Endogenous Growth Theories: Agglomeration Benefits and Transportation Costs*

G. Alfredo Minerva† and Gianmarco I.P. Ottaviano‡

October 27, 2007

Abstract

We propose a simple theoretical framework to study the impact of infrastructure on economic growth and regional unbalances. The framework presents in a unified way the main insights of NEG models with endogenous growth and free capital mobility. Two main results stand out. First, there is a trade off between growth and regional equality as improved infrastructure in developed 'core' regions fosters both agglomeration and growth, which are instead hampered by improved infrastructure in developing 'peripheral' regions. Second, better interregional connections may increase rather than decrease regional inequality as improved transport and communication infrastructure between core and peripheral regions fosters not only growth but also agglomeration. Nonetheless, increased agglomeration does not necessarily imply the impoverishment of peripheral regions as long as its positive impact on growth is strong enough.

Keywords: Business services; communication costs; endogenous growth; infrastructure; knowledge spillover; transportation costs.
JEL Classification: O31, 040, R11, R12.

*Paper prepared for the volume "Regional Dynamics and Growth: Advances in Regional Economics" edited by Roberta Capello and Peter Nijkamp. Financial support from MIUR and the University of Bologna is gratefully acknowledged. We have benefited from comments by an anonymous referee.

†Dipartimento di Scienze Economiche, Università di Bologna, Italy. *E-mail*: ga.minerva@unibo.it

‡Corresponding author. Dipartimento di Scienze Economiche, Università di Bologna, Italy. *E-mail*: gianmarco.ottaviano@unibo.it

1 Introduction

The role of infrastructure in global and local economic development can be hardly overstated (World Bank, 1994). In particular, as reported by Calderon and Serven (2004), its role has been stressed along two main dimensions: its effects on economic growth and its effects on income inequality. Along the first dimension, most studies focus on the impact of infrastructure on aggregate output finding it positive. This is highlighted in a seminal contribution by Aschauer (1989), who finds that the stock of public infrastructure capital is a significant driver of aggregate TFP. Even though subsequent efforts question Aschauer's quantitative assessment, overall his qualitative insight survives more sophisticated econometric scrutiny (see, e.g., Gramlich, 1994; Röller and Waverman, 2001). In particular, Calderon and Serven (2003) identify positive and significant impacts on output of three types of infrastructures (telecommunications, transport and energy) and show that such impacts are significantly higher than those of non-infrastructure capital.

The link between infrastructure and long-run growth is much less explored. Easterly and Rebelo (1993) find that public expenditures in transport and communications foster growth. This result is confirmed by Sanchez-Robles (1998) in the case of physical infrastructure and by Easterly (2001) as well as Loayza, Fajnzylber and Calderon (2003) in the case of communications (telephone density). On the other hand, it is argued that sometimes the inefficiency of infrastructure provision can curb and even reverse the sign of its impact on long-run growth (Devarajan et al, 1996; Hulten, 1996; Esfahani and Ramirez, 2002).

Turning to the effects on income inequality, the issue is whether infrastructure has a disproportionate impact on the income and welfare of the poor (World Bank, 2003). The presence of a disproportionately positive impact finds some support in the evidence surveyed by Brenneman and Kerf (2002). Several studies point at the effects of infrastructure on human capital accumulation: better transportation and safer roads promote school attendance; electricity allows more time for study and the use of computers; access to water and sanitation reduces child and maternal mortality. Infrastructure also connects poor people in underdeveloped areas to core economic activities, thus expanding their employment opportunities (Estache, 2003). Finally, better infrastructure in poorer regions reduces production and transaction costs (Gannon and Liu, 1997). Overall, existing studies show that infrastructure is important for economic growth and income inequality. The exact impact may depend, however, on the type of infrastructure. In the words of Sugolov et al (2003): "All in all, there is a broad consensus that ... infrastructure is a necessary but not sufficient ingredient of economic growth, and that the efficient supply of the right kind of infrastructure (material and institutional) in the right place is more important than the amount of money disbursed or the pure quantitative infrastructure capacities created" (p.3).

The aim of the present paper is to discuss the foregoing issues from the specific point of view of New Economic Geography (NEG), an approach to economic geography firmly grounded on recent developments in mainstream industrial organization and international trade theory.[1] NEG explains the evolution of the economic landscape as a self-organising process driven by pecuniary externalities whose relative intensity depends on a set of well-defined microeconomic parameters. Among these, the obstacles to the geographical mobility of goods and factors are of crucial importance and can be readily related to infrastructure efficiency.

The focus of our analysis is on the effects of infrastructure on the costs of exchanging goods ('transport costs') and ideas ('communication costs'). In both cases, infrastructure can be thought of as having 'border effects' (i.e. effects on the exchanges between regions) as well as 'behind-the-border effects' (i.e. effects on the exchanges within regions). The result of our paper is a unified framework that summarizes the main insights of NEG on the relation between infrastructure, economic growth and agglomeration: (1) there is a *trade off between growth and regional equality* as improved infrastructure in developed 'core' regions fosters agglomeration and growth, which are instead hampered by improved infrastructure in developing 'peripheral' regions; (2) better *interregional connections may increase rather than decrease regional inequality* as improved transport and communication infrastructure between core and peripheral regions may foster not only growth

[1] There exist many surveys of NEG and alternative approaches to spatial issues. See, e.g., Fujita et al (1999), Fujita and Thisse (2002), Baldwin et al (2003).

but also agglomeration.

