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Agglomeration and growth: the effects of commuting costs

by Antonio Accetturo

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AGGLOMERATION AND GROWTH: THE EFFECTS OF COMMUTING COSTS

by Antonio Accetturo*

Abstract

We present a model of industrial location and endogenous growth with congestion costs. According to the interplay between knowledge spillovers and commuting costs, we are able to obtain both a Krugman-type and a bell-shaped agglomeration outcome. In the first case, the economy experiences a permanent income inequality in the steady state and income divergence in the transitional dynamics. In the second case, we observe an enlargement of the industrial core of the economy with a strong catching up by the periphery. Welfare analysis shows that congestion create (in the bell-shaped agglomeration case) a negative welfare effect on peripheral unskilled workers and renders the agglomerated equilibrium Pareto inferior to dispersion.

JEL Classification: R11, O11.
Keywords: congestion, endogenous growth, migration.

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* Bank of Italy, Regional Economic Research Staff, Milan Branch.

1 Introduction[1]

In their survey of the agglomeration and growth literature Baldwin and Martin (2004) divide the history of world industrial location into two main waves. The first wave consisted in a rapid industrialization of the "North" of the world and a sudden death of all industrial activities in the "South" at both international and regional level (see Hohenberg and Lees, 1985, for Europe; and Kim and Margo, 2004, for North America). The second wave of globalization (i.e. the re-industrialization of the South) emerged more recently and can be perfectly exemplified by the spectacular rise of China and India. Anyway, many second waves also have occurred on a smaller (regional) scale in the past both in Europe (Combes and Overman, 2004) and in the US (Kim and Margo, 2004).

In the last decade, a number of theoretical contributions (Walz, 1996 and 1997; Baldwin and Forslid, 2000; Fujita and Thisse, 2002; Baldwin and Martin, 2004; Cerina and Pigliaru, 2005) have addressed the issue of regional income *divergence*. They show that the interaction between location of industrial activities and regional long-run growth is not negligible as disparities in the agglomeration process tend to persist, or even widen, once we allow for the existence of growth takeoffs in standard New Economic Geography (NEG) models. None of the existing dynamic models, anyway, take into account the possibility of second waves, i.e. the industrial takeoff of the periphery. The reason is that in these models each region is treated as an a-dimensional space, where all firms can concentrate without congestion problems. This hypothesis, apparently reasonable in the international analyses (e.g. Baldwin et al., 2001), is not particularly appealing at regional level.

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The aim of this paper is to build a model of agglomeration and growth that allows for the existence of congestion costs in the form of a simple internal structure in each region.[2] The model extends the Fujita and Thisse (2002, ch. 11) (FT) framework of Romerian growth with localized knowledge spillovers and patent immobility. In their model, FT use a "footloose entrepreneur" framework in which skilled workers (i.e. R&D workers) are allowed to migrate across regions. Interregional labour movements create both a pecuniary externality in the typical form of expenditure shift and technological externality due to localized knowledge spillovers which are likely to boost economic growth under agglomeration. They show that under capital immobility (i) geography matters for growth, i.e. agglomeration is likely to increase the long-run growth due to knowledge externalities; (ii) interregional trade integration leads to catastrophic agglomeration and technical progress is likely to magnify the centripetal forces and (iii) economic growth attenuates the distributional impact of catastrophic agglomeration whenever knowledge spillovers are localized.

Compared with FT our results show that (i) congestion may affect the long-run (steady state) growth rate of the economy if congestion in the core significantly hampers the creation of knowledge; (ii) whenever congestion costs in the core are strong enough, the initial income divergence may be followed by a catching-up process by peripheral regions (i.e. core-periphery reversal) and (iii) in the welfare analysis, agglomeration might not be Pareto improving for the economy whenever congestion significantly lowers the aggregate growth rate of the economy.

Although the core-periphery reversal ("bell-shaped" agglomeration) is not new in

[2] From the policy-maker's point of view this is extremely interesting as there is great concern that "agglomeration economies may be reduced by congestion" (Glaeser and Kahn, 2004). For example, in its recent territorial review of the area of Milan the OECD (2006) points out that "The shortage of housing and the ensuing prohibitive costs in the core of Milan pushed out into the periphery hordes of workers [...]. [Milan's] unique potential to build a comprehensive engine for innovation with regional, national and international spillovers may fade out". This is regarded as a typical problem for all industrialized regions in the OECD countries.

the literature, we present it for the first time in a dynamic framework. This has a number of advantages. First, it solves an intrinsic contradiction in the existing literature. Theoretical models make extensive use of knowldge spillovers, thus implying that the space *within* a region is comparatively smaller than the distance *across* regions, but they actually neglect the possibility of congestion in such a small area. Second, it seems a better representation of reality, especially when we model the core-periphery reversal process. While, in static models, dispersion implies that the core region looses in terms of active firms, in this model it involves just a greater catching up by periphery: both regions continue to grow at positive rates, although the periphery registers higher rates than the core (as actually happened in the post-war core-periphery reversal in the US; see Holmes and Stevens, 2004). Third, this model has particularly rich implications in terms of welfare analysis as we observe a non-linear trade-off between static losses and dynamic gains from agglomeration.

The economics of this model may be explained by the following scheme (Table 1), in which we present the forces shaping the long-run equilibria and their relation with the existing literature according to the following taxonomy:

- Static centripetal forces;
- Static centrifugal forces;
- Dynamic centripetal forces;
- Dynamic centrifugal forces.

Table 1. Economics of the model.

	Centripetal	Centrifugal
Static	Scale economies$^{(*)(**)}$, Transportation costs$^{(*)(**)}$	Commuting costs (lower net wage)$^{(*)}$ Market crowding$^{(*)(**)}$
Dynamic	Localized knowledge spillovers$^{(**)}$	Commuting costs (lower intertemporal spillovers)
$^{(*)}$ elements in the static NEG literature with congestion		
$^{(**)}$ elements in the dynamic agglomeration and growth literature		

Static centripetal forces are due to the interaction between economies of scale and transport costs. Scale economies attract more firms in the larger markets, while transportation costs attract skilled workers in the core due to a lower price level, thus creating a demand linkage between location of production and location of demand.

Static centrifugal forces are linked to market-crowding in the final product markets and commuting costs. A large number of firms in a local market renders competition particularly tough, thus reducing firm profits and creating an incentive to escape from crowded markets. Commuting costs, instead, are likely to reduce labour supply and therefore net wages, creating an incentive for workers to leave large cities.

Dynamic centripetal forces take the form of localized knowledge spillovers. The more concentrated the skilled workers, the higher their productivity and the aggregate growth for the whole economy.

Dynamic centrifugal forces take the form of lower labour supply (due to commuting) in the R&D sector, which harms the production of new varieties and aggregate growth.

Asterisks indicate the elements already existing in the literature.[3] This model

[3] We refer to Helpman (1998), Fujita et al. (1999, ch. 7), Picard and Zeng (2005), Tabuchi (1998), Ottaviano et al. (2002) and Murata and Thisse (2005) for static NEG models with congestion costs. We refer to Walz (1996 and 1997), Baldwin and Forslid (2000) and Fujita and Thisse (2002) for

blends elements of the NEG literature and encompasses all existing migration models in a unified framework. For example, the FT model can be easily obtained by setting the commuting costs equal to zero, while the main results of static models with congestion can be obtained by fixing the existing number of varieties. Footloose Entrepreneur model results may be obtained by setting the commuting costs to zero without growth. We also have an additional force (dynamic centrifugal) due to the interaction between congestion and growth, which is entirely new and proves to be extremely interesting in the analyses of the equilibria.

