Agglomeration Economies and Spatial Sustainability

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ABSTRACT

This paper illustrates how welfare analysis can clarify the spatial dimension of environmentally sustainable development. For this purpose the interplay between three determinants of spatial sustainability is examined, namely agglomeration effects, environmental externalities, and trade advantages. This is accomplished by formulating a dynamic general equilibrium model for alternative configurations of a two-region economy *à la* Dixit-Stiglitz and Krugman. The model incorporates the following elements: (i) a distinction between form and size of a spatially distributed economy, (ii) migration in response to differences in regional welfare, and (iii) the impact of pollution assimilative capacity on the sustainability of economic equilibria. We use the model to examine long-run spatial-economic equilibria under different settings for the three determinants of spatial sustainability, and derive a ranking of spatial configurations according to their performance in terms of sustainability and global welfare. The existence of welfare-offsetting effects between the three determinants of spatial sustainability is relevant to sustainability policies, as these are expected to affect location behavior of firms and employees, and indirectly the long-run spatial development of the economy.

Keywords: Environmental policy, Location choice, Pollution assimilation, Spatial configurations, Trade advantages, Urban and regional economies.

JEL classification: D62, F12, Q56, R12.

1. INTRODUCTION

In spite of repeated and widely supported claims for international action to enhance sustainable development, the actual implementation of it has been slow and far from complete. An important reason is the difficulty to translate the general and arguably vague notion of sustainable development into concrete principles and actions at local, regional and national levels, where governance is most concrete and effective (OECD, 2007). This is partly due to analyses of sustainable development lacking systematic attention for spatial dimensions, such as land use, transport, regional and urban development, international trade and various spatial and trade policies. An adequate treatment of spatial sustainability involves a combination of dynamic, spatial and economic model components. A natural way to operationalize this is to adopt a system of regions and trade relations. The lack of such a framework has already been recognized in the literature on sustainable development, and some conceptual starting points are available (van den Bergh and Verbruggen, 1999; Verhoef and Nijkamp, 2002).

This paper presents a theoretical framework and analysis of the impact of the spatial configuration of economic activities (agriculture and industry), employees and consumers on the (un)sustainability of the economy in the long run. In this context, we make use of the concept of 'spatial sustainability', reflecting a spatial configuration and spatial dynamics of local production and consumption activities that is consistent with environmental sustainability. The proposed formal spatial-economic model uses a general equilibrium approach to integrate three important factors of influence on both welfare and (un)sustainability, namely agglomeration economies, advantages of international or interregional trade, and environmental externalities at regional as well as global scales. We then study the long-run welfare and sustainability consequences of the interaction between consumption, production, positive agglomeration externalities, and negative environmental externalities in terms of location behavior by individuals and firms, for alternative spatial configurations of the world economy. Two possible spatial structures for each region are identified, characterized by the spatial distribution of manufacturing activities (or in a broader sense, the built-up environment) and land uses, namely agricultural and non-productive (nature-dominated) land. One spatial regional structure describes an urban agglomeration of manufacturing activities, and a second a spread-out structure. We consider a two-region system which then leads to three possible spatial configurations of the economy, as shown in Figure 1.[1]

The model presented is an extension of Grazi *et al.* (2007), who focused on a (relatively) short-run equilibrium of the spatial economy. Their model extended the well-known Core-Periphery model by Krugman (1991), which describes agglomeration and trade in a two-region system, with regional and transboundary (global) environmental degradation and with various types of land uses. This

[1] Actually, with the two possible regional structures described, $2^2 = 4$ spatial configurations for the two-region economy are possible. However, two of these are each other's (spatial) mirror images.

model assumes a given homogenous population distribution across regions for each spatial configuration. Regions are thus identical in terms of the endowment of the two primary input factors, namely human capital and unskilled labor. By following Forslid and Ottaviano's (2003) assumption on labor skill heterogeneity, the model was solved analytically and subsequently used to derive a performance ranking of spatial configurations on the basis of social welfare and an influential (though debated) environmental indicator, namely the ecological footprint.

