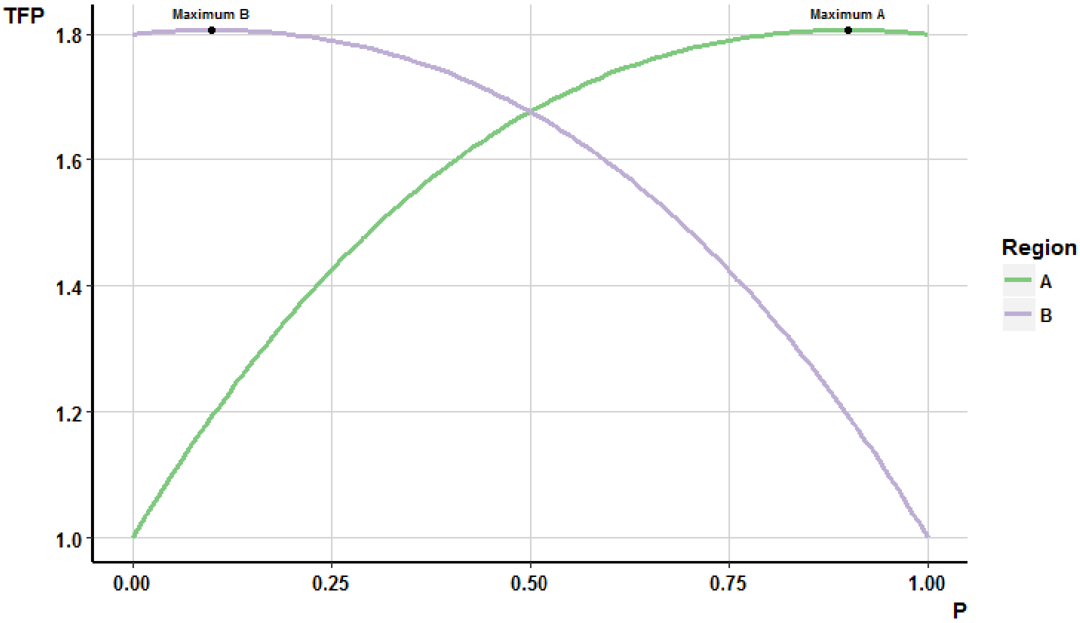
where k denotes capital-labor ratios. Since $\alpha < 1$, the elasticity of the relative capital-labor ratio with respect to relative TFP exceeds 1. Let κ denote the share of capital in A. Equation (1) implies:

$$\frac{\kappa}{1-\kappa} = \frac{p}{1-p}\left(\frac{TFP_A}{TFP_B}\right)^{1/_{1-\alpha}} \qquad (2)$$

The relative capital share in A varies directly with its relative share in employment (population) and relative TFP.

TFP in A and B are assumed to depend on scale, measured by p and 1 – p. For example, $TFP_A = a + bp + cp^2 + dP^3$, where b + c +d > a, and if TFP externalities are symmetric $TFP_B = a + b(1-p) + c(1-p)^2 + d(1-p)^3$. Figure 1 illustrates the relation between TFP_A and p when a = 1, b = 2.0903, c = - 1.659, d = 0.369 and $\alpha = 0.3$. Externalities are positive until p = 0.9 and negative thereafter. The schedules for A and B intersect when p = ½, schedule A has a maximum at p = 0.9, and schedule B has a maximum at p = 0.1.

Figure 1 Total Factor Productivity and Scale



If labor is paid its marginal product, the relative wage is:

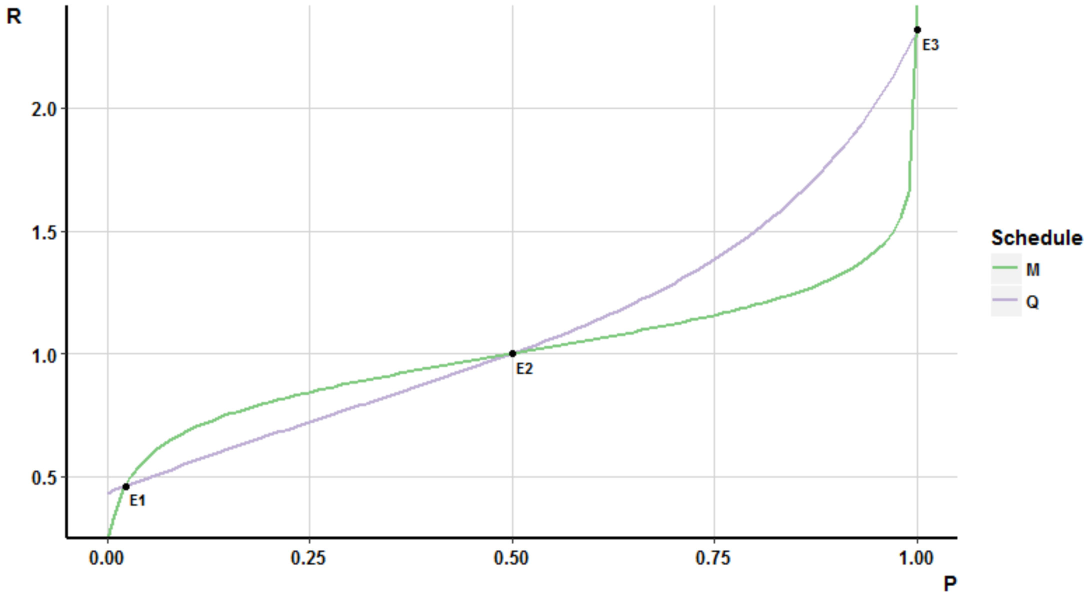
$$\frac{w_A}{w_B} = R = \left[\frac{TFP_A}{TFP_B}\right]^{1/1-\alpha} \qquad (3)$$