The paper is organized as follows. Section 2 presents the endogenous growth model that will be used as theoretical framework. Section 3 discusses the feedback from growth to agglomeration. Section 4 highlights the effects of agglomeration on growth. Section 5 studies the effects of transportation and communication infrastructure on agglomeration and growth. Section 6 concludes.

2 Theoretical framework

We follow Martin and Ottaviano (1999, 2001) in modeling a spatial economy where long-run growth is sustained by ongoing product innovation and knowledge spillovers.[2] There are two regions, North and South, with the same given number Q of workers. Workers are geographically immobile and each supplies one unit of labor inelastically so that Q also measures the regional endowment of labor. Regions are also endowed with an identical initial stock of knowledge capital K_0.[3] Knowledge capital is accumulated through profit-seeking innovation performed by R&D laboratories and is freely mobile between regions. Laboratories finance their efforts by selling bonds to workers in a perfect interregional capital market and we call $r(t)$ the riskless return on those bonds. For the sake of parsimony, in the presentation, we focus on North with the implicit understanding that symmetric expressions apply to the South.

2.1 Consumption

Workers' preferences are defined over the consumption of two goods, a homogeneous 'traditional' good Y and a horizontally differentiated 'modern' good D. Their preferences are captured by the following utility function:

$$U = \int_{t=0}^{\infty} \log \left[D(t)^{\alpha} Y(t)^{1-\alpha} \right] e^{-\rho t} \mathrm{d}t \tag{1}$$

where

$$D(t) = \left[\int_{i=0}^{N(t)} D_i(t)^{1-1/\sigma} \mathrm{d}i \right]^{1/(1-1/\sigma)} , \quad \sigma > 1 \tag{2}$$

is the CES consumption basket of the different varieties of good D. In (2) $D_i(t)$ is the consumption of variety i and $N(t)$ the total number of varieties available in the economy. Instantaneous utility maximization implies that in each period workers allocate a share α of their individual expenditures $E(t)$ to the consumption of the modern good and the complementary share $1-\alpha$ to the consumption of the traditional good. The share $\alpha E(t)$ is then distributed across varieties according to their relative prices. For any variety i, the result is individual demand:

$$D_i(t) = \frac{p_i(t)^{-\sigma}}{P(t)^{1-\sigma}} \alpha E(t) \tag{3}$$

where

$$P(t) = \left[\int_{i=0}^{N(t)} p_i(t)^{1-\sigma} \mathrm{d}i \right]^{1/(1-\sigma)} \tag{4}$$

is the exact price index associated with the CES consumption basket (2) and σ is both the own- and cross-price elasticity of demand. Intertemporal utility maximization finally determines the evolution of expenditures according to a standard Euler equation:

$$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho \tag{5}$$

where we have used the fact that (1) exhibits unit elasticity of intertemporal substitution.

[2] See Baldwin and Martin (2004) for a broader survey of NEG models with endogenous growth.

[3] Assuming identical factor endowments across regions allows us to highlight the specific role of infrastructure in determining regional specialization.

2.2 Production

The traditional good is produced under perfect competition and constant returns to scale using labor as its only input. The unit input requirement is set to 1 by choice of units for labor, so the profit maximizing price of Y equals the wage. Moreover, the traditional good is freely traded both between and within regions, which implies that its price and therefore its wage are the same in both regions.[4] By choosing good Y as numeraire, the common wage is also pinned down to 1.

The varieties of the modern good are produced under monopolistic competition and increasing returns to scale due to fixed and variable costs. Fixed costs are incurred in terms of knowledge capital, one unit per variety, and variable costs in terms of labor, β units per unit of output. Accordingly, in any instant t the global capital stock $K^w(t)$ determines the total number of varieties available in the economy. As in equilibrium each variety is produced by one and only one firm, $K^w(t)$ also determines the total number of firms. However, as knowledge capital is freely mobile, where varieties are actually produced is endogenously determined by the entry decisions of firms and we call $n(t)$ the number of firms producing in North. In any instant there is a large number of potential entrants that need knowledge capital to start producing. As in a given instant capital supply is fixed, their bidding for capital ends up transferring all operating profits to capital owners.

Exchanges of differentiated varieties are hampered by *transport costs*. These are modelled as iceberg frictions that absorb part of the quantity shipped: $\tau_N > 1$ and $\tau_R > 1$ units have to be sent by a northern firm for one unit to be delivered to a northern and to a southern customer respectively. Symmetrically, $\tau_S > 1$ and $\tau_R > 1$ units have to be shipped by a southern firm for one unit to be delivered to a southern and to a northern customer respectively. The larger the τ's, the worse the corresponding transport infrastructure. We assume that intra-regional transportation is less costly than interregional transportation but this cost advantage in more pronounced for North:

$$\tau_N < \tau_S < \tau_R$$

which identifies North as the developed 'core' region and South as the developing 'peripheral' one.