The paper is organized as follows. Section 2 presents the basic features of the model. In particular, in Section 2.1 we present the internal structure of each region, in Section 2.2 we present the consumers' problem, in Section 2.3 we present the producers' problem and in Section 2.4 we show the market clearing conditions and the migration law of motion. In Section 3 we present the dynamic framework of the model: the steady-state growth path when skilled workers are immobile (3.1) and the steady-state growth path when migration is possible (3.2). In Section 4 we present the welfare impact of the emergence of a core-periphery equilibrium. Section 5 concludes the paper. Appendix 1 shows an exercise of comparative statics achieved by numerical simulations. Appendix 2 includes proofs of the propositions of the model.

2 The model

2.1 Commuting costs and skilled labour supply

Suppose there are two regions (A and B), two factors (skilled workers H and unskilled workers L) and four goods/sectors (an industrial horizontally differentiated one, a traditional one, R&D and land). L-workers work in both the industrial and traditional

dynamic models with migration and to Baldwin and Martin (2004) and Cerina and Pigliaru (2005) for surveys on "Footloose Capital" dynamic models.

sectors as unique factor of production, while H-workers are employed in the R&D (patent) sector. Workers in this sector work at the creation of new varieties of the industrial good. As in FT, we assume that unskilled workers are geographically immobile, while skilled workers are allowed to move across regions whenever their lifetime expected utility is higher in the other region. The ownership structure of the economy is such that L-workers own the entire regional endowment of Land and they rent it to the H-workers,[4] while skilled workers own the stock of existing patents in the initial period.

Each region is a unidimensional space where H-workers live in a residential area and research facilities locate in a central business district (CBD). Each H-worker consumes one unit of land and commutes to the CBD to work. For the sake of simplicity, we assume that L-workers live downtown and do not have commuting costs. This hypothesis greatly simplifies the algebra of the model and does not have any impact on the spatial distribution of economic activities as unskilled workers are geographically immobile.[5]

[4]This assumption is particularly useful for the derivation of the model as it greatly simplifies the algebra, but it does not influence our results either in terms of spatial equilibria or welfare analysis. It introduces a source of positive pecuniary externality (for the unskilled) in the location of skilled workers. This does not impact on the spatial equilibria because unskilled workers are not allowed to migrate. Two alternatives are available in this framework. First, it is possibile to assume that land rents may be shared with the skilled workers. This may create an attenuation of the positive (negative) externality for the unskilled (skilled), but as Murata and Thisse (2005) point out, the redistribution of the rents to the mobile factor is a second order effect, which has no impact on the spatial equilibria. Second, we could assume that land is owned by citizens from an outside country, but once again this does not impact on the spatial allocation of the skilled workers.

[5]This assumption is actually inconsequential for the spatial equilibria of this model. Indeed, (i) unskilled workers are not allowed to migrate and (ii) if regions are symmetric in size, the average productivity of an industrial firm is the same in both regions. We should assume asymmetries in the number of L-workers to obtain a Ricardian difference in productivity, but the study of this hypothesis goes beyond the scope of this paper. The economic interpretation of this assumption may be twofold. On one hand, empirical evidence on urban sprawl in US cities shows (Glaeser et al.,

The total number of H-workers in the economy is normalized to one, while the total number of unskilled workers is 2L (L for each region). Each region r has a share λ_r of H-workers living within its borders. In equilibrium, in each region H-workers symmetrically distribute around the CBD on the interval $\left[-\frac{\lambda_r}{2}; \frac{\lambda_r}{2}\right]$, where the CBD locates at $x = 0$.

Skilled labour supply is influenced by commuting costs to the CBD. As in Murata and Thisse (2005), we assume that commuting costs are an increasing linear function of the distance to the CBD. Labor supply for an H-worker is:

$$s\left(x\right) = 1 - 2\theta\left|x\right| \tag{1}$$

$\theta < 1$ to ensure strictly positive labour supply and $|x|$ is the distance to the CBD. The worse the infrastructure endowment (high θ) or the greater the distance to the CBD, the lower the labour supply.

Wage for an H-worker living on the edge of the region is $s\left(\frac{\lambda_r}{2}\right)w_r = \left(1 - \theta\lambda_r\right)w_r$, where w_r is the skilled wage prevailing in region r.

Hence, all the H-workers living on the interval $\left(-\frac{\lambda_r}{2}; \frac{\lambda_r}{2}\right)$ have a proximity rent $w_r\theta\left(\lambda_r - 2\left|x\right|\right)$ for $x \in \left(-\frac{\lambda_r}{2}, \frac{\lambda_r}{2}\right)$.

Aggregate rent in region r is therefore:

$$ALR_r = \int_{-\frac{\lambda_r}{2}}^{\frac{\lambda_r}{2}} w_r\theta\left(\lambda_r - 2\left|x\right|\right)dx = \theta w_r\frac{\lambda_r^2}{2} \tag{2}$$

Since proximity rents are transferred to the L-workers, aggregate rent per capita is $\theta w_r\frac{\lambda_r^2}{2L}$.

2000) that rich people tend to "escape" from city centres and usually have longer commuting times due to transportation by car. On the other hand, it is possible to think of the CBD as a research cluster in which all research labs concentrate, while production facilities locate elsewhere. In this case, regions are totally segmented and skilled and unskilled tend to live and work in separate places.

2.2 Consumer's problem

Each worker is an infinitely living consumer, who maximizes the following intertemporal problem:

$$\begin{aligned} \max V_l &= \int_0^\infty e^{-\gamma t} \ln V_l^r(t)\, dt \\ & s.t. \\ \int_0^\infty e^{-\nu(t)t} E_l(t)\, dt &= I_l \end{aligned} \tag{3}$$

$V_l^r(t)$ is the utility level attained by consumer l in region r at time t. γ is his subjective discount rate. $E_l(t)$ is the expenditure of consumer l at time t and I_l is the present discounted values of his labour wages and rents. $\nu(t)$ is the instantaneous interest rate of a global bond, which is available in both regions and can be traded across time. Budget constraint states that the (present discounted) value of expenditure must equalize the consumer's wealth, which is made by the present discounted value of labour wage plus assets (land rents for unskilled and industrial rents for skilled). The equality condition is particularly important as it rules out the possibility of chain-letters (Ponzi games): each individual is not allowed to borrow a positive amount of assets without being able to repay it in future times. Therefore, the value of the financial assets at $t \to \infty$, should always be non-negative.

Utility level $V_l^r(t)$ is obtained by solving the following maximization problem for each period t:

$$\begin{aligned} \max U &= \frac{\left\{ \left[\int_{i\in M} q(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}} \right\}^{\mu} T^{1-\mu}}{\mu^{\mu} (1-\mu)^{1-\mu}} \\ & s.t. \\ E_l(t) &= p^T T + \int_{i\in M} p(i) q(i)\, di \end{aligned} \tag{4}$$

T represents the consumption of the traditional good, μ is the share of expenditure on the industrial good, M is the total mass of varieties, $q(i)$ is the consumption of variety i of the horizontally differentiated goods and $p(i)$ is its price. σ is the elasticity of substitution among varieties and p^T is the price of the traditional good.