R = 1 If TFP is the same in A and B, in which case regional wages and capital-labor ratios are equated. The derivative of the relative wage with respect to p is a nonlinear 3rd order polynomial:

$$\frac{\partial R}{\partial p} = \frac{R^{\alpha}}{1-\alpha}\frac{TFP_B[b + 2cp + 3p^2] + TFP_A[b + 2c(1-p) + 3d(1-p)^2]}{TFP_B^2} \qquad (4)$$

This derivative is represented in Figure 2 by schedule Q, which is based on Figure 1. Schedule 2 has a positive slope, implying that relative wages in A vary directly with its population share. As expected from equation (4), schedule Q is nonlinear. Its quasi monotonicity stems from the fact that in Figure 1 TFP is maximized at p = 0.9. Had this value been smaller, schedule Q might have decreased as p approached 1. Symmetry implies that $TFP_A = TFP_B$ when p = ½, and that the relation between relative TFP and p is symmetric about p = ½. It also means that the unweighted sum of TFP is maximized when p = ½, but the population weighted sum of TFP is minimized when p = ½.

Figure 2 Spatial General Equilibrium



The model is closed by assuming that individuals have regional preferences, which are heterogeneous. Whereas capital has no regional attachments, matters are different in the case of people. Residents in A do not regard B as a perfect substitute for A, and residents in B do not regard A as a perfect substitute for B. This imperfect substitution is captured by a logit model in which this imperfection varies inversely with β:

$$p = \frac{1}{1 + \exp(\beta - \beta R)} \qquad (5)$$

Equation (5) implies that p varies directly with R, and tends to 1 as R tends to infinity. Equation (5) implies that p = ½ when R = 1. Glaeser agglomeration may be introduced by specifying -βR –ep in the denominator of equation (5). In this case the desire to live in A varies directly with A's population share provided as well as its relative wage. The relation between R and p implied by equation (5) is represented by schedule M in Figure 2.

Figure 2 illustrates the spatial general equilibria of this simple model of agglomeration. When R = 1 p = ½ and $TFP_A = TFP_B$. Schedule M approaches the vertical as R tends to infinity. Schedule Q is upward sloping and nonlinear. There are three spatial equilibria denoted by E_1 (the lower intersection of schedules M and Q), E_2 (the middle intersection) and E_3 (the higher intersection), of which E_1 and E_3 are stable and E_2 is unstable. E_1 and E_3 are agglomerating equilibria. Symmetry implies that the p/(1-p) at E_3 equals (1-p)/p at E_1.

At E_3, for example, the majority of the population live in A ($p = p_3$). Wages and TFP are larger in A than in B, and equation (2) implies that A's share of capital is greater than B's. If agglomeration is asymmetrical the relative positions of E_1 and E_3 will not be symmetric. A permanent TFP shock in A shifts schedule Q to the left so that the new equilibria are north-east of E_3 and E_1. A permanent increase in amenities in A shifts schedule M to the left so that the new equilibria are to the south-west of E_1 and north-east of E_3.

If externalities are asymmetric, schedule Q in Figure 3 may assume more exotic forms. It may cease to be monotone, it may not intersect schedule M at p = ½, it does not imply that E_3 and E_1 are reciprocal, and it may intersect schedule M more than three times. In the latter case, the number of agglomerating equilibria will be greater than two.

GDP and Gross Regional Products

Having defined spatial equilibrium, the next step is to explore its implications for GDP, which is the sum of the gross regional products (GRP) in A and B. For convenience, national population and capital are normalized to 1 in which case the gross regional products are:

$$\begin{aligned} GRP_A &= TFP_A \kappa^{\alpha} p^{1-\alpha} \\ GRP_B &= TFP_B (1-\kappa)^{\alpha} (1-p)^{1-\alpha} \end{aligned} \qquad (6)$$

Solving equation (2) for κ and substituting the result into equation (6), it may be shown that under symmetry the effect of A's population share on GDP is:

$$\frac{\partial GDP}{\partial p} = [w_A - w_B] + [\kappa^{\alpha} p^{1-\alpha}(b + 2cp + 3dp^2) - (1-\kappa)^{\alpha}(1-p)^{1-\alpha}\big(b + 2c(1-p)\big) + 3d(1-p)^2] + \psi[MPK_A - MPK_B] \qquad (7)$$

Where:

$$\psi = \frac{RTFP^{1/1-\alpha}}{p^2}[1 - p(1-p)RTFP^{\alpha}]\frac{\partial RTFP}{\partial p}$$

$$RTFP = \frac{TFP_B}{TFP_A}$$

Since marginal products of capital (MPK) are equated, the last component in equation (7) is zero. If R > 1 the first component is positive. So is the second component positive because the weighted sum of TFP varies directly with p > ½. Figure 3 and 4 extend the numerical illustration in Figures 1 and 2 to GRP and GDP. GRP in A varies directly with its population share, and GRP in B varies inversely and symmetrically. The GRPs are equal when p = ½.