Given our assumptions on demand and technology, all firms in any market face the same constant elasticity of demand σ and the same marginal production cost β. Hence, their profit maximizing producer price ('mill price') is the same and equal to a constant markup over marginal cost:

$$p = \frac{\sigma}{\sigma - 1}\beta \tag{6}$$

Moreover, the consumer price ('delivered price') simply reflects different transport costs:

$$p_N = p\ \tau_N,\ p_S = p\ \tau_S,\ p_R = p\ \tau_R \tag{7}$$

Accordingly, operating profits are

$$\pi(t) = \frac{\beta x(t)}{\sigma - 1} \tag{8}$$

where $x(t)$ is firm output inclusive of the quantity absorbed by the iceberg frictions.

Finally, given (7), the price index (4) can be rewritten as:

$$P(t) = pN(t)^{\frac{1}{1-\sigma}} \left[\delta_N \gamma(t) + \delta_R(1 - \gamma(t))\right]^{\frac{1}{1-\sigma}} \tag{9}$$

where $\gamma(t) = n(t)/N(t)$ is the share of firms located in North and $N(t) = K^w(t)$ is the global number of firms as well as the global stock of knowledge capital. The parameters $\delta_N = (\tau_N)^{1-\sigma}$ ($\delta_S = (\tau_S)^{1-\sigma}$) and $\delta_R = (\tau_R)^{1-\sigma}$ measure the efficiency of transportation within and between regions respectively. They are bounded between zero and one, and ranked $\delta_N > \delta_S > \delta_R$.

[4]The assumption that the traditional good is freely traded is rather standard in NEG models. However, it is not innocuous. For instance, the computable general equilibrium analysis by Kilkenny (1998) suggests that the location of the modern sector reacts differently to improved transportation depending on the relative importance of the transport costs on the modern and the traditional goods. See also Chapter 7 in Fujita et al (1999) on the same topic.

2.3 Innovation

The global capital stock $K^w(t)$ is accumulated through profit seeking R&D. This is performed by perfectly competitive laboratories under constant returns to scale. In the long run ongoing innovation is sustained by knowledge spillovers that increase the productivity of researchers as knowledge accumulates.

Martin and Ottaviano (1999, 2001) highlight two main channels through which firms' location can affect the cost of innovation: localized knowledge spillovers and intermediate business services. A general specification of the R&D technology that encompasses both is the following constant-returns-to-scale production function:

$$\dot{K}(t) = A(t) \left[\frac{D(t)}{\varepsilon} \right]^{\varepsilon} \left[\frac{Q_I(t)}{1-\varepsilon} \right]^{1-\varepsilon} \tag{10}$$

where $\dot{K}(t) = dK(t)/dt$ is the flow of knowledge created at time t, $Q_I(t)$ is labor employed in R&D, and $D(t)$ is the basket of business services. This is assumed to be the same as the consumption basket for analytical convenience. Then, $0 < \varepsilon < 1$ is the share of business services in R&D production. The term $A(t)$ is total factor productivity in R&D, which is affected by knowledge spillovers. In particular, we assume that $A(t) = A\, K^w(t)^{\mu} \left[\omega_N \gamma + \omega_R(1-\gamma)\right]^{\mu}$ where A is a positive constant. Accordingly, $A(t)$ is an increasing function of the global stock of knowledge $K^w(t)$ as embodied in the activities of modern firms. The positive parameter μ measures the intensity of the knowledge spillover. The diffusion of knowledge is, however, hampered by *communication costs* with frictional decay regulated by the ω's. These are positive and smaller than one: ω_N measures the knowledge diffusion from northern firms to northern laboratories while ω_R the knowledge diffusion from southern firms to northern laboratories. The larger the ω's, the better the corresponding communication infrastructure. As in the case of transportation, we assume that communication is more efficient within than between regions and this gap is more pronounced for North:

$$\omega_R < \omega_S < \omega_N$$

The marginal cost associated with the R&D technology (10) is equal to

$$F(t) = \frac{P(t)^{\varepsilon} w^{1-\varepsilon}}{A(t)} = \frac{\eta}{N(t) \left[\omega_N \gamma(t) + \omega_R(1-\gamma(t))\right]^{1-\frac{\varepsilon}{\sigma-1}} \left[\delta_N \gamma(t) + \delta_R(1-\gamma(t))\right]^{\frac{\varepsilon}{\sigma-1}}} \tag{11}$$

where $\eta = p^{\varepsilon}/A$ is a positive constant and we have used (9) as well as the fact that the equilibrium wage equals one. We have also constrained parameters so that in the long run the spatial economy develops along a balanced growth path, namely $\mu + \varepsilon/(\sigma-1) = 1$. This ensures that the marginal cost of innovation decreases through time at the same rate as its benefit as expressed by the value of (newly created) firms, thus preserving the incentive to invest in R&D (more on this in Section 4).