The Traditional good is freely traded and produced under constant returns to scale, with a one-to-one production function. Its price is constant across regions and it can be normalized to one (T is the nummeraire). The Industrial good is subject to a transportation cost which, as usual in the literature, takes the form of a "melting iceberg": in order to deliver one unit to region m, a producer in region r must ship $\tau \geq 1$ units. Industrial firms find it optimal to adopt mill pricing (Baldwin et al., 2003).

Problems (3) and (4) are solved in two consecutive steps.

In step one, using the standard intertemporal maximization condition (Barro and Sala-i-Martin, 1995) consumers choose the intertemporal consumption path obtaining the usual Euler condition:[6]

$$\frac{\frac{\partial E}{\partial t}}{E} = \nu(t) - \gamma \tag{5}$$

Once the expenditure level is chosen for each period of time, Cobb-Douglas preferences imply that each consumer spends a constant fraction of expenditure on each type of good. In particular, Marshallian demands for T-good and each variety i of M-good are:

[6]Formal derivation of the Euler condition implies the presence of a trasversality condition on the assets: the value of financial assets as $t \to \infty$ is zero. Consumers find it optimal to consume their assets in $t \in [0, \infty)$, rather than to save them until $t \to \infty$. The reason is that asset detention does not raise the utility level, while consumption does. Formally, the trasversality condition implies that $\lim_{t\to\infty} h(t)\, b(t) = 0$, where $b(t)$ is the total amount of assets at time t and $h(t)$ is the shadow price of income (i.e. the constraint of the Hamiltonian, see Barro and Sala-i-Martin, 1995, ch. 2).

$$T = (1-\mu) E_l(t) \tag{6}$$

$$q(i) = \mu p(i)^{-\sigma} P_r^{\sigma-1} E_l(t) \tag{7}$$

$$P_r = \left[\int_{i\in M_r} p_r(i)^{1-\sigma} di + \int_{i \in M_m} \phi p_m(i)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}} \tag{8}$$

P_r is a price aggregator for the industrial good. M_r is the total number of varieties produced in region r and $\phi \equiv \tau^{1-\sigma}$ is a measure of free-ness of trade.[7]

The utility level at time t is equal to real expenditure $V_l^r(t) = \frac{E_l(t)}{P_r^{\mu}}$.

2.3 Producer's problem

2.3.1 Final good sector (industrial/differentiated)

The industrial good is produced under increasing returns to scale due to the presence of a fixed cost, which takes the form of the purchase of a patent, a necessary condition to start the production of a differentiated good. Patents last forever and each producer has a monopoly over the variety produced. The marginal cost is determined by the use of an additional worker L, whose wage (and marginal product) is one, under the hypothesis of non-full specialization of the most industrialized region.

Standard profit maximization implies that the price for good i is $p(i) = \frac{\sigma}{\sigma-1}$. The equilibrium output for each firm in region r and its operating profits are equal to:

$$q_r^* = \mu \frac{\sigma-1}{\sigma}\left[\frac{E_r}{M_r + \phi M_m} + \frac{\phi E_m}{M_m + \phi M_r}\right] \tag{9}$$

$$\pi_r^* = \frac{q_r^*}{\sigma - 1} \tag{10}$$

m is the region other than s. Imperfect competition and iceberg trade costs imply that (a) consumption of the industrial good is home-biased and operating profits tend

[7]When $\phi = 1$, free trade prevails, for $\phi = 0$, interregional trade is prohibitive.

to be higher in the larger market and (b) tougher competition in the home-market (M_r) lowers the operating profits due to the market crowding effect.

2.3.2 Innovation

Patents are produced by perfectly competitive laboratories. The productivity of each H-worker is influenced by (a) the accumulated stock of knowledge: the larger the stock of knowledge available for each researcher the less costly the production of an additional patent. This condition ensures endogenous growth; (b) localized knowledge spillovers among researchers: the productivity of each researcher is positively influenced by face-to-face "exchanges of ideas" within each region; research conducted in the other region only partially filters across space. The idea is based upon extensive empirical evidence according to which "location and proximity clearly matter in exploiting knowledge spillovers" (Audretsch and Feldman, 2004); (c) congestion costs within each region: R&D activities can be performed only in the labouratories located in the CBD and all commuting time is "wasted".[8]

We adopt a very simple regional knowledge production function. The total number of patents developed in region r per unit of time is:

$$\begin{aligned} n_r &= LS_r^H \left(LS_r^H + \eta LS_m^H \right) M \qquad (11) \\ M &= M_r + M_s \end{aligned}$$

$\eta \in [0, 1]$ represents the extent of interregional knowledge spillovers. When $\eta = 1$, knowledge spillovers are global, when $\eta = 0$ knowledge spillovers are absent. LS_r^H is

[8]This hypotheisis neglects all social and working interactions during the commuting time. In practical terms, R&D workers never work on an hypothetical train to the CBD, but tend to use their car to go to work. This hypothesis is supported by Glaeser et al. (2000) according to which skilled and wealthy people tend to commute by car, while poorer people concentrate in areas with a better access to public transport.

the total amount of labour supplied by skilled workers in region r. LS_r^H is influenced by both the total number of skilled workers residing in r and the degree of congestion in region r:

$$\begin{aligned} LS_r^H &= \int_{-\frac{\lambda_r}{2}}^{\frac{\lambda_r}{2}} s(x)\,dx = \int_{-\frac{\lambda_r}{2}}^{\frac{\lambda_r}{2}} (1-2\theta\,|x|)dx = \lambda_r\left(1-\theta\frac{\lambda_r}{2}\right) && (12) \\ n_r &= \lambda_r\left(1-\theta\frac{\lambda_r}{2}\right)\left[\lambda_r\left(1-\theta\frac{\lambda_r}{2}\right)+\eta\lambda_m\left(1-\theta\frac{\lambda_m}{2}\right)\right]M && (13) \end{aligned}$$

As in Romer (1990) and Grossman and Helpman (1991), the steady state growth path is determined by the endogenous production of new varieties in the economy. Hence, the growth rate is determined by:

$$\begin{aligned} \frac{\partial M}{\partial t} &= n_A + n_B = Mg(\lambda) \\ g(\lambda) &= 1 && \text{Maximum growth rate} && (14) \\ &\quad -2\lambda(1-\lambda)(1-\eta) && \text{Knowledge Spillovers Effect} \\ &\quad -\theta\left[1-3\lambda(1-\lambda)\right] && \text{Commuting costs effect} \\ &\quad -\theta\lambda(1-\lambda)\eta + \frac{\theta^2}{4}\left[1-4\lambda+2\lambda^2(3+\eta)-2\lambda^3(1+\eta)(2-\lambda)\right] && \text{Interaction term} \end{aligned}$$

Where $\lambda = \lambda_A$ and $1-\lambda = \lambda_B$. $g(\lambda)$ indicates the aggregate growth function and depends solely on the spatial distribution of skilled workers. $g(\lambda)$ can be decomposed into four elements.

The first is the maximum growth rate (equal to one) that can be achieved by the economy if localized knowledge spillovers and commuting costs do not matter. The second is the knowledge spillovers effect (KSE), according to which aggregate growth is maximized either when skilled workers agglomerate in one region (λ=1 or 0) or when knowledge spillovers are global (η=1). The third component represents the impact of the commuting costs effect (CCE) on the growth rate. Commuting costs minimize the aggregate growth rate when skilled workers concentrate in one region only. The fourth is a term indicating higher order interaction effects between KSE and CCE.