The current study aims to examine the interaction between individuals' location behavior, spatial patterns of development, and patterns of trade when environmental sustainability is accounted for. To achieve this, we extend the model by Grazi *et al.* (2007) with dynamic features, which will allow us to generate information about long-term aspects of sustainable development. This requires attention for dynamic aspects of land use, environmental damage, location decisions, and trade. These aspects enter the model through dynamics mechanisms that account for factor mobility, long-run trade patterns, and constraints on future emissions. As a result, the economy can include an uneven spatial distribution of the population and safe levels of pollution in the long term. The model allows us to examine spatial sustainability of the economy in a thorough manner. Spatial sustainability depends on both the form (agglomeration or spread-out pattern) and the regional concentration (size) of the population and economy, as these will affect the level of negative, environmental externalities.

In addition to studying spatial sustainability drivers like population migration and environmental dynamics, we depart from the earlier work in three main ways. First, we study the influence of the parameter that captures the agglomeration effect on the short- and long-term structure of the spatial economy. This is relevant as agglomeration types of spillover effects (or positive externalities) have been recognized in the economic literature on trade theory and urban economics since Marshall and Chamberlin but their formal representation has turned out to be difficult and controversial (Ciccone, 2002). Second, we decompose the influence of the environmental externalities to (un)sustainable location decisions by economic agents in the long term into externalities associated with domestic production and with international trade. Finally, the response of individual welfare to different degrees of environmental pressure intensity is examined.

The reminder of this paper is organized as follows. In Section 2 we provide information on the structure of the two-region economy with agglomeration economies, environmental externalities and trade, and extend the basic model with migration and environmental dynamics. Section 3 is devoted to deriving long-run spatial equilibria under the condition of environmental sustainability, and examines the combined effect of positive (agglomeration, trade advantages) and negative (environmental) externalities on long-run welfare. Section 4 tests the robustness of the model findings by performing comparative statics and sensitivity analyses. Section 5 concludes.