Figure 3 Gross Regional Products in Spatial General Equilibrium

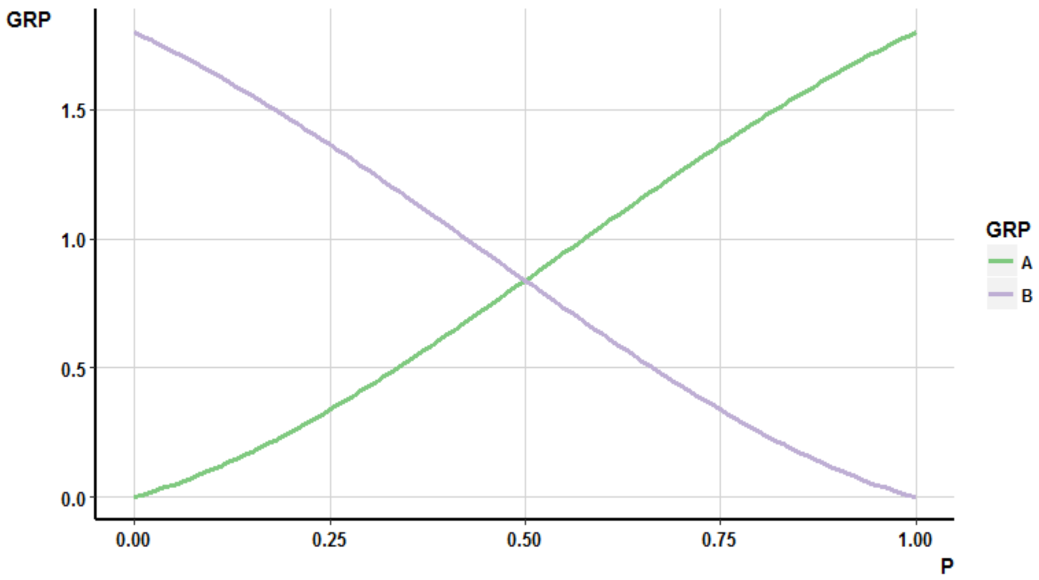
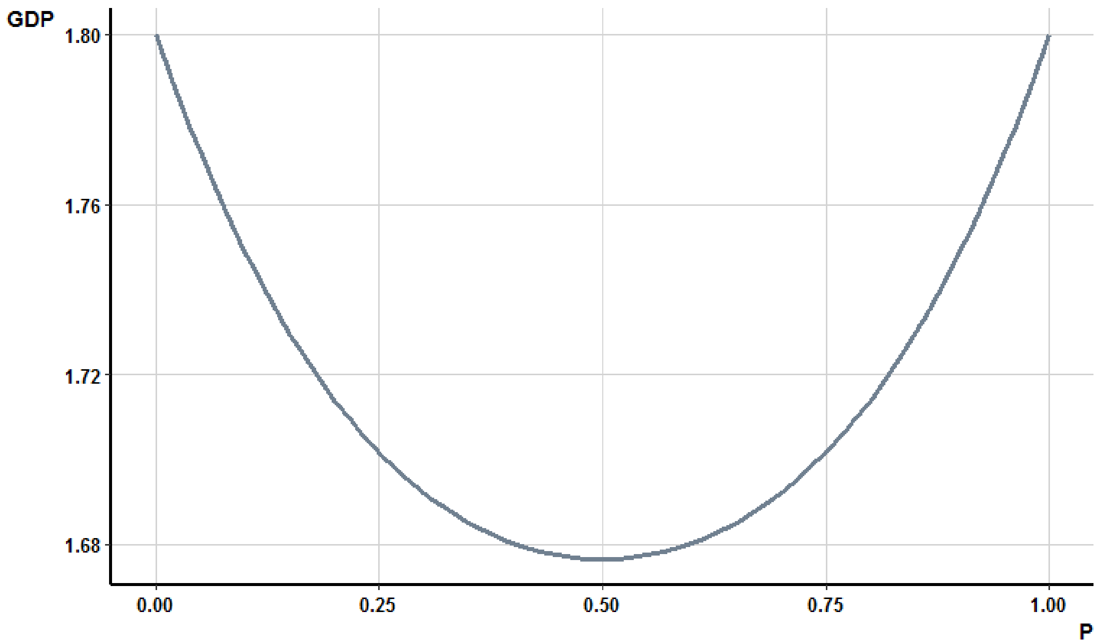


Figure 4 GDP in Spatial General Equilibrium



However, GDP is minimized when p = ½ and increase symmetrically when p is greater or less than a half. The illustrative gains from agglomeration in Figure 4 may be as large as 7 percent.

Technological Heterogeneity

Thus far we have assumed that A and B share common Cobb-Douglas technologies. Heterogeneity in technology may take two forms. In the first, the technology is Cobb-Douglas but α_A is different from α_B. In the second, A's technology is Cobb-Douglas while B's is e.g. CES so that the elasticities of substitution (ESS) between labor and capital are different. To focus on the role of spatial heterogeneity in technology, we assume that TFP is fixed in A and B, i.e. there are no externalities within or between regions. We continue to assume that capital is perfectly mobile, while people are imperfectly mobile according to equation (5).

Cobb – Douglas Heterogeneity

If α_A and α_B are different the marginal products of capital are different in A and B for given capital-labor ratios (k). MPK_A is less than MPK_B when $k < (\alpha_B/\alpha_A)^{1/(\alpha_A-\alpha_B)}$ and is greater otherwise. Marginal products of capital are equated in A and B when:

$$\frac{\kappa^{\alpha_A-1}}{(1-\kappa)^{\alpha_B-1}} = \frac{\alpha_B p^{\alpha_A-1}}{\alpha_A(1-p)^{\alpha_B-1}} \qquad (8a)$$

The wage ratio is:

$$R = \frac{(1-\alpha_A)\left(\frac{\kappa}{p}\right)^{\alpha_A}}{(1-\alpha_B)\left(\frac{1-\kappa}{1-p}\right)^{\alpha_B}} \qquad (8b)$$

Substituting equation (8a) into equation (8b) generates the result that R = 1 regardless of p, i.e. schedule Q in Figure 2 is horizontal, and intersects schedule M at p = ½. If amenities in A increase, schedule M shifts to the right and intersects schedule Q at p > ½. GRP increases in A but decreases symmetrically in B so that GDP does not change. In summary, technological heterogeneity does not matter for GDP under Cobb-Douglas technologies.