Eq. (14) is a fourth degree polynomial and it shows a clear trade-off between the effects of knowledge spillovers and commuting costs on location and growth. Quite interestingly, this equation suggests the existence of possible decreasing returns from agglomeration in the growth equation. This is a new feature in the agglomeration and growth literature as it suggests the existence of a more complex relationship between the location of skilled workers and the steady state growth. The novelty lies in the fact that, in this model, geography matters for growth, but its effects depend on the interactions between the extent of knowledge spillovers and the degree of congestion costs. In particular:

Proposition 1:

For $2-2\sqrt{\frac{1+\eta}{3-\eta}} < \theta \leq 1-\eta$, $g(\lambda)$ has three local maxima in $\lambda=0$, $\lambda=1/2$ and $\lambda=1$, and two local minima symmetric around $\lambda=1/2$. Moreover, $g\left(\frac{1}{2}\right) \geq g(1) \Leftrightarrow \theta \geq \hat{\theta}$; $\hat{\theta} = \left(\frac{3-\eta}{2} - \sqrt{\frac{1+\eta}{2}}\right)\frac{8}{7-\eta}$ and $\hat{\theta} \in \left(2-2\sqrt{\frac{1+\eta}{3-\eta}}, 1-\eta\right]$

Proof:

See Appendix 2.■

Proposition 1 states that, at an intermediate level of commuting costs ($\theta \in \left(2-2\sqrt{\frac{1+\eta}{3-\eta}}, 1-\eta\right]$), both symmetric and agglomerated equilibria represent local maxima. Proposition 1 is able to detect whether aggregate growth is lower under symmetry rather than agglomeration. In particular, for commuting costs smaller than $\hat{\theta}$, core-periphery maximizes aggregate growth because KSE is larger than CCE.

2.4 Market clearing and migration

We can now determine the market clearing conditions for unskilled and skilled workers.

Unskilled - Being $L_r^M = M_r q_r$ the demand for unskilled workers by the M-sector in region r, the world demand for unskilled workers in the manufacturing sector is $L_A^M + L_B^M = \mu \frac{\sigma-1}{\sigma}(E_A + E_B) = \mu \frac{\sigma-1}{\sigma} E$ where E is the aggregate expenditure in the economy.

Demand for unskilled workers by the T-sector in the economy is $L^T = (1-\mu) E$. Since $L^T + L_A^M + L_B^M = 2L$, we obtain:

$$E = \frac{2L}{1 - \frac{\mu}{\sigma}} \tag{15}$$

Eq.(15) shows that aggregate expenditure is constant over time and depends solely on the total number of unskilled workers ($2L$), on the share of manufacturing on expenditure (μ) and on the monopolistic distortion in the M-sector (σ). Moreover, eq. (15) implies that expenditure path is constant and consumers smooth their consumption over time (eq. (5) is equal to zero and $\nu(t) = \gamma$ in each point in time): instantaneous individual expenditure equals a share γ of the present discounted value of individual incomes. Finally, we can state the incomplete specialization condition in a more formal way: the T-sector is active in both regions if production of T-good in one region is not sufficient to cover world demand, i.e. $L < (1-\mu) \frac{2L}{1-\frac{\mu}{\sigma}} \Rightarrow \mu < \frac{\sigma}{2\sigma-1}$.

Skilled - The Skilled market clears by imposing the zero profit condition on the industrial and R&D sectors. Entrepreneurs invest the present discounted value of the operating profits to buy one patent to start production.

The average cost for producing one patent is given by the ratio between the total amount of H-workers' wages in region r (i.e., $LS_r^H w_r$) and the production of patents in region r (i.e., $MLS_r^H \left[LS_r^H + \eta LS_m^H\right]$).

The average cost of one patent should equalize the present discounted value of the operating profits, Π_r; the equilibrium wage for the H-workers is therefore:

$$\begin{aligned} w_r^* &= Mk(\lambda_r)\Pi_r \\ k(\lambda_r) &\equiv LS_r^H + \eta LS_s^H \end{aligned} \tag{16}$$

Migration - Migration occurs whenever the present discounted value of the utility level in one region is higher than the present discounted value of the utility level in the other region. We assume a migration law such that, when agglomeration occurs, skilled workers smoothly decide to migrate. Migration occurs in the transitional dynamics, while in the steady-state skilled workers do not have any incentive to migrate.

Suppose that migrations take place in a period of time between 0 and T. This implies that all skilled workers are indifferent in their migration time $t \in [0, T]$. The aggregate migration law is therefore:

$$\frac{d\lambda}{dt} = \zeta e^{\gamma t} \left[V(0,t) - V(0,T) \right] \tag{17}$$

$\zeta > 0$ is the speed of adjustment (i.e. a parameter for the migration cost) and $V(0,t)$ is the utility level for a skilled worker who lived in region B from time 0 to time t and then migrates to region A.[9]

3 Agglomeration and Growth with immobile patents

3.1 Steady-state growth path when λ is fixed

Suppose that each patent created in region r can be used only by manufacturing firms in region r. The growth ratio of new varieties in each region is equal to:

$$\frac{\partial M_r}{\partial t} = LS_r^H k(\lambda_r) M = LS_r^H k(\lambda_r) e^{g(\lambda)t} M_0 \tag{18}$$

It is easy to show that the regional growth rate is equal to $\frac{\dot{M}_r(t)}{M_r(t)} = \frac{\delta_r(\lambda) g(\lambda) e^{g(\lambda)t} M_0}{[M_r(0) - \delta_r(\lambda) M_0] + \delta_r(\lambda) e^{g(\lambda)t} M_0}$ where $\delta_r(\lambda) = \frac{LS_r^H k(\lambda_r)}{g(\lambda)}$ represents the share of growth due to the contribution of region r.

[9] For a microfoundation of this migration law (with migration costs) we refer to FT.

In the steady state (i.e. $M_r(0) = \delta_r(\lambda) M_0$), the regional share of aggregate growth is constant over time and it is a function of the spatial distribution of the H-workers:[10]

$$\begin{aligned} \frac{M_r(t)}{M(t)} &= \delta_r(\lambda) \qquad (19) \\ \frac{\partial M_r}{\partial t} &= g(\lambda) M_r(t) \end{aligned}$$

We can now re-write steady state regional price levels, wage rates for skilled workers and the present discounted value of the initial assets in the steady state as follows:

$$P_r(t) = \frac{\sigma \left(M_0 e^{g(\lambda)t}\right)^{\frac{1}{1-\sigma}}}{\sigma - 1} \left[\delta_r(\lambda) + \phi \delta_m(\lambda)\right]^{\frac{1}{1-\sigma}} \qquad (20)$$

$$w_r^* = \frac{\mu k_r(\lambda)}{\sigma\left[\gamma + g(\lambda)\right]} \left[\frac{E_r^*(\lambda)}{\delta_r(\lambda) + \phi \delta_m(\lambda)} + \frac{\phi E_m^*(\lambda)}{\delta_m(\lambda) + \phi \delta_r(\lambda)}\right] \qquad (21)$$

$$a = \frac{\mu E}{\sigma\left[\gamma + g(\lambda)\right]} \qquad (22)$$

$E_r^*(\lambda)$ represents the steady state expenditure level in region r under spatial distribution of skilled workers λ.

3.2 SS-growth path when migration is allowed

In the long-run, skilled workers move across regions in response to regional differences in the present discounted values of their indirect utilities. Since in steady-state migration does not occur, we focus on "migration proof" spatial configurations, in which each worker has no incentives to "change place" over time.