As we will verify, thanks to its better local transport infrastructure, North is the larger market. Given the rankings of ω's and δ's, (11) implies that the marginal cost of innovation is lower there. Therefore, given perfect competition in R&D, in equilibrium North will attract all laboratories, so that long-run growth will be entirely driven by northern innovation.[5] Innovation in our model will be nonetheless financed in a global capital market by both northern and southern workers,

[5] In principle, it is possible to imagine alternative configurations for transportation and communication costs. For example, Hirose and Yamamoto (2007) set $\varepsilon = 0$, and $\delta_S = \delta_N = \omega_S = \omega_N = 1$. They also allow for asymmetric interregional communication costs. For instance, firms in South may benefit more than firms in North from interregional knowledge spillovers. If this advantage in absorptive capacity is strong enough, South (the smaller market) will end up hosting the innovation sector, and this will affect the relations among agglomeration, growth, and regional inequality. However, it can be argued that, even under asymmetric interregional communication costs that favor knowledge absorption in South, allowing $\varepsilon > 0$, as we do in our paper, makes the location of innovation in North more likely.

which implies that in equilibrium the value $v(t)$ of a unit of knowledge capital obeys the following arbitrage condition:

$$r(t) = \frac{\dot{v}(t)}{v(t)} + \frac{\pi(t)}{v(t)} \tag{12}$$

This condition requires the bond yield $r(t)$ to match the percentage return on investment in knowledge capital; which consists of the percentage capital gain $\dot{v}(t)/v(t)$ and the percentage dividend $\pi(t)/v(t)$ as each unit of knowledge gives right to the operating profits of a modern firm. Profit maximization by perfectly competitive labs finally implies that knowledge capital is priced at marginal cost: $v(t) = F(t)$.

3 Growth affects location

In equilibrium the arbitrage condition (12) implies that all firms generate the same operating profits independently from their actual locations. Given (8), that requires all firms to reach the same scale of output, $x(t)$, independently from their locations. Accordingly, using (3) and (7), the market clearing conditions for northern and southern firms can be written as:

$$\begin{aligned} x(t) &= \frac{p^{-\sigma}\delta_N}{P(t)^{1-\sigma}}\left[\alpha E(t)Q + \varepsilon F(t)\dot{N}(t)\right] + \frac{p^{-\sigma}\delta_R}{P^*(t)^{1-\sigma}}\alpha E^*(t)Q \\ x^*(t) &= \frac{p^{-\sigma}\delta_S}{P^*(t)^{1-\sigma}}\alpha E^*(t)Q + \frac{p^{-\sigma}\delta_R}{P(t)^{1-\sigma}}\left[\alpha E(t)Q + \varepsilon F(t)\dot{N}(t)\right] \end{aligned} \tag{13}$$

where variables with an asterisk pertain to South. The asymmetry between the two conditions comes from the fact that the R&D sector is active only in North. Since R&D demands varieties as intermediate business services, northern demand is augmented by intermediate expenditures $\varepsilon F(t)\dot{N}(t)$.

From now on, let us define the growth rate of knowledge capital as $g = \dot{K^w}(t)/K^w(t) = \dot{N}(t)/N(t)$. Moreover, to alleviate notation, let us drop the explicit dependence of variables on time when this does not generate confusion. Then, using (6) and (9), the market clearing conditions (13) can be solved together to yield the implied output scale:

$$x = \frac{\sigma - 1}{\beta\sigma}\frac{2\alpha EQ + \varepsilon FNg}{N} \tag{14}$$

and the associated location of firms

$$\gamma = \frac{1}{2} + \frac{1}{2}\frac{\delta_R\left(\delta_N - \delta_S\right)}{\left(\delta_N - \delta_R\right)\left(\delta_S - \delta_R\right)} + \frac{\delta_N\delta_S - \delta_R^2}{\left(\delta_N - \delta_R\right)\left(\delta_S - \delta_R\right)}\left(\theta - \frac{1}{2}\right) \tag{15}$$

where

$$\theta = \frac{\alpha EQ + \varepsilon FNg}{2\alpha EQ + \varepsilon FNg} \tag{16}$$

is the share of modern sector expenditures accruing to northern firms. Since regions share the same initial endowments, we have also set $E = E^*$. Expression (15) shows that North hosts a larger number of firms because it is larger ($\varepsilon FNg > 0$ implies $\theta > 1/2$) and because it has a better intra-regional transport infrastructure ($\delta_N > \delta_S$). Both effects are amplified by any improvement in the interregional transport infrastructure (larger δ_R). Hence, we have:

Result 1 For a given growth rate, firms are attracted to the region offering larger local demand. Any improvement in the interregional transport infrastructure strengthens such attraction.

Result 2 For a given growth rate, firms are attracted to the region offering better intra-regional transport infrastructure. Any improvement in the interregional transport infrastructure strengthens such attraction.

Moreover, as θ is an increasing function of g, we can also write:

Result 3 For given expenditures, faster growth strengthens the attraction of firms to the region offering larger local demand. Any improvement in the interregional transport infrastructure magnifies such effect.