ESS Heterogeneity

The elasticity of substitution between labor and capital is 1 in Cobb-Douglas technologies. We show that schedule Q ceases to be horizontal when ESS in A differs from ESS in B, and that it slopes downwards. This means that there is a unique spatial equilibrium (where schedules Q and M intersect) at which R no longer equals 1 and p no longer equals a half. This means that an increase in amenities in A shifts schedule

M to the right, and the relative wage in A increases. Surprisingly, however, GDP remains unchanged.

We assume that ESS = 1 in B and is 1/(1 - ρ) in A where the production function for GRP is:

$$GRP_A = [a\kappa^\rho + (1-a)p^\rho]^{\frac{1}{\rho}} \qquad (9a)$$

The production function for B is Cobb – Douglas. The counterparts to equation (8a) and (8b) are:

$$a + (1-a)\left(\frac{p}{\kappa}\right)^\rho = \left[\frac{\alpha}{a}\left(\frac{1-p}{1-\kappa}\right)^{1-\alpha}\right]^{\frac{\rho}{1-\rho}} \qquad (9b)$$

$$R = \frac{(1-a)p^{\rho-1}[a\kappa^\rho + (1-a)p^\rho]^{\frac{\rho}{1-\rho}}}{(1-\alpha)\left(\frac{1-\kappa}{1-p}\right)^\alpha} \qquad (9c)$$

When a = α the solution to equation (9b) is p = κ = ½ since both sides of equation (9b) equal 1. Table 1 illustrates solutions when a = 0.3, α = 0.4 and ρ = 0.23 (ESS_A = 1.3).

Table 1 Spatial Heterogeneity in Elasticities of Substitution

p	κ	R	GRP_A	GRP_B	GDP
0.5	0.395	1.025	0.466	0.540	1
0.6	0.475	0.992	0.560	0.446	1

The capital share in A is smaller than its population share. When p = ½ wages in A are 2½ percent greater than in B, hence schedule Q no longer intersects schedule M at p = ½. Also schedule Q slopes downwards because when p = 0.6 wages in A are less than in B. However, GDP does not depend on p because the changes in GRP offset each other.

Because schedule Q slopes downwards an increase in amenities in A shifts schedule M to the right and generates a new spatial equilibrium at which the relative wage in A is lower and its population (and capital) share is higher. Its share in GDP is also higher, but GDP is not affected. Heterogeneity in ESS matters for spatial general equilibrium but (surprisingly) it does not matter for GDP.

Spatial Spillover: Interspatial Externalities

We now assume that b = c = d = 0 so that TFP in A and B does not depend scale-induced externalities within spatial units. Hence, there is no agglomeration. Also we assume that there is no technological heterogeneity, hence $\alpha_A = \alpha_B$. and ESS = 1. Instead, there are externalities between spatial units, which induce spatial spillovers in TFP such that:

$$TFP_A = a_A + \omega_A TFP_B \qquad (10a)$$

$$TFP_B = a_B + \omega_B TFP_A \qquad (10b)$$

where the spatial spillover parameters (ω) are positive fractions, which are assumed to be asymmetric. Therefore:

$$TFP_A = \frac{a_A + \omega_A a_B}{1 - \omega_A \omega_B} \qquad (10c)$$

$$TFP_B = \frac{a_B + \omega_B a_A}{1 - \omega_A \omega_B} \qquad (10d)$$

and the TFP ratio is:

$$\frac{TFP_A}{TFP_B} = \frac{a_A + \omega_A a_B}{a_B + \omega_B a_A} \qquad (10e)$$

In the absence of spatial spillover $TFP_A = a_A$ and $TFP_B = a_B$, in which case schedule Q is horizontal at R = 1, and intersects schedule M at p = ½. If the numerator of equation (10e) exceeds the denominator ($a_A > a_B$, $\omega_A > \omega_B$) schedule Q continues to be horizontal but at R > 1, and it intersects schedule M at p > ½. The majority of the population resides in A, as a result of which GRP in A exceeds GRP in B because its shares of population and capital exceed a half and TFP in A is larger than TFP in B.

A productivity shock in A (a_A increases) directly increases TFP in A and indirectly increases TFP in B through spatial spillover. Since the spillover coefficient is less than 1 the latter is smaller than the former. However, because the denominators of equations (10c) and (10d) are less than one, a spatial spillover multiplier is induced. If, for example, ω = 0.5 in A and B the multiplier is 1.33 in A and 0.66 in B.