[10] It is important to note that when the manufacturing sector concentrates in region A, in steady-state region B grows at the same rate as region A. This is due to a terms of trade effect. Continuous production of new varieties decreases the price index of the industrial good (which is exported by region A). As a result, terms of trade and income of region B increase over time as the relative price of the traditional good increases. Real permanent income (and expenditure) may differ over time due to the presence of transportation costs and land rents.

Consider, for each $t > 0$, a piecewise continuous function $\varphi(t)$ which assumes the value one when the individual is located in A and zero when he lives in B.

Let $\tilde{W}(\lambda, \varphi(t))$ be the present discounted value of all the net wages received by a skilled worker according to his migration path.

$$
\begin{aligned}
\tilde{W}(\lambda, \varphi(t)) &= \int_0^\infty e^{-\gamma t} \varphi(t)(1-\theta\lambda) w_A^*(\lambda)\, dt \\
&\quad + \int_0^\infty e^{-\gamma t} [1-\varphi(t)][1-\theta(1-\lambda)] w_B^*(\lambda)\, dt \\
&= \bar{\varphi}(1-\theta\lambda) w_A^*(\lambda) + (1-\bar{\varphi})[1-\theta(1-\lambda)] w_B^*(\lambda) \qquad (23) \\
\bar{\varphi} &\equiv \gamma \int_0^\infty e^{-\gamma t} \varphi(t)\, dt \in [0,1]
\end{aligned}
$$

$\bar{\varphi}$ is the (present discounted) share of time spent in region A.

$V_H(\lambda, \bar{\varphi})$ is defined as the lifetime utility of a skilled worker under location path $\bar{\varphi}$:

$$
\begin{aligned}
V_H(\lambda, \bar{\varphi}) &= \qquad (24) \\
&\quad \frac{1}{\gamma}\ln\gamma + \frac{1}{\gamma}\ln\left[a(\lambda) + \tilde{W}(\lambda, \bar{\varphi})\right] \\
&\quad -\mu \int_0^\infty e^{-\gamma t} \{\varphi(t) P_A(t) + [1-\varphi(t)] P_B(t)\}\, dt \\
&= \frac{1}{\gamma}\ln[\gamma a(\lambda) + \bar{\varphi}(1-\theta\lambda) w_A^*(\lambda) + (1-\bar{\varphi})[1-\theta(1-\lambda)] w_B^*(\lambda)] \\
&\quad -\frac{\mu}{\gamma}\bar{\varphi}\ln\left[P_{\frac{A}{B}}(\lambda)\right] - \mu\int_0^\infty e^{-\gamma t}\ln P_B(t)\, dt
\end{aligned}
$$

$P_{\frac{A}{B}}(\lambda) = \frac{P_A(t)}{P_B(t)}$. Eq. (24) represents the life-time utility level of an individual who spends a share $\bar{\varphi}$ of his life in region A and a share $1-\bar{\varphi}$ in region B. A skilled worker chooses his optimal migration path by maximizing eq. (24) with respect to $\bar{\varphi}$. Moreover, a spatial equilibrium $\tilde{\lambda}$ is "migration proof" if and only if $V_H\left(\tilde{\lambda}, 1\right) = V_H\left(\tilde{\lambda}, 0\right)$ is a maximum.

In order to find an analytical solution to this intertemporal problem, we first derive first and second order conditions for eq.(24):

$$\frac{\partial V_H(\lambda,\bar{\varphi})}{\partial\bar{\varphi}} = \frac{1}{\gamma}\frac{[1-\theta\lambda]\,w_A^*(\lambda)-[1-\theta(1-\lambda)]\,w_B^*(\lambda)}{\gamma a(\lambda)+\bar{\varphi}(1-\theta\lambda)\,w_A^*(\lambda)+(1-\bar{\varphi})[1-\theta(1-\lambda)]\,w_B^*(\lambda)} - \frac{\mu}{\gamma}\bar{\varphi}\ln\left[P_{\frac{A}{B}}(\lambda)\right] \tag{25}$$

$$\frac{\partial^2 V_H(\lambda,\bar{\varphi})}{\partial\bar{\varphi}^2} = -\frac{1}{\gamma}\left\{\frac{[1-\theta\lambda]\,w_A^*(\lambda)-[1-\theta(1-\lambda)]\,w_B^*(\lambda)}{\gamma a(\lambda)+\bar{\varphi}(1-\theta\lambda)\,w_A^*(\lambda)+(1-\bar{\varphi})[1-\theta(1-\lambda)]\,w_B^*(\lambda)}\right\}^2 \leq 0 \tag{26}$$

Proposition 2:

If a steady-state "migration proof" spatial configuration is not Core-Periphery, then it is a symmetric equilibrium.

Proof:

See Appendix 2. ■

Proposition 2 states the existence of at most two steady-state spatial configurations in this model: a symmetric one and an agglomerated one. This implies that when core-periphery configuration is unstable, symmetry prevails and viceversa.

Stability analysis is performed by analysing the effects of a small perturbation in the individual's migration decisions. We assume that $\bar{\varphi}$ diminishes in a contour of $\bar{\varphi}=1$ when all skilled workers are concentrated in region A (i.e. $\lambda=1$). In other words, we suppose that a skilled worker decides to "try" to migrate for a small period of time to region B, when all skilled workers live in the core. Whenever his lifetime utility diminishes, this perturbation is self-stabilizing and the agglomerated equilibrium is stable. Otherwise, core-periphery is unstable and symmetry prevails. In analytical terms, agglomeration is a stable equilibrium if and only if:

$$\left.\frac{\partial V_H\left(1,\bar{\varphi}\right)}{\partial\bar{\varphi}}\right|_{\bar{\varphi}=1} \geq 0 \Leftrightarrow \tag{27}$$

$$\frac{1}{\gamma}\frac{\left[1-\theta\right]w_A^*\left(1\right)-w_B^*\left(1\right)}{\gamma a\left(1\right)+\left(1-\theta\right)w_A^*\left(1\right)} \geq \frac{\mu}{\gamma}\ln\left[P_{\frac{A}{B}}\left(1\right)\right]$$

Using wage, price and growth equations and recalling that $E=\frac{2L}{1-\frac{\mu}{\sigma}}$, $E_B\left(1\right)=L$, $E_A\left(1\right)=\frac{1+\frac{\mu}{\sigma}}{1-\frac{\mu}{\sigma}}L$ we obtain:

$w_A\left(1\right)=\frac{\mu\left(1-\frac{\theta}{2}\right)}{\sigma\left(1+\gamma-\theta+\frac{\theta^2}{4}\right)}\frac{2L}{1-\frac{\mu}{\sigma}}$,

$w_B\left(1\right)=\frac{\mu\eta\left(1-\frac{\theta}{2}\right)}{\sigma\left(1+\gamma-\theta+\frac{\theta^2}{4}\right)}\frac{2L}{1-\frac{\mu}{\sigma}}\left[\frac{1+\phi^2-\frac{\mu}{\sigma}\left(1-\phi^2\right)}{\phi}\right]$ and

$P_{\frac{A}{B}}\left(1\right)=\phi^{\frac{1}{\sigma-1}}$.