This shows that *growth affects location*. In particular, agglomeration is an increasing function of the growth rate.

4 Location affects growth

To characterize the long-run growth of the economy, we focus on a balanced path along which expenditures as well as the growth rate are constant. With constant expenditures, $\dot{E} = 0$ so that (5) gives $r = \rho$. Since, by (11) and (15), also FN and γ are constant, the evolution of the value of knowledge capital is driven by the growth rate through the implied change in the marginal cost of R&D, $\dot{v}/v = \dot{F}/F = -g$, which shows that the marginal cost (F) and the marginal benefits of innovation (v) both fall at the same costant rate. Then, by (8) and (14), the arbitrage condition (12) can be rewritten as

$$\rho = -g + \frac{2\alpha EQ + \varepsilon FNg}{\sigma FN} = \frac{2\alpha EQ}{\sigma FN} - g\left(\frac{\sigma - \varepsilon}{\sigma}\right) \tag{17}$$

The model is closed by imposing the labor market clearing condition whereby the global endowment of labor $2Q$ is fully employed in innovation $Q_I = (1-\varepsilon)FNg$, in modern production $Q_D = [(\sigma - 1)/\sigma][2\alpha EQ + \varepsilon FNg]$, and in traditional production $Q_Y = 2(1-\alpha)EQ$. Simplification leads to the full employment condition:

$$2Q = \frac{\sigma - \varepsilon}{\sigma} FNg + 2\frac{\sigma - \alpha}{\sigma} EQ \tag{18}$$

Solving (17) together with (18) shows that in equilibrium expenditures equal permanent income:

$$2EQ = 2Q + \rho FN \tag{19}$$

where $2Q$ is labor income and ρFN is the additional income from ('annuity value' of) the initial stock of knowledge capital. Accordingly, both terms on the right hand side of (19) are evenly split between regions.[6]

By (17) or (18) the corresponding growth rate is

$$g = \frac{\alpha}{\sigma - \varepsilon}\frac{2Q}{FN} - \rho\frac{\sigma - \alpha}{\sigma - \varepsilon} \tag{20}$$

which shows that *location affects growth* through the cost of innovation FN.[7] In particular, given (11), more agglomeration in North makes innovation cheaper and leads to faster growth. The more so, the better northern infrastructure is with respect to the interregional one.

Accordingly, we can write that:

Result 4 Further agglomeration in the core region offering better intra-regional transport and communication infrastructure fosters growth.

Moreover, in (20) the growth rate is a function of ε, which measures how much business services matter for R&D with respect to labor. A larger ε has three effects on growth. Two effects are

[6] Since regional incomes are equalized in nominal terms, disparities in real incomes are driven by firm location and different intra-regional transport costs.

[7] FN is the marginal cost of innovation net of the spillover from accumulated knowledge capital.

direct and promote growth. The third is indirect, works through the cost of innovation and is ambiguous in sign. First, if R&D becomes relatively more intensive in business services than in labor, a higher demand for differentiated inputs by the innovation sector increases firms' operating profits. Along a balanced growth path, g accelerates to keep capital markets in equilibrium (see (17)). Second, from the labor market equilibrium, as ε goes up, the number of workers hired in the modern sector is not enough to compensate for those fired in the innovation sector, unless g goes up too (see (18)). Third and last, if business services become more important for R&D, the cost of innovation may rise or not depending on the relative efficiency of communication with respect to transportation (see (11)). For this reason, the overall impact of larger ε on growth is ambiguous.

5 Infrastructure, agglomeration and growth

The equilibrium of the model is fully characterized by expressions (11), (15), (16), (19) and (20). It therefore features complex interactions between changes in location ($\Delta\gamma$) and growth (Δg) filtered through changes in expenditures (ΔE) and R&D costs (ΔFN). These interactions are summarized graphically in Figure 1.

Abstracting from the feedback (16) going from growth, R&D costs and expenditures to location, changes in intra-North and interregional communication infrastructure ($\Delta\omega_N$,$\Delta\omega_R$) affect the diffusion of knowledge (ΔFN). In particular, better intra-North and interregional communication reduces the cost of innovation ($\Delta FN < 0$) and fosters growth ($\Delta g > 0$). Changes in intra-South communication infrastructure ($\Delta\omega_S$) are instead irrelevant as no R&D takes place in South. This does not hold for changes in intra-South transport infrastructure ($\Delta\delta_S$). In particular, any improvement ($\Delta\delta_S > 0$) attracts firms to South ($\Delta\gamma < 0$), which increases the cost of innovation ($\Delta FN > 0$) and slows growth ($\Delta g < 0$). On the other hand, better intra-North and interregional transportation attracts firms to North ($\Delta\gamma > 0$), which decreases the cost of innovation ($\Delta FN < 0$) and fosters growth ($\Delta g > 0$). The overall picture can be gauged by substituting (11) into (20), which allows us to write *growth as function of location*:

$$g = \frac{\alpha}{\sigma-\varepsilon}\frac{2Q}{\eta}\left[\omega_N\gamma + \omega_R(1-\gamma)\right]^{1-\frac{\varepsilon}{\sigma-1}}\left[\delta_N\gamma + \delta_R(1-\gamma)\right]^{\frac{\varepsilon}{\sigma-1}} - \rho\frac{\sigma-\alpha}{\sigma-\varepsilon} \tag{21}$$