Equations (5) and (10e) imply that the effect of a TFP shock in A on its population share is:

$$\frac{\partial p}{\partial a_A} = \beta p(1-p)\frac{R^\alpha}{1-\alpha}\frac{a_B}{TFP_B^2} > 0 \qquad (11a)$$

Since capital is perfectly mobile, A's capital share increases through equation (2). The effect of productivity shocks in A on its capital share is:

$$\frac{\partial \kappa}{\partial a_A} = \kappa^2 \frac{1-p}{p(1-\alpha)}\left(\frac{TFP_B}{TFP_A}\right)^{\alpha/1-\alpha} \frac{a_A + \omega_B(1-\omega_B)}{(a_A + \omega_A a_B)^2} > 0 \qquad (11b)$$

Using equation (6), the effect of productivity shocks in A on its gross regional product is:

$$\frac{dGRP_A}{da_A} = \frac{\kappa^\alpha p^{1-\alpha}}{1-\omega_A\omega_B} + MPL_A\frac{\partial p}{\partial a_A} + MPK_A\frac{\partial \kappa}{\partial a_A} > 0 \qquad (11c)$$

The counterpart of equation (11c) for GRP in B is:

$$\frac{\partial GRP_B}{\partial a_A} = \frac{\omega_B(1-\kappa)^\alpha(1-p)^{1-\alpha}}{1-\omega_A\omega_B} - MPL_B\frac{\partial p}{\partial a_A} - MPK_B\frac{\partial \kappa}{\partial a_A} \qquad (11d)$$

The first term in equation (11d) is positive because of spillover from A to B. The subsequent terms are obviously negative. Since $MPK_A = MPK_B$, the implications of equations (11c) and (11d) for GDP are:

$$\frac{\partial GDP}{\partial a_A} = \frac{\kappa^\alpha p^{1-\alpha} + \omega_B(1-\kappa)^\alpha(1-p)^{1-\alpha}}{1-\omega_A\omega_B} + (MPL_A - MPL_B)\frac{\partial p}{\partial a_A} \qquad (11e)$$

The first term is positive because TFP increases in A and B. The second term will be positive if $MPL_A > MPL_B$.

The effect of productivity shocks in B on GDP differ to the effect of productivity shocks in A because ω_A differs from ω_B. If ω_B is greater than ω_A, the first terms in equation (11c) for a_B will be smaller because there is more spillover from A to B then from B to A. The second term is also smaller because equation (11a) is larger. Therefore, the effect on GDP of productivity shocks in A exceed the effect of productivity shocks in B when $\omega_B > \omega_A$.

In summary, productivity shocks induce multiple increases in TFP in A and B. GRP in A increases for three reasons. First, TFP increases. Second, the latter induces out migration from B to A, which increases GRP in A. Third, because capital is mobile, the increase in A's population share and its relative TFP increases its capital share. GRP in B increases directly because TFP benefits from spillover effects. However, outward migration of labor and capital have the opposite effect. Although GRP in B may or may not increase, GDP increases. Finally, if externality spillover effects are heterogeneous, the effects of productivity shocks on GDP are spatially dependent. If productivity increases in A but decreases in B, such that average TFP does not change, GDP will increase if $\omega_B > \omega_A$.

Empirical Analysis

Spatial General Equilibrium Model

The empirical salience of spatial disaggregation on the determination of GDP is assessed by investigating a spatial econometric model for Israel (Beenstock, Felsenstein and Xieer 2017). The model shares some common features with the theory in the previous section in that internal migration is motivated by wage differentials, and capital is internally mobile. However, capital in the model is imperfectly mobile. A major difference consists of a housing sector in which regional house prices, housing construction and housing stocks are determined. Internal migration is also motivated by the cost of housing. In addition, internal migration depends on amenities.

It should be emphasized that the design of the model was not motivated by its implications for spatial general equilibrium rather than its implications for GDP. More attention to spatial spillovers within and between regions might have altered its implications for GDP. The model solves for the regional distributions of population, house prices, housing stocks, capital, employment and GRP. The main exogenous variables include the national population, regional demographics such as the proportions of Jews and Arabs, regional investment policy conducted by the Center for Investment at the Ministry of Industry and Trade, and housing construction on land released by the Israel Land Authority.

There are 9 regions (see map) and the model was estimated using annual data during 1987 – 2015. Since the spatial panel data are nonstationary, spatial panel cointegration tests (SpIPS Beenstock and Felsenstein, 2018, chapter 7) are used to specify the model. Spatial spillover effects are captured by spatial lagged variables (Anselin 1988).

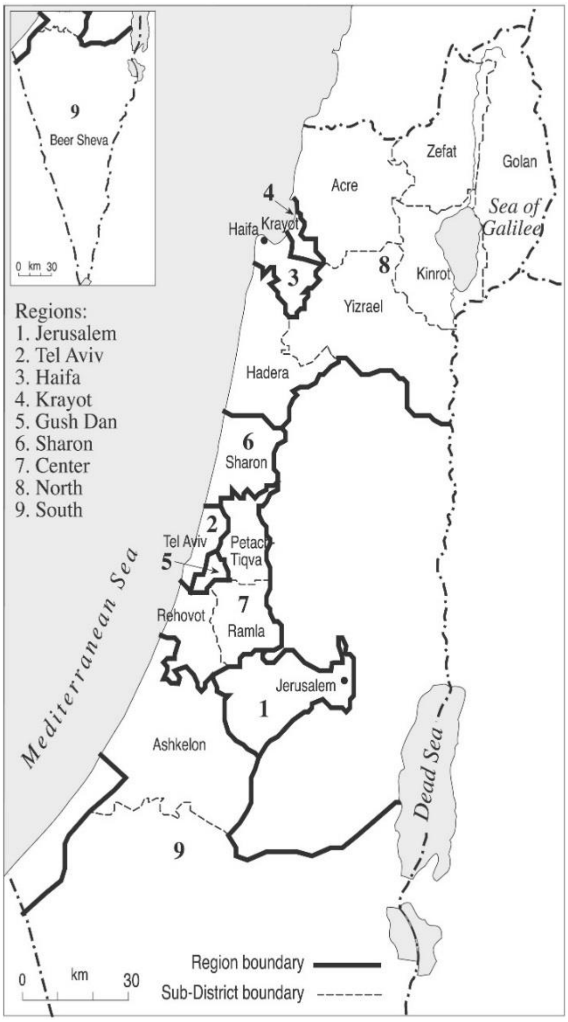


Table 2 The Model

$$I.\ \ln S_{it} = fe_i + \underset{0.39\;\;0.47}{0.428}\ln\left(\frac{P_{it}}{C_t}\right) + \underset{0.33\;\;0.50}{0.415}\ln\left(\frac{P_t}{C_t}\right) - \underset{-0.54\;\;-0.43}{0.486}\ln\left(\frac{\tilde{P}_{it}}{C_t}\right) + \underset{1.00\;\;1.18}{1.098}\,Z_t - \underset{0.78\;\;-0.54}{0.66}\,\tilde{Z}_t + \underset{0.76\;\;0.82}{0.79}\ln\tilde{S}_t$$