The condition in (27) becomes:

$$\Gamma\left(\phi\right)=\frac{1-\frac{\theta}{2}}{\gamma+\left(1-\theta\right)\left(1-\frac{\theta}{2}\right)}\left\{2\left(1-\theta\right)-\frac{\eta}{\phi}\left[1+\phi^2-\frac{\mu}{\sigma}\left(1-\phi^2\right)\right]\right\}-\frac{\mu}{\sigma-1}\ln\phi\geq 0 \tag{28}$$

As usual in the NEG literature, the stability of spatial equilibria depends on the level of trade freeness ϕ, on the elasticity of substitution across varieties (σ), on the share of income spent on manufactures (μ) and on the degree of commuting costs (θ). Moreover, given the dynamic nature of this model, the extent of localized knowledge spillovers (η) and the subjective discount rate (γ) play an important role in shaping the stability of the steady-state equilibria. In the remaining part of this Section we perform the classical "thought experiment" of the NEG literature by analysing what happens when a trade liberalization occurs (i.e. when parameter ϕ gradually passes from zero to one), by focussing on two main parameters of this model: the extent of commuting costs and inter-regional knowledge spillovers.

Inequality (28) shows that the smaller the extent of localized knowledge spillovers ($\eta\to 0$), the more likely a core-periphery outcome. The intuition is simple and well known in the literature. The more productive a skilled worker under agglomeration the higher his wage. This is a strong centripetal force. Commuting costs have two opposite effects on the stability of core-periphery. On one hand, higher commuting costs diminish skilled workers' net wage under agglomeration (a centrifugal force). On the other hand, high commuting costs decrease the speed of creation of new patents and increase the firms' present discounted value of profits, the value of each patent and skilled workers' wage (a centripetal force).

Analytically, $\Gamma(\phi)$ is a concave function with a unique maximum in ϕ^*, $\Gamma(0) \to -\infty$, $\Gamma'(1) < 0$. Unfortunately, we are not able to solve this equation analytically for $\Gamma(\phi) = 0$, given the logarithmic part in the price effect. Anyway, when trade costs diminish, we are able to observe three different configurations (or outcomes) depending on the level of parameters η and θ:

(a) $\eta \leq 1-\theta$, $\exists \phi^{sustain} : \Gamma\left(\phi^{sustain}\right) = 0, \Gamma(\phi) < 0$ for $\phi < \phi^{sustain}$, $\Gamma(\phi) > 0$ for $\phi > \phi^{sustain}$;

(b) $\widetilde{\eta} \geq \eta > 1-\theta$; $\exists \phi^{s1}, \phi^{s2} : \Gamma(\phi) \geq 0, \forall \phi \in \left[\phi^{s1}, \phi^{s2}\right]$;

$\widetilde{\eta}$ is defined by the following conditions: $\begin{cases} \Gamma(\phi^*)\Big|_{\eta=\widetilde{\eta}} = 0 \\ \Gamma'(\phi^*)\Big|_{\eta=\widetilde{\eta}} = 0 \end{cases}$

(c) $\eta \geq \widetilde{\eta}$; $\Gamma(\phi) < 0, \forall \phi$.

In other words, under configuration (a) there exists a unique solution for $\Gamma(\phi) = 0$ in the economically relevant interval $\phi \in (0,1]$. Under configuration (b) the equation has two solutions, while under configuration (c) function $\Gamma(\phi)$ is always negative and the equation has no real-valued solutions. Unfortunately, while we are able to discriminate between configuration (a) and (b), it is not possible to obtain a closed form value for $\widetilde{\eta}$, which separates configuration (b) and (c). We provide an implicit expression.

Due to these difficulties and the triviality of configuration (c) (in which symmetry is never broken), we focus on configurations (a) and (b) only, which are also the most economically interesting results.[11]

Configuration (a) is the typical Krugman-type agglomeration in which the economy experiences two phases. When trade costs are high ($\phi < \phi^{sustain}$), symmetry across regions prevails. At $\phi = \phi^{sustain}$ symmetry is no longer sustainable and skilled workers start migrating from region B to A. This process is smooth and income divergence occurs in the economy until a new (agglomerated) steady-state equilibrium is reached. Region A experiences a growth take-off in the transitional dynamics, while region B slows down and specializes in the traditional sector. Once the new agglomerated steady state is reached ($\phi \geq \phi^{sustain}$), income inequality persists, as the only source of income growth in region B is a terms of trade effect due to the technical progress in region A.

Configuration (b) has richer implications and describes a "bell-shaped" agglomeration process. The economy experiences three phases. When trade costs are very high ($\phi < \phi^{s1}$), symmetry is the only steady state outcome. For $\phi \in \left[\phi^{s1}, \phi^{s2}\right]$, as in configuration (a) divergence occurs and industrial activities concentrate in region A. When trade liberalizes further, ($\phi > \phi^{s2}$), spatial equilibria change and, in the transitional dynamics, skilled workers start to migrate back to the periphery. This triggers a process of cumulative growth in region B.

Interestingly, dispersion does not imply that the core region loses in terms of active firms. It just implies that region B catches up with region A, which slows down due to the loss of human capital. In other words, in the transitional dynamics the number of firms in region A continues to increase, although at a slower rate than

[11] It should be noted that a sufficient condition for configuration (b) to exist is that $\hat{\eta} \geq \eta > 1 - \theta$ where $\hat{\eta} = \frac{\sigma(1-\theta)}{\sqrt{\sigma^2-\mu^2}} - \frac{1}{4D}\frac{\sigma\mu}{\sqrt{\sigma^2-\mu^2}}\frac{1}{\sigma-1}\ln\left(\frac{\sigma-\mu}{\sigma+\mu}\right)$ and $D \equiv \frac{1-\frac{\theta}{2}}{\gamma+(1-\theta)\left(1-\frac{\theta}{2}\right)}$. The sketch for this derivation is as follows. First, divide function $\Gamma(\phi) = F(\phi) + G(\phi)$, where $F(\phi) = D\left\{2(1-\theta) - \frac{\eta}{\phi}\left[1+\phi^2 - \frac{\mu}{\sigma}\left(1-\phi^2\right)\right]\right\}$ and $G(\phi) = \frac{\mu}{\sigma-1}\ln\phi$. $G(\phi)$ is an increasing monotonic function, while $F(\phi)$ is concave with a unique maximum in $\phi = \frac{\sigma-\mu}{\sigma+\mu}$. $\widetilde{\eta}$ is approximated by setting $F\left(\frac{\sigma-\mu}{\sigma+\mu}\right) - G\left(\frac{\sigma-\mu}{\sigma+\mu}\right) = 0$. Note, however, that $\hat{\eta} < \widetilde{\eta}$ since $\Gamma'\left(\frac{\sigma-\mu}{\sigma+\mu}\right) = G'\left(\frac{\sigma-\mu}{\sigma+\mu}\right) > 0$.

before, but region B registers a steady growth in the creation of new firms, which is much larger than the region A rate of growth. This describes a regional convergence process in the economy. Compared with static models of economic geography, this seems a more reasonable representation of reality, as many “second waves” at regional scale frequently imply an “enlargement” of the industrial core, rather than a rough relocation of economic activities to the periphery.[12] The economics of the dispersion is simple: as soon as trade costs become low enough, peripheral producers are able to serve the core (the bigger market) without locating in the agglomerated region, in which both congestion and competition are particularly tough. However, interregional knowledge spillovers play also an important role. A necessary condition for re-dispersion is that once a small number of skilled workers decide to migrate to the periphery, they should benefit from the R&D spillovers from the core, otherwise their productivity is too low to trigger the catching-up process (note that when $\eta = 0$, configuration (b) is never reached). In other words, the two regions should not be “too distant” in terms of trade and knowledge flows. This mechanism clearly resembles the findings of Kim (1995, 1998): the spectacular catching up of southern states in the US in the second half of the twentieth century can be attributed mainly to a sharp change in the southern economic structure (from agriculture to manufacturing), even when the north-south wage gap was filled in the second post-war period. The increase in the number of industrial plants in the South may be due to a fall in interregional transportation costs, which rendered the location of an industrial plant in the south comparatively more profitable (see Kim and Margo, 2004, for a discussion). Once again, we did not observe a rough relocation of industrial plants, rather, industrial activity, once thin on the ground of the southern states, started to expand with a self-sustained cumulative growth process.