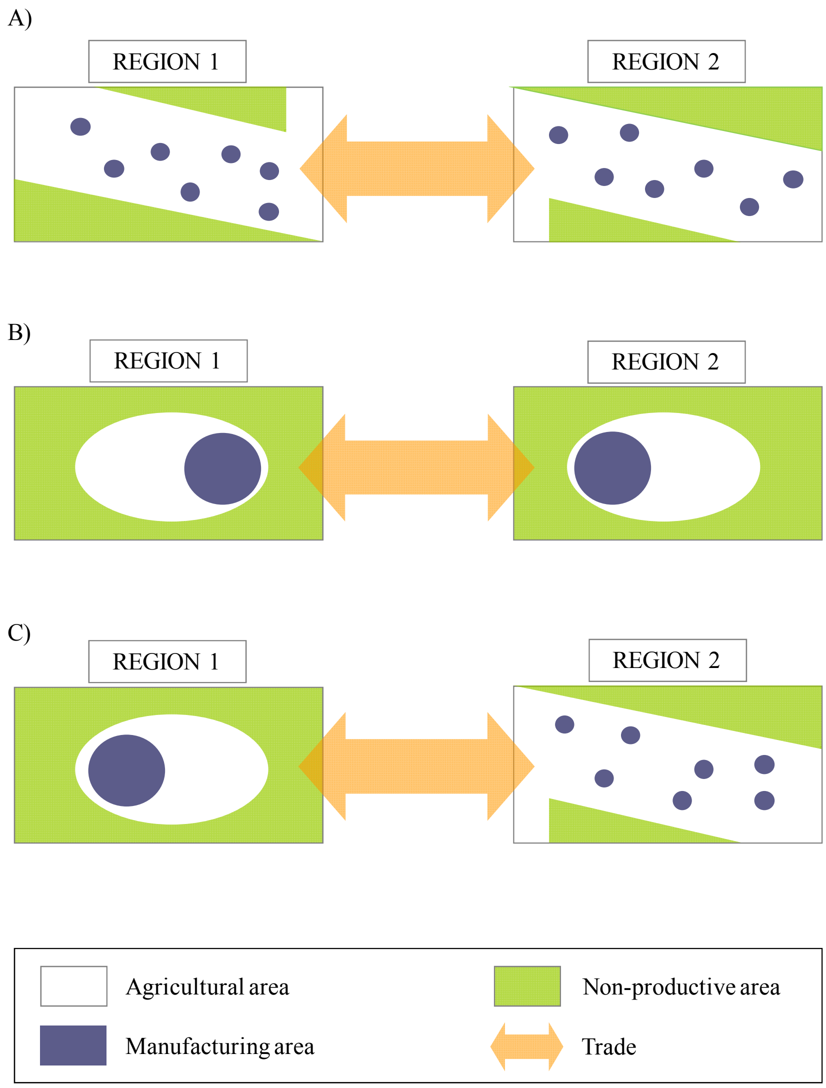

FIGURE 1. *A schematic representation of the spatial configurations*

2. THE SPATIAL ECONOMY

2.1. The baseline model

Here we first briefly sketch the core model of Grazi *et al.* (2007), make a few changes, and then extend it in section 2.2. Note that the original model contained a land use module (Grazi *et al.*, 2007, Section 3.4). This is omitted here as it is not required for the current analysis.

The model describes a global economy consisting of two regions (labeled $j = 1,2$) and two production sectors. One is a manufacturing sector, *M*, which produces a continuum of *n* varieties of a horizontally differentiated good through mobile human capital *H* and immobile unskilled labor *L* as input factors; the second one is the food sector *F* producing agricultural goods with unskilled force. *M* is characterized by increasing returns and monopolistic competition *à la* Dixit and Stiglitz (1977). *F* produces under Walrasian conditions (constant returns to scale and perfect competition). Food is the *numéraire* good (*i.e.* its price is set at unity). At any time, any $i \in N = n_1 + n_2$ variety can be traded between the two regions by assuming the well-known iceberg structure for transport costs (Samuelson, 1952): $T_{1,2} > 1$ and is the same in both directions, *i.e.* $T = T_{1,2} = T_{2,1}$. Conversely, food can be freely traded across regions. Transportation costs are zero for intraregional shipment of both goods. Each firm produces one variety of the good: *N* is then the total amount of active firms in the two-region economy, while n_j is the total amount of firms operating in region *j*, as well as the amount of variety domestically available. $L = L_1 + L_2$ and $H = H_1 + H_2$ denote the total available amount of unskilled and skilled laborers, respectively. Unskilled workers are assumed to be evenly spread across regions, such that $L_j = L/2$ and each worker supplies one unit of labor.

Short-run equilibrium

Workers maximize utility through consumption of the two goods. Aggregate utility is a Cobb-Douglas function of consumption of the agricultural commodity *F* and consumption of the aggregate manufactured good *M*. The latter in turn is modeled as a CES function of consumption levels $c_{jj}(i)$ and $c_{jk}(i)$ of a particular variety *i* of the manufactured good that is sold in region *j*, and produced in regions *j* and *k*, respectively.[2] In addition, utility is calculated net of environmental external effects associated with transport *T* and domestic and global production, captured by (E_j) and (E), respectively.

$$U_j = F_j^{(1-\delta)} M_j^{\delta} \left[1 + \left(E_j + E\right)\right]^{-\theta}, \text{ with}$$

$$M_j = \left[\int_{i=0}^{n_j} c_{jj}(i)^{(\varepsilon-1)/\varepsilon} di + \int_{i=0}^{n_k} c_{kj}(i)^{(\varepsilon-1)/\varepsilon} di \right]^{\frac{\varepsilon}{\varepsilon-1}} ; j,k = \{1,2\}, j \neq k;\ i \in N. \tag{1}$$

Here $0 < \delta < 1$ is the share of income Y_j spent on manufactures, $\varepsilon > 1$ is the elasticity of substitution between goods, and $\theta > 0$ represents the intensity of the environmental externality affecting individuals' utility.

Note that this deviates from Grazi *et al.* (2007), where the environmental parameter θ could take a zero value or no environmental impact on individual welfare. Here we perform a different type of analysis so as to address sustainability in a dynamic setting. Pollutive emissions are assumed to always affect decisions by individuals, in both the short and long term.