$$II.\ F_{it} = \underset{0.32\;\;0.39}{0.354}\,U_{it} + \underset{0.35\;\;0.42}{0.389}\,S_{it}$$

$$III\ \ln P_{it} = fe_i + \underset{0.87\;\;1.18}{1.027}\ln N_{it} - \underset{-1.13\;\;-0.83}{0.982}\ln H_{it} + \underset{0.27\;\;0.48}{0.375}\ln w_{it} + \underset{1.07\;\;1.37}{1.221}\ln\tilde{N}_{it} + \underset{0.38\;\;0.49}{0.439}\ln\tilde{P}_{it}$$

$$IV.\ Z_{it} = \frac{S_{Git}}{S_{it}}$$

$$V.\ U_{it} = U_{it-1} + S_{it-1} - F_{it-1}$$

$$VI.\ H_{it} = H_{it-1} + F_{it-1} - D_{it-1}$$

$$VII.\ \ln w_{it} = fe_i + \underset{0.11\;\;0.12}{0.114}\ln k_{it} + \underset{0.098\;\;0.106}{0.102}\,E_{it} + \underset{0.14\;\;0.19}{0.167}\,Jews_{it} + \underset{0.49\;\;0.54}{0.512}\,\mathrm{Im}\,mig_{it} + \underset{0.21\;\;0.22}{0.215}\,Age_{it} - \underset{-0.0026\;\;-0.0028}{0.0027}\,Age_{it}^2$$

$$VIII.\ \ln k_{it} = fe_i + \underset{0.082\;\;0.094}{0.0881}\,E_{it} - \underset{-0.044\;\;-0.042}{0.4273}\ln L_{it} + \underset{1.093\;\;1.121}{1.107}\ln k_{it}^* + \underset{0.091\;\;0.096}{0.0936}\ln IS_{it} - \underset{-0.165\;\;-0.199}{0.1821}\,\mathrm{Im}\,mig_{it}$$

Legend: EGLS (SUR) with fixed regional effects except for equation III, which is estimated by ML. 95 percent bootstrapped confidence intervals reported below their respective parameter estimates, except for equation III. S: housing starts (square meters 1000s), S_G: starts initiated by MOH (exogenous), F: completions, D: demolitions (exogenous), P: house price index, C: construction cost index (exogenous), N: population, H housing stock, w: wages, U: housing under construction, k: capital-labor ratio, E: average years of schooling, Jews: percentage of Jews in population, Age: average age of population of working age. Immig: share of new immigrants in the population.
Spatial lagged variables are over-scripted with ~.
The z ~ N(0,1) statistic for Pedroni's GADF are I -3, II -2.3, III -2.13, VII -5.67, VIII -4.28
SpIPS critical values for T = 25, N = 9 and W as specified in equation (2) at p = 0.05 in parentheses: I 0.78 (0.78), II 0.56 (0.79), III 0.17 (0.79), VII -0.28 (0.78), VIII 0.20 (0.79)

Key equations of the model are presented in Table 2, where variables involving inter regional spillovers are crowned with ~. The first five equations refer to regional housing markets, which play a central role in the model. For example, equation I relates housing starts (measured in square meters) to house prices (P) relative to construction costs (C) locally, nationally and spatially. Housing starts also vary directly with building permits on residential land auctioned by the Israel Land Authority (Z), locally and spatially. Finally, starts vary directly with the spatial lag of starts. The SpIPS statistics reported in Table 2 test for stationarity in the residuals of their respective equations.

Equation VII refers to wages, which vary directly with physical and human capital, and equation VIII refers to capital-labor ratios, where k* denotes a spatial lag. Not shown in Table 2 are logit models for regional population shares, based on equation (5), which vary directly with relative wages adjusted for relative house prices. Regional labor supplies are driven by regional populations (of working age). Unlike spatial spillover effects that are specified for the housing market and capital investment, agglomeration effects have not been specified in Table 2. Nor are there spatial spillovers on internal migration and wages.

Gross Regional Products

The Central Bureau of Statistics (CBS) does not produce data for GRP. We distinguish between three types of GRP: general government, business, and imputed housing services. The model excludes the former, generates business output is determined using the Cobb-Douglas technology that is implicit in equation VII, and imputed housing services are equal to regional housing stocks multiplied by rents. Figure 5 plots the model solutions for GRP. In the absence of data to check these solutions, we compare (Figure 6) the cross-section sums of GRP with time series data for GDP. The blue schedule refers to cross-section sums of GRP generated by the model. The red schedule refers to total GDP, while the black schedule excludes GDP of general government. The blue schedule tracks total GDP better than it tracks GDP excluding general government.

Figure 7 plots implicit housing services by region. Not surprisingly, these implicit housing services by region are strongly positively correlated with GRP. The cross-section sums of these estimates of implicit housing services under predicted the CBS estimate of implicit housing services at the national level. Unlike us, the CBS does not have data on housing stocks measured in square meters, which are necessary for the calculating implicit housing services. Therefore, the CBS estimates may be too high. Nevertheless, we have inflated the data in Figure 7 to track these CBS data.