Finally, using Proposition 1 we find that, under configuration (b), core-periphery

[12]See, for example, the industrialization processes in the North-East of Italy or in Bavaria (Germany) in the post-war period.

does not maximize aggregate growth as $\theta > 1-\eta$. This implies that the "enlargement" of the industrial core of the economy is coupled with a growth acceleration of the *entire* economy. We will make use of this prediction in the next Section for the welfare analysis.

4 "Should we mind the gap?" Maybe yes!

In chapter 11 of their book, FT present their welfare analysis with an interesting question: "Should we mind the gap?". Their answer is that, probably we should not mind the welfare gap agglomeration creates since, with localized knowledge spillovers, static loss of unskilled workers in the periphery (i.e. higher price level) are likely to be overcome by the dynamic gains due to higher growth.[13]

In this model we allowed for the existence of congestion costs adding both an additional static loss (i.e. loss of land rents) and a dynamic loss (lower growth due to longer commutes) for the unskilled living in the periphery.

Our welfare analysis takes the very simple form of a Pareto optimality evaluation of the core-periphery outcome. We are aware that this definition is quite restrictive (Pflueger and Suedekum, forthcoming; Charlot et al., 2006), but it has the clear advantage of being directly comparable with FT analyses.

Pareto optimality of agglomeration emerges if unskilled workers in the periphery are at least indifferent (or better-off) under agglomeration compared to dispersion.[14]

[13] Fujita and Thisse conclude that "the increase of regional disparities does not necessarily imply the impoverishment of the peripheral region. [...] it is not clear that agglomeration, growth and equity do conflict: even people residing in the periphery are better-off in the core-periphery structure than under dispersion".

[14] Skilled workers always choose their migration pattern to maximize the present discounted value of the utility levels. Therefore, agglomeration never occurs if it does not maximize their welfare. Unskilled workers living in the core enjoy, under agglomeration, both a lower price level and higher land rents and they are always better-off under agglomeration.

Expenditure at each point in time for an L-worker residing in B is composed of his labour income plus the aggregate land rent per capita: $E_L^B(t,\lambda) = 1 + \frac{\theta w_B^*(\lambda)(1-\lambda)}{2L}$.

Given the upper-tier Cobb-Douglas utility function, we obtain that the indirect utility of an L-worker residing in region B at time t under distribution λ of H-workers is equal to:

$$V_L^B(t,\lambda) = \frac{1 + \frac{\theta w_B^*(\lambda)(1-\lambda)}{2L}}{\left\{ \frac{\sigma\left(M_0 e^{g(\lambda)t}\right)^{\frac{1}{1-\sigma}}}{\sigma-1} \left[\delta_B(\lambda) + \phi\delta_A(\lambda)\right]^{\frac{1}{1-\sigma}} \right\}^{\mu}} \tag{29}$$

Defining $V_L^B(\lambda) = \int_0^\infty e^{-\gamma t} V_L^B(t,\lambda)\,dt$ and using (3), we obtain:

$$\begin{aligned} V_L^B(1) - V_L^B\left(\frac{1}{2}\right) &= \\ & \frac{1}{\gamma}\left[\ln\frac{2L}{2L + \frac{\theta}{4}w_B^*\left(\frac{1}{2}\right)} + \frac{\mu}{\sigma-1}\ln\frac{2\phi}{(1+\phi)}\right] \\ & + \frac{1}{\gamma^2}\frac{\mu}{\sigma-1}\left[g(1) - g\left(\frac{1}{2}\right)\right] \end{aligned} \tag{30}$$

Equation (30) describes the welfare gains and losses for an unskilled worker in the periphery when a core-periphery configuration emerges. The first term (in squared brackets) on the right-hand side describes the static loss derived from agglomeration. In particular, $\ln\frac{2L}{2L+\frac{\theta}{4}w_B^*\left(\frac{1}{2}\right)}<0$ is the land rent loss occurring when all skilled workers leave region B for region A. $\frac{\mu}{\sigma-1}\ln\frac{2\phi}{(1+\phi)}<0$ is the price level loss when unskilled workers in B have to pay a higher price (due to transport costs) for all the M-good varieties. $\frac{\mu}{\sigma-1}\left[g(1) - g\left(\frac{1}{2}\right)\right]$ is the (possible) dynamic gain from agglomeration derived from higher growth under core-periphery.

A necessary condition for an overall welfare improvement is that growth under core-periphery is larger than under symmetry. As we have seen in the previous Section, this condition is *never* respected under configuration (b) when $\theta > 1-\eta$. Therefore, although from a qualitative point of view our result is similar to that of FT (i.e.

core-periphery is Pareto improving if and only if it creates enough growth), from the quantitative point of view we observe a huge difference due to the presence of both a larger static loss (the loss of housing rents) and a smaller dynamic gain (lower aggregate growth). A policy-maker should now intervene whenever the economy is under configuration (b).

5 Conclusions

Localized knowledge spillovers and congestion are two of the most distinguishing characteristics of the regional analysis. They are likely to shape both the spatial configurations and the long-run productivity gains of an economy. The aim of this paper is to treat both in a unified framework by showing the effects of congestion on a process of agglomeration and growth in a dynamic general equilibrium process with endogenous growth and location of workers/production.

Our results show that the introduction of congestion costs in a model of "agglomeration and growth" is likely to greatly influence the long-run spatial configurations of the economy.

First, we show how congestion may affect the long-run (steady state) growth rate of the economy even in the presence of localized knowledge spillovers.

Then, according to the interplay between the knowledge spillovers and the congestion costs, we are able to obtain both a Krugman-type and a Bell-shaped agglomeration effects. In the first case (configuration (a)) we obtain the well-known result of a permanent income inequality in the steady state and income divergence in the transitional dynamics. This occurs when interregional knowledge spillovers are low compared with the congestion costs; i.e. when the knowledge transmission is sticky and can be done mainly by face-to-face interactions. In the second case (configuration (b)) we have richer implications. After an initial period of income divergence and agglomeration in the core region, we observe a re-dispersion of economic activities which takes the form of an "enlargement of the core". This occurs when regional integration in terms of knowledge transmission is strong enough, i.e. knowledge spillovers are large compared with congestion costs. Quite interestingly, aggregate growth is likely to be larger under symmetry than under agglomeration.

Finally, welfare analysis shows that core-periphery creates a welfare gap between unskilled workers in the core and unskilled workers in the periphery. The existence of decreasing returns of agglomeration in the knowledge production function may create (in the bell-shaped agglomeration case) a negative welfare effect on peripheral unskilled workers and it renders the agglomerated equilibrium Pareto inferior to dispersion.

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Appendix 1: Simulations and Comparative Statics

The values of the sustain points $\phi^{sustain}$, ϕ^{s1} and ϕ^{s2} may vary at any change of knowledge spillovers and commuting costs.