Manufacturing firms produce using both labor factors, *L* and *H*, as input factors. Workers are hired at a domestic wage rate w_j. The cost structure of a typical *j*-firm entails fixed costs in human capital, αw_j, and variable costs in unskilled labor per unit of output, $\beta_j x_j$:

$$\chi_j = \alpha w_j + \beta_j x_j. \tag{2}$$

As in Grazi *et al.* (2007), the parameter β_j captures the *j*-specific agglomeration effect. At lower values, it represents positive externalities of production activities, while for higher values, production

[2] For ease of notation and without loss of generality we drop the index *i* for varieties in the remainder of the paper.

costs increase due to the spreading market effect (Fujita *et al.*, 1999). Given the relevance of the agglomeration parameter in determining the economy's supply set-up, we discuss numerical values for β_j (see sub-section 2.3., below).

Production of food is a linear function of labor. Given that $\beta_j n_j x_j$ unskilled workers are employed in manufacturing production (see eq. (2)), the domestic supply of food is:

$$F_j = L/2 - n_j \beta_j x_j \tag{3}$$

For a given regional distribution of the skilled labor factor H_j the short-run model is determined by a set of four equations:

$$Y_j = w_j H_j + L/2 \tag{4}$$

Here Y_j is the income generated in each region j by w_j, the wage rate of skilled workers H_j, and the *numéraire* wage of unskilled workers $L_j = L/2$.[3]

$$n_j = \frac{H_j}{\alpha}. \tag{5}$$

Here a fixed input requirement α implies proportionality of the total amount of firms operating in region j, n_j, to locally available skilled laborers.

$$w_j = \frac{\beta_j x_j}{\alpha(\varepsilon - 1)} \tag{6}$$

Here w_j is the equilibrium wage rate.

$$x_j = \delta \left[\frac{(\varepsilon - 1)}{\beta_j \varepsilon} \right]^{\varepsilon} \left(\frac{Y_j}{I_j^{1-\varepsilon}} + \frac{\phi Y_k}{I_k^{1-\varepsilon}} \right), \text{ with}$$
$$I_j = \frac{\varepsilon}{\varepsilon - 1} \left(n_j \beta_j^{1-\varepsilon} + \phi n_k \beta_k^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}}; j,k = \{1,2\}; j \neq k. \tag{7}$$

Here x_j is the market-clearing size of a typical firm in equilibrium, I_j is the price index of a j-firm in equilibrium, and $\phi = T^{1-\varepsilon}$ is a variable representing the openness to trade, defined as the reciprocal of the transport cost T. For $\phi = 0$, barriers to interregional trade are maximal and lead to autarky, while $\phi = 1$ represents free trade across regions.

By combining equations (4), (5), (6), and (7) the model can be analytically solved (for details see Grazi *et al.*, 2007):

$$w_j = \frac{\delta/\varepsilon}{1-(\delta/\varepsilon)} \frac{L}{2} \frac{2\phi \beta_j^{2(1-\varepsilon)} H_j + \left[1-(\delta/\varepsilon)+(1+(\delta/\varepsilon))\phi^2\right]\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon} H_k}{\phi\left(H_j^2 \beta_j^{2(1-\varepsilon)} + H_k^2 \beta_k^{2(1-\varepsilon)}\right) + \left[1-(\delta/\varepsilon)+(1+(\delta/\varepsilon))\phi^2\right]\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon} H_j H_k} \tag{8}$$

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[3] This is a consequence of assuming free trade for the agricultural good F, whose price is thus equalized to 1 across regions: $p_j^F = p_k^F = 1$, with $j,k = (1,2), j \neq k$. Marginal cost pricing implies then interregional equalization of the wages of unskilled labor input L used in the food sector: $p_j^F = w_j^L = 1$, with $j = (1,2)$.