Figure 5 Gross Regional Products (excluding general government)

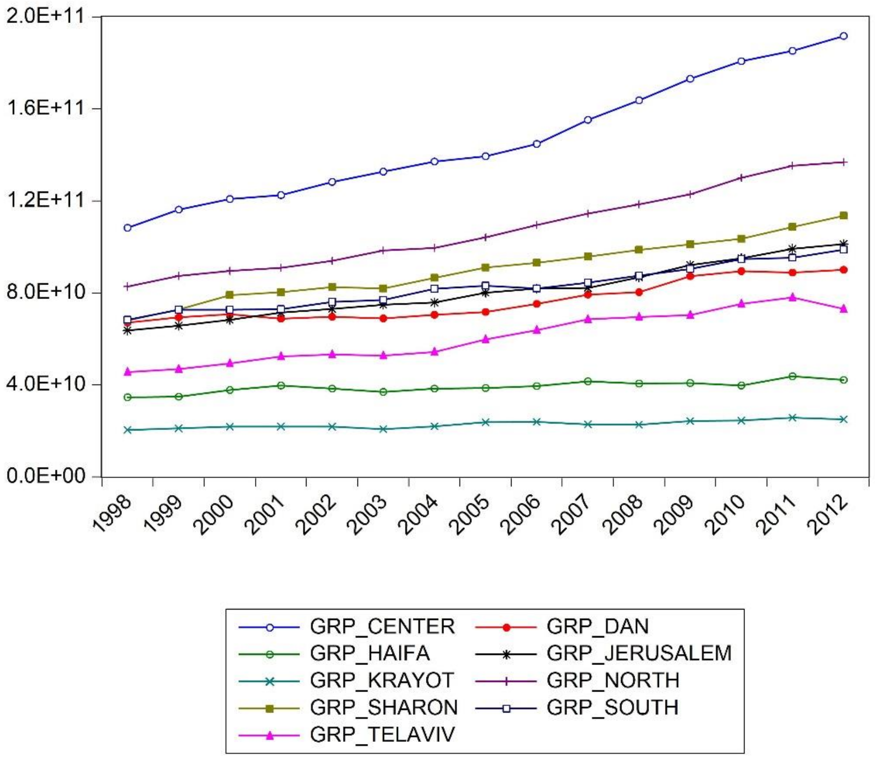


Figure 6 GDP

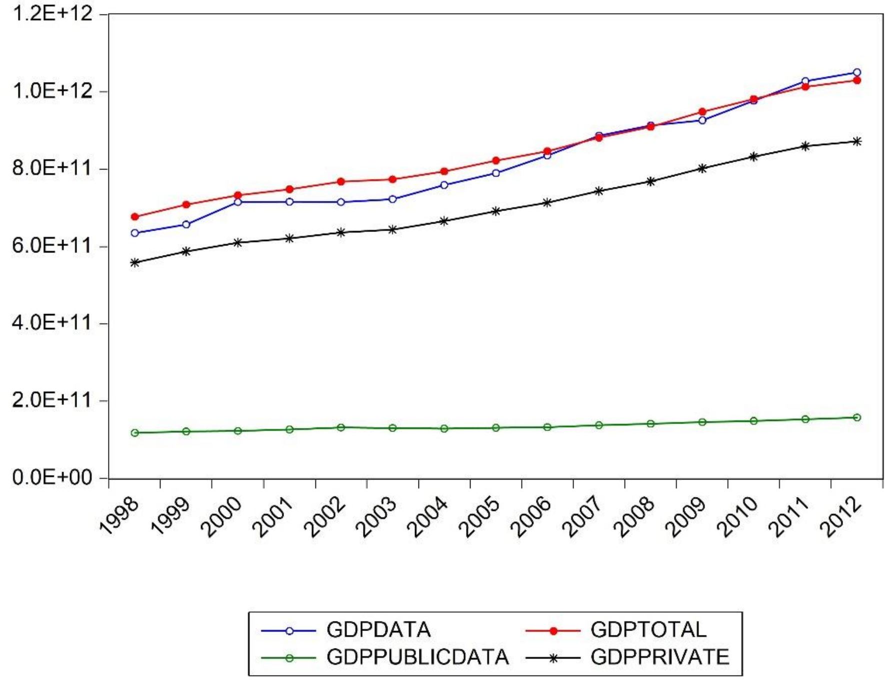
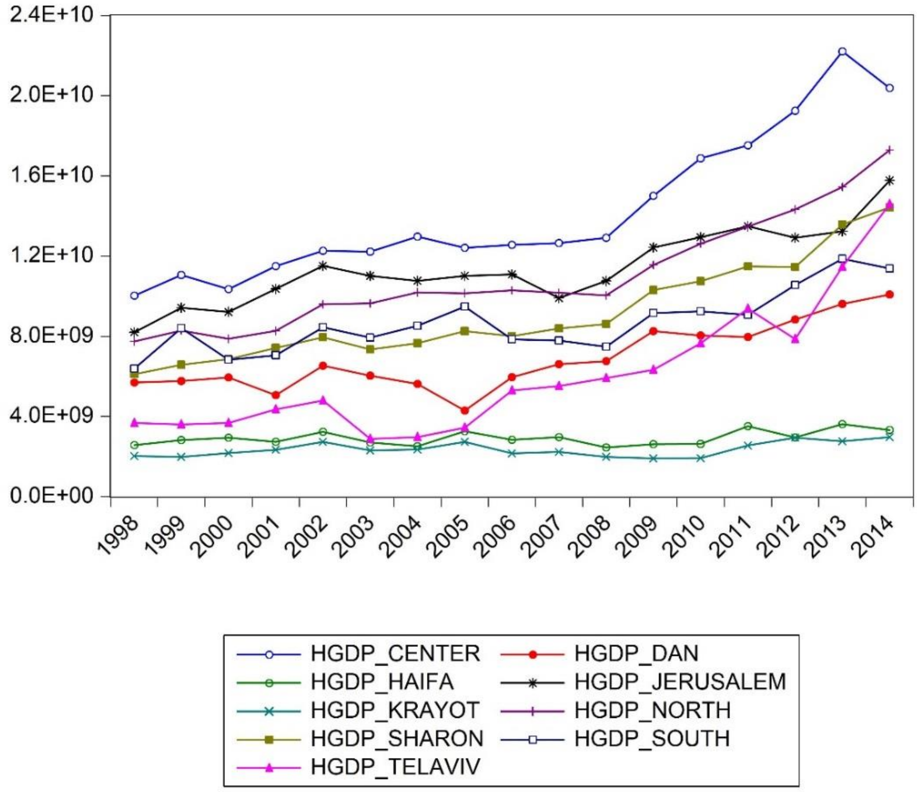