Turning to the feedback, (16) implies that changes in the cost of innovation (ΔFN), growth (Δg) and expenditures (ΔE) affect the share of northern demand ($\Delta\theta$) and thus firms' location ($\Delta\gamma$). Specifically, using (19) and (20), the share of northern demand (16) can be rewritten as

$$\theta = \frac{1}{2} + \frac{1}{2}\frac{\varepsilon}{\sigma}\frac{g}{g+\rho} \tag{22}$$

and, hence, (15) as:

$$\gamma = \frac{1}{2} + \frac{1}{2}\frac{\delta_R\left(\delta_N-\delta_S\right)}{\left(\delta_N-\delta_R\right)\left(\delta_S-\delta_R\right)} + \frac{1}{2}\frac{\delta_N\delta_S-\delta_R^2}{\left(\delta_N-\delta_R\right)\left(\delta_S-\delta_R\right)}\frac{\varepsilon}{\sigma}\frac{g}{g+\rho} \tag{23}$$

which shows *location as a function of growth* through its influence on the share of expenditures.

The foregoing expressions highlight the crucial result of our NEG framework: *there is 'circular causation' between agglomeration* (larger γ) *and growth* (larger g). As growth fosters agglomeration and agglomeration fosters growth, policy makers face a trade-off between promoting growth and challenging regional inequality. Given Results 1 and 2, the implication is:

Result 5 Policies designed to improve interregional and intra-core infrastructure foster agglomeration in the core region as well as growth. Policies designed to improve intra-periphery infrastructure foster relocation from the core to the peripheral regions but hamper growth.

Expression (23) also shows that the feedback from growth to agglomeration gets stronger the more R&D relies on business services (the larger ε). By (21), the impact of ε on the effect of agglomeration on growth is, instead, ambiguous.

Finally, taken together, (21) and (23) implicitly define the equilibrium values of g and γ along the balanced growth path. As both are highly non linear, they are not amenable to explicit analytical solution. One way to gain extra analytical insight is to focus on the two scenarios analyzed by Martin and Ottaviano (1999) and Martin and Ottaviano (2001). These can be retrieved from our framework as specific polar cases that arise when the cost of innovation is respectively affected by communication costs only ($\varepsilon = 0$) and by transport costs only ($\varepsilon = \sigma - 1$).

5.1 Communication costs

When $\varepsilon = 0$, the cost of innovation does not depend on transport costs as business services are not used in R&D. Accordingly, (11) becomes simply:

$$FN = \frac{\eta}{\omega_N \gamma + \omega_R (1-\gamma)} \tag{24}$$

In this case, since by (23) the expenditure share is the same in both regions ($\theta = 1/2$), *location is unaffected by growth*:

$$\gamma = \frac{1}{2} + \frac{1}{2} \frac{\delta_R \left(\delta_N - \delta_S\right)}{\left(\delta_N - \delta_R\right)\left(\delta_S - \delta_R\right)} \tag{25}$$

where $\delta_N / \left(\delta_N - \delta_R\right) > \delta_R / (\delta_S - \delta_R)$ has to be imposed to concentrate on the meaningful case in which at least some firms locate in South.

On the contrary, growth is affected by location as (20), (24) and (25) together imply

$$g = \frac{\alpha}{\sigma} \frac{Q}{\eta} \left[(\omega_N + \omega_R) + (\omega_N - \omega_R) \frac{\delta_R \left(\delta_N - \delta_S\right)}{\left(\delta_N - \delta_R\right)\left(\delta_S - \delta_R\right)} \right] - \rho \frac{\sigma - \alpha}{\sigma} \tag{26}$$

Hence, by inspection of (26), we get:

Result 6 When the cost of innovation is affected by communication costs only, improved communication infrastructure within the core region fosters growth and has no impact on agglomeration. The same applies to improved interregional communication. Differently, improved communication within the peripheral region has no impact whatsoever as long as no innovation takes place there. Changes in transport infrastructure affect location but have no impact on growth.