Environmental externalities and welfare

Transboundary environmental externalities are generated jointly with production and trade of goods:

$$E_j = m\left[a\left(n_j x_j\right) + b\left(F_j\right) + d\left(\frac{Tc_{jk} + Tc_{kj}}{2}\right)\right], \text{ with } a,b,d > 0 \tag{9}$$

Here m is a constant and a,b,d represent the intensity of externalities generated by manufacture M_j, food supply F_j and trade Tc_{jk}, respectively. The expression for domestic consumption of traded goods c_{kj} comes from standard utility maximization in (1), as follows:

$$c_{kj} = \frac{\delta Y_j}{n_j \beta_j^{1-\varepsilon} + \phi n_k \beta_k^{1-\varepsilon}} \tag{10}$$

Note that the expression for externalities in (9) deviates from Grazi *et al.* (2007), where a multiplicative functional form is used. The choice of additive factors is motivated by the need to address environmental externalities deriving from trade and food production, even in the case of absence of domestic industrial production ($n_j = 0$), as this is a possible outcome of long-term location choices by firms and individuals. In the previous study that focused on short-term spatial setting of the world economy, a fraction of domestic industrial production was always present ($n_j > 0$) to address environmental externalities ($E_j > 0$).

The negative externality E alters individuals' welfare at regional and global scales through the utility function (eq. (1)). We note E_j and E to distinguish regional from global externalities, respectively. Global and domestic externalities are linked as follows: $E = \sum_j E_j$.

Finally, aggregate global social welfare is derived as a weighted geometric mean of the j-utility in (1), the weights being region's population size:

$$W = \left[U_j^{\left(H_j + L_j\right)} U_k^{\left(H_k + L_k\right)}\right]^{\frac{1}{H+L}} \tag{11}$$

2.2. Dynamic extension of the basic model

Here we extend the model so as to address long-term impacts of different spatial configurations of the economy, in terms of sustainability and global and regional welfare. For this reason we include two important dynamic mechanisms, namely migration (interregional factor mobility) and environmental dynamics (accumulation and assimilation of environmental pollution). The two mechanisms interact since welfare differences induced by environmental (un)sustainability may contribute to interregional migration flows.

Factor mobility is the result of migration of skilled workers over 'time'. The model variable that can capture this type of dynamics is the share of skilled workers living in region 1 defined by:

$$h = H_1 / H \tag{12}$$

Skilled workers are assumed to migrate in response to expectations about higher well-being in another region, or more generally due to differences in well-being between the two regions. We define the indirect utility differential between region 1 and 2 (given equation 1) as $\Omega(h,\phi)=V_1(h,\phi)-V_2(h,\phi)$, where indirect utility V_j is specified as:

$$V_j(h,\phi)=\Gamma\frac{w_j(h,\phi)}{I_j^{\delta}(h,\phi)}\left[1+E(h,\phi)+E_j(h,\phi)\right]^{-\theta},\ \text{ with }\ \Gamma=\delta^{\delta}(1-\delta)^{1-\delta};\ j=(1,2)\,. \tag{13}$$

Here Γ is a constant that relates individuals' indirect utility to the utility in (1) through the share of income devoted to manufacturing good purchases, *δ*.

In the long-run model all the variables are expressed as a function of the endogenous variable *h*, and of parameters and exogenous variables: $\delta,\ \varepsilon,\ \beta_j,\ \beta_k,\ L,\ H$. The study of long-run behavior of the central variables of the model is carried out for different values of the parameter ϕ, which stimulates us to consider wage, price index, emissions, indirect utility, etc. as functions of *h* and ϕ, and to denote them as: $w_j(h,\phi), I_j(h,\phi), E_j(h,\phi)$ and $V_j(h,\phi)$,

Substituting 13 in the indirect utility differential $\Omega(h,\phi)$ gives the following derived relation, which represents the incentive to move from region 2 to region 1:

$$\Omega(h,\phi)=\Gamma\left[\frac{w_1(h,\phi)}{I_1^{\delta}(h,\phi)}\left(1+E(h,\phi)+E_1(h,\phi)\right)^{-\theta}-\frac{w_2(h,\phi)}{I_2^{\delta}(h,\phi)}\left(1+E(h,\phi)+E_2(h,\phi)\right)^{-\theta}\right]. \tag{14}$$