In Figure 1, we show the values of $\phi^{sustain}$, ϕ^{s1} and ϕ^{s2} when the parameter η is allowed to vary between zero and one. Simulation parameters are $\theta = 0.3$, $\sigma = 2.5$, $\mu = 0.6$, $\gamma = 0.02$.

[Figure 1, here]

For all the values of ϕ above the red (continuous) and below the blue (dashed) lines, core-periphery is sustainable, otherwise symmetry is the only steady-state outcome. For all the values above the green (dotted) line, the core-periphery outcome is Pareto superior to symmetry.

When knowledge spillovers are zero, configuration (a) is always sustainable.

As knowledge spillovers increase, the economy, starting from a configuration (a) situation changes in a configuration (b) whenever η becomes bigger than $1 - \theta = 0.7$. This is due to the fact that dynamic centripetal forces lose their strength and static and dynamic centrifugal forces overcome them. Moreover, figure 1 shows that all the core-periphery configurations below the green (dashed) line and all the symmetric configurations above the same line are not Pareto optimal. As we show in the text, core-periphery under configuration (b) is never Pareto improving. A welfare maximizing policy-maker, therefore, should intervene to correct these externalities.

A similar picture occurs when the parameter θ is allowed to vary between zero and one.

Appendix 2: proofs

Proof of Proposition 1:

Given its symmetric shape around $\lambda = 1/2$, $g(\lambda)$ has a unique minimum in $\lambda = 1/2$.

$$g'(\lambda) = -2(1-2\lambda)(1-\eta) - \theta(3-\eta)(2\lambda - 1)$$
$$+\frac{\theta^2}{4}\left[-4 + 4\lambda(3+\eta) - 2(1+\eta)\left(6\lambda^2 - 4\lambda^3\right)\right]$$

$$g''(\lambda) = -4(1-\eta) - 2\theta(3-\eta)$$

$+\frac{\theta^2}{4}\left[4(3+\eta)-2(1+\eta)\left(12\lambda-12\lambda^2\right)\right]$

For $\theta \in \left(2-2\sqrt{\frac{1+\eta}{3-\eta}}, 1-\eta\right]$, its first derivative in $\lambda = 0$ is negative and its second derivative in $\lambda = 1/2$ is negative. In particular, $g'(0) \leq 0 \Leftrightarrow \theta \leq 1-\eta$; and $g''\left(\frac{1}{2}\right) \leq 0 \Leftrightarrow \theta \leq 2-2\sqrt{\frac{1+\eta}{3-\eta}}$. This implies that there exist two additional stationary points.

Moreover,

$g(1) = 1-\theta+\frac{\theta^2}{4}$

$g\left(\frac{1}{2}\right) = 1-\frac{1}{2}(1-\eta)-\theta\left[1-\frac{1}{4}(3-\eta)\right]+\frac{\theta^2}{4}\left[-1+\frac{1}{2}(3+\eta)-\frac{3}{8}(1+\eta)\right]$

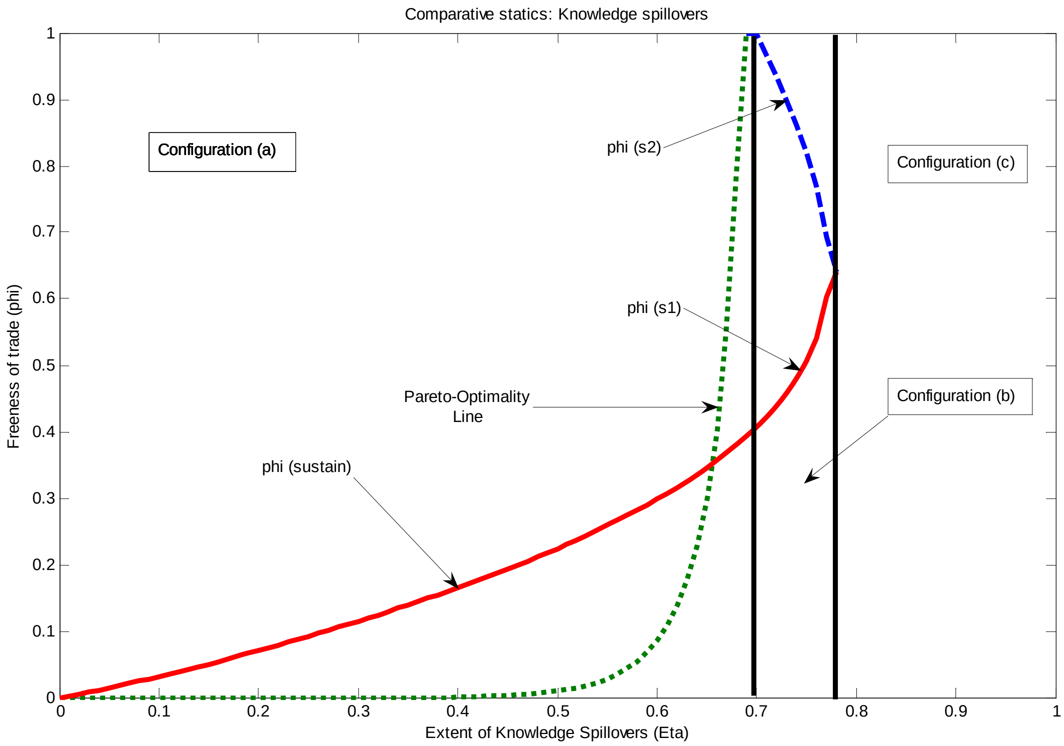
$g\left(\frac{1}{2}\right) \leq g(1) \Leftrightarrow \theta \leq \hat{\theta}$; $\hat{\theta} = \left(\frac{3-\eta}{2}-\sqrt{\frac{1+\eta}{2}}\right)\frac{8}{7-\eta}$ and $\hat{\theta} \in \left(2-2\sqrt{\frac{1+\eta}{3-\eta}}, 1-\eta\right]$

Proof of Proposition 2:

$\bar{\varphi}$ takes the value of one, when the H-worker spends all his life in region A, while it takes the value of zero, when he spends all his life in region B. Therefore, spatial distribution $\lambda \in (0,1)$ is migration-proof if and only if the present discounted utility level in region A is equal to the present discounted utility level in region B. This means that $V(\lambda,1) = V(\lambda,0) = \max\{V(\lambda,\bar{\varphi}) : \bar{\varphi} \in [0,1]\}$. This implies that $V(\lambda,\bar{\varphi})$ is not strictly concave[15] on the compact set $\bar{\varphi} \in [0,1]$. Hence, in order for $\lambda \in (0,1)$ to be a maximum (and eq. (26) to hold), $w_A^*(1-\theta\lambda) = w_B^*[1-\theta(1-\lambda)]$. Therefore eq. (25) is equal to zero if and only if $P_{\frac{A}{B}}(\lambda) = 1$. This happens when $\lambda = \frac{1}{2}$.

[15]It should be pointed out that the use of both condition (26) and definition of a migration proof equilibrium ($V(\lambda,1) = V(\lambda,0) = \max\{V(\lambda,\bar{\varphi}) : \bar{\varphi} \in [0,1]\}$) automatically discard the possibility of existence of local maxima, i.e. points in $\bar{\varphi} \in [0,1]$ in which the equation is locally concave.

Figure 1


Comparative statics: Knowledge spillovers
Configuration (a)
Configuration (b)
Configuration (c)
phi (s2)
phi (s1)
Pareto-Optimality Line
phi (sustain)
Freeness of trade (phi)
Extent of Knowledge Spillovers (Eta)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

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