5.2 Transportation costs

When $\varepsilon = \sigma - 1$, the cost of innovation is affected by transport costs but not by communication costs. In this case knowledge spillovers are 'global' since all laboratories benefit from the global stock of knowledge capital in the same way independently from their actual locations. Expressions (11) and (22) respectively become:

$$FN = \frac{\eta}{\delta_N \gamma + \delta_R (1-\gamma)} \tag{27}$$

$$\gamma = \frac{1}{2} + \frac{1}{2} \frac{\delta_R \left(\delta_N - \delta_S\right)}{\left(\delta_N - \delta_R\right)\left(\delta_S - \delta_R\right)} + \frac{1}{2} \frac{\delta_N \delta_S - \delta_R^2}{\left(\delta_N - \delta_R\right)\left(\delta_S - \delta_R\right)} \frac{\sigma - 1}{\sigma} \frac{g}{g + \rho} \tag{28}$$

which shows that, even with global spillovers, when R&D uses business services, *location is affected by growth.* On the other hand, setting $\varepsilon = \sigma - 1$ in (21) also shows that location affects growth:

$$g = \alpha \frac{2Q}{\eta} \left[\delta_N \gamma + \delta_R (1-\gamma) \right] - \rho \left(\sigma - \alpha\right) \tag{29}$$

The two conditions (28) and (29) can be respectively visualized as a concave and a linear increasing functions mapping from g to γ. To see this, simply invert (29) to express γ as a function of g:

$$\gamma = \frac{g + \rho(\sigma - \alpha)}{2 \frac{\alpha}{\eta} Q (\delta_N - \delta_R)} - \frac{\delta_R}{\delta_N - \delta_R} \tag{30}$$

An increase in δ_S has no impact on (30) as no R&D takes place in South. Instead, it shifts (28) downwards, which reduces agglomeration and growth. Moreover, most naturally, what we proved in the general case also holds in this specific case: increases in δ_N and δ_R foster both agglomeration and growth. Hence, we can write:

Result 7 When the cost of innovation is affected by transport costs only, improved transportation infrastructure within the core region and between regions fosters agglomeration and growth whereas improved transportation infrastructure in the periphery hampers them. Changes in communication infrastructure have no impact whatsoever.

6 Conclusion

We have proposed a simple theoretical framework to study the impact of infrastructure on economic growth and regional unbalances. The framework has presented in a unified way the main insights of NEG models with endogenous growth and free capital mobility. Two main results stand out. First, there is a *trade off between growth and regional equality* as improved infrastructure in developed 'core' regions fosters both agglomeration and growth, which are instead hampered by improved infrastructure in developing 'peripheral' regions. Second, *better interregional connections may increase rather than decrease regional inequality* as improved transport and communication infrastructure between core and peripheral regions fosters not only growth but also agglomeration. These insights are confirmed by Fujita and Thisse (2003) when also labor is mobile. These authors stress the fact that increased agglomeration does not necessarily imply the impoverishment of peripheral regions as long as its positive impact on growth is strong enough.

Two caveats are in order. On the one hand, our results hold no matter whether improvements involve transportation or communication. This equivalence does not survive the introduction of barriers to capital mobility. In that case, Baldwin et al (2001) show that improved transportation increases whereas improved communication decreases regional inequality. On the other hand, as suggested by Fujita and Mori (2005), endogenous growth theories embodied in NEG have so far assumed some kind of ad-hoc knowledge spillovers or externalities without providing their microfoundations. Our framework is no exception and that issue surely deserves further attention by future research.

References

[1] Aschauer D. (1989) Is Public Expenditure Productive? Journal of Monetary Economics 23, 177-200.

[2] Baldwin R., Martin P., Ottaviano G.I.P. (2001) Global Income Divergence, Trade and Industrialization: The Geography of Growth Take-Off. Journal of Economic Growth 6, 5-37.

[3] Baldwin R., Forslid R., Martin P., Ottaviano G.I.P., Robert-Nicoud F. (2003) Economic Geography and Public Policy. Princeton: Princeton University Press.

[4] Baldwin R., Martin P. (2004) Agglomeration and regional growth, in J. V. Henderson and J.-F. Thisse, eds., Handbook of Urban and Regional Economics, Volume 4. New York: North Holland.

[5] Brenneman A., Kerf M. (2002) Infrastructure and Poverty Linkages: A Literature Review. The World Bank, Mimeo.

[6] Calderon C.A., Serven L. (2003) The Output Cost of Latin America's Infrastructure Gap, in W. Easterly and L. Serven, eds., The Limits of Stabilization: Infrastructure, Public Deficits, and Growth in Latin America. Stanford: Stanford University Press and the World Bank.

[7] Calderon C.A., Serven L. (2004) The Effects of Infrastructure Development on Growth and Income Distribution. World Bank Policy Research Working Paper No. 3400.

[8] Devarajan S., Swaroop V., Zhou H. (1996) The Composition of Public Expenditure and Economic Growth. Journal of Monetary Economics 37, 313-44.

[9] Easterly W. (2001) The Lost Decade: Developing Countries' Stagnation in Spite of Policy Reform. The World Bank, Mimeo.

[10] Easterly W., Rebelo S. (1993) Fiscal Policy and Economic Growth: An Empirical Investigation. Journal of Monetary Economics 32, 417-58.

[11] Esfahani H., Ramirez M.T. (2002) Institutions, Infrastructure and Economic Growth. Journal of Development Economics 70, 443–77.

[12] Estache A. (2003) On Latin America's Infrastructure Privatization and its Distributional Effects. The World Bank, Mimeo.

[13] Fujita M., Mori T. (2005) Frontiers of the New Economic Geography. Papers in Regional Science 84, 377-405.