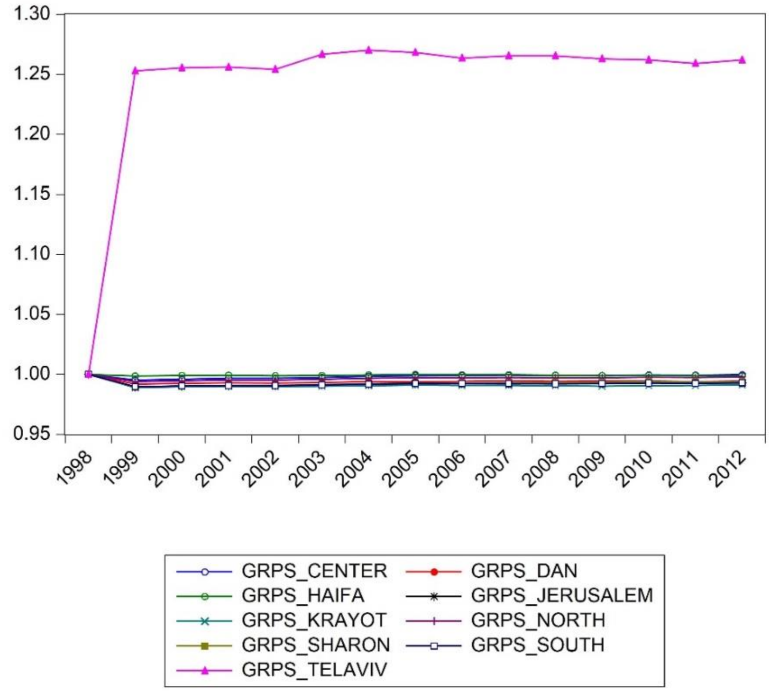
Figure 7 Implicit Housing Services



Simulations

The baseline is represented by a full dynamic simulation of the model from 1999 - 2012 in which the exogenous variables equal their actual values in the data. Since there are 9 regions and 8 key state variables, the model solves for 72 endogenous variables. Subsequently, the exogenous variables are shocked permanently from 1999 and the new solutions are compared to their baseline values to calculate spatiotemporal impulse responses for the 72 endogenous variables. The impulse responses reflect the spatial lag structure of the model as well as its temporal dynamics, which are induced by equations V and VI in Table 2.

Figure 8 Amenity increase in Tel Aviv – GRP



We begin by simulating a 40% increase in amenities in Tel Aviv, which is expected to induce inward migration into Tel Aviv. The increase in population in Tel Aviv increases the demand for housing so that house prices increase in Tel Aviv, but decrease in the source regions from which these migrants emigrated. Subsequently, increased housing construction in Tel Aviv and decreased housing construction elsewhere mitigates these house price effects. Migration into Tel Aviv increases labor supply, which lowers wages rates in Tel Aviv. The opposite happens in the regions, which have lost population. Details of this simulation as well as other simulations in Table 3 may be found in Beenstock, Felsenstein and Xieer (2017).

Figure 8 plots the spatiotemporal impulse responses for GRP in all regions. The large increase in GRP in Tel Aviv is largely offset by decreases in GRP elsewhere. Table 3 reports the implications for GDP, which increases by about 1½ percent. Simulation 2 in Table 3 refers to an increase in human capital in Jerusalem, which directly increases wages in Jerusalem through equation VII in Table 2. The increase in income raises housing demand in Jerusalem, which induces out-migration of labor and then capital. Simulation 3 refers to an increase in housing construction in North enabled by the release of land by the Israel Land Authority, as a result of which house prices decrease in North. The latter induces inward migration of labor and capital from the rest of the country. Although the implications for spatial general equilibrium of these location specific shocks are empirically important, they have almost no effect on GDP.

Table 3 Spatial Impulse Responses for GDP (percent)

Impulse **Year**	**1** **Amenities in Tel Aviv**	**2** **Schooling in Jerusalem**	**3** **House starts in North**
2	1.29	0.04	0
7	1.58	0.03	0.01
12	1.61	0.02	0.02

Notes: 1 Increase in amenities in Tel Aviv of 40%.

2. Increase in schoolyears in Jerusalem of 8%

3. Increase in public sector housing starts in North of 60%

Conclusion

To be written.

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