[14] Fujita M., Thisse J.-F. (2002) Economics of Agglomeration. Cambridge: Cambridge University Press.

[15] Fujita M., Thisse J.-F. (2003) Does Geographical Agglomeration Foster Economic Growth? And Who Gains and Loses from It? Japanese Economic Review 54, 121-145.

[16] Fujita M., Krugman P., Venables A. (1999) The Spatial Economy. Cambridge MA: MIT Press.

[17] Gannon C., Liu Z. (1997) Poverty and Transport. The World Bank, Mimeo.

[18] Gramlich E. (1994) Infrastructure Investment: A Review Essay. Journal of Economic Literature 32, 1176–96.

[19] Hirose K., Yamamoto K. (2007) Knowledge Spillovers, Location of Industry, and Endogenous Growth. Annals of Regional Science 41, 17-30.

[20] Hulten C. (1996) Infrastructure Capital and Economic Growth: How Well You Use It May Be More Important than How Much You Have. NBER Working Paper 5847.

[21] Kilkenny M. (1998) Transport Costs and Rural Development. Journal of Regional Science 38, 293-312.

[22] Loayza N., Fajnzylber P., Calderon C. (2003) Economic Growth in Latin America and the Caribbean: Stylized Facts, Explanations and Forecasts. The World Bank, Mimeo.

[23] Martin P., Ottaviano G.I.P. (1999) Growing Locations: Industry Location in a Model of Endogenous Growth. European Economic Review 43, 281-302.

[24] Martin P., Ottaviano G.I.P. (2001) Growth and Agglomeration. International Economic Review 42, 947-968.

[25] Röller L-H., Waverman L. (2001). Telecommunications Infrastructure and Economic Development: A Simultaneous Approach. American Economic Review 91, 909–23.

[26] Sanchez-Robles B. (1998). Infrastructure Investment and Growth: Some Empirical Evidence. Contemporary Economic Policy 16, 98-108.

[27] Sugolov P., Dodonov B., von Hirschhausen C. (2003) Infrastructure Policies and Economic Development in East European Transition Countries: First Evidence. DIW Berlin WP-PSM-02.

[28] World Bank (1994) World Development Report. Washington DC: The World Bank.

[29] World Bank (2003) Inequality in Latin America and the Caribbean. Washington DC: World Bank Latin American and Caribbean Studies.

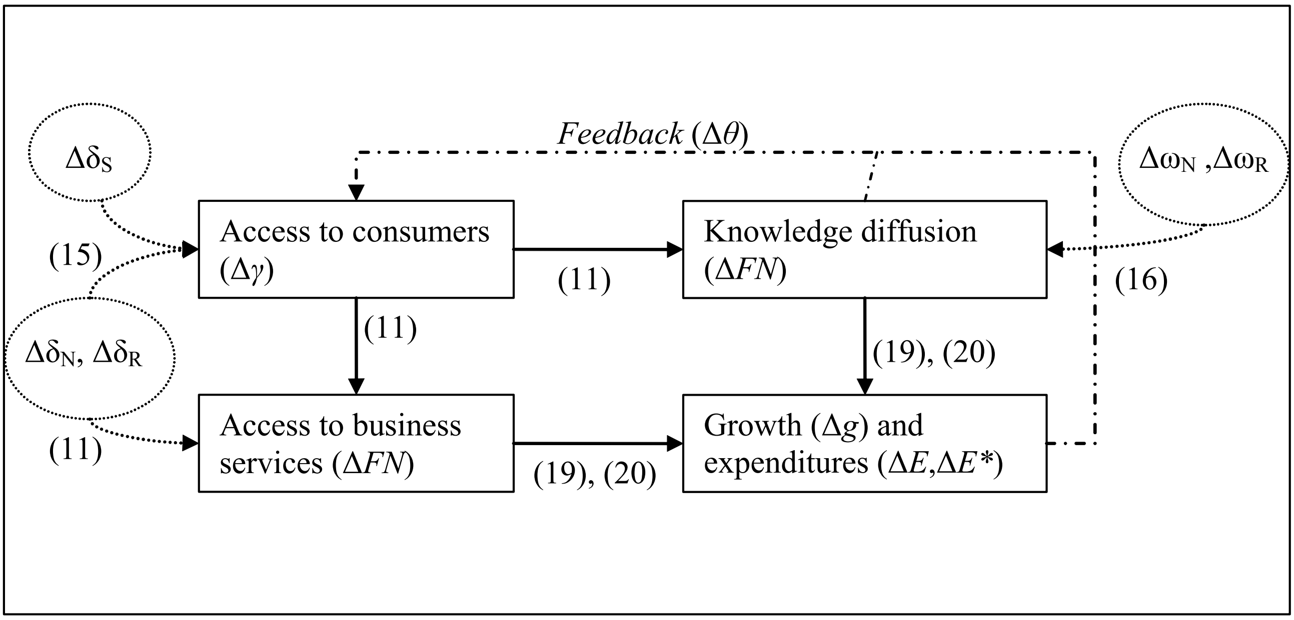

Figure 1: Infrastructure, location and growth