Given $h\in[0,1]$, the equation describing the dynamics of factor mobility can be expressed as follows:[4]

$$\frac{dh}{dt}=\begin{cases}\Omega(h,\phi) & \text{if } 0<h<1\\ \max\left(0,\Omega(h,\phi)\right) & \text{if } h=0\\ \min\left(0,\Omega(h,\phi)\right) & \text{if } h=1\end{cases}. \tag{15}$$

Clearly, a long-run spatial equilibrium is defined by condition:

$$\frac{dh}{dt}=0. \tag{16}$$

An equilibrium as defined by (16) is always stable if it is a corner configuration ($h=0$, or $h=1$), while an interior equilibrium ($0<h<1$) is stable only if $\frac{\partial\Omega}{\partial h}(h,\phi)\le 0$ (Forslid and Ottaviano, 2003). Hereafter, we only consider long-run equilibria satisfying this stability condition.[5]

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[4] Note that dynamics is implicit-in-time in this type of modeling framework (Krugman, 1991). This allows us to skip the index for time dependence on the variables of the long-run model.

[5] Note that if h is a stable equilibrium for $j=1$ and $k=2$, then $1-h$ is a stable equilibrium for $k=1$ and $j=2$. The symmetry assumption with respect to $h=0.5$ is then valid for all the spatial configurations considered and allows us to narrow the range of values of interest for the study of long-run equilibria to: $0.5\le h\le 1$.

The second dynamic extension concerns a dynamic environmental externality, which we operationalize through specifying the accumulation and assimilation of environmental pollution. We employ a standard equation for this, in which a stock S represents the cumulative pollution due to a flow of pollution $E_j(h,\phi)$ (eq. 9). The stock can decrease because of assimilation (reducing, transforming or buffering) of pollution, captured by the process A. This results in the following dynamic equation for environmental pollution:

$$\frac{dS}{dt} = E(h,\phi) - A. \tag{17}$$

The sustainability of long-run spatial configurations requires non-increasing cumulative pollution in the long term. This is expressed by the condition:

$$\frac{dS}{dt} \leq 0. \tag{18}$$

Recalling that global pollution externalities are defined over the corresponding domestic pollution levels through: $E = \sum_j E_j$ (see subsection 2.1), by using equations (6) and (12) we can re-write the firm's domestic production size in (7) as a function of the regional population share h and trade cost ϕ:

$$x_{j=\{1,2\}} = \begin{cases} x_1(h,\phi) = \dfrac{\alpha(\varepsilon-1)\delta L}{2\beta_1(\varepsilon-\delta)} \dfrac{2\phi\beta_1^{2(1-\varepsilon)}h + \left[1-\frac{\delta}{\varepsilon}+\left(1-\frac{\delta}{\varepsilon}\right)\phi^2\right]\beta_1^{1-\varepsilon}\beta_2^{1-\varepsilon}(1-h)}{\phi\left[\beta_1^{2(1-\varepsilon)}h^2+\beta_2^{2(1-\varepsilon)}(1-h)^2\right]+\left[1-\frac{\delta}{\varepsilon}+\left(1-\frac{\delta}{\varepsilon}\right)\phi^2\right]\beta_1^{1-\varepsilon}\beta_2^{1-\varepsilon}h(1-h)} \\ x_2(h,\phi) = \dfrac{\alpha(\varepsilon-1)\delta L}{2\beta_2(\varepsilon-\delta)} \dfrac{2\phi\beta_2^{2(1-\varepsilon)}(1-h) + \left[1-\frac{\delta}{\varepsilon}+\left(1-\frac{\delta}{\varepsilon}\right)\phi^2\right]\beta_1^{1-\varepsilon}\beta_2^{1-\varepsilon}h}{\phi\left[\beta_1^{2(1-\varepsilon)}h^2+\beta_2^{2(1-\varepsilon)}(1-h)^2\right]+\left[1-\frac{\delta}{\varepsilon}+\left(1-\frac{\delta}{\varepsilon}\right)\phi^2\right]\beta_1^{1-\varepsilon}\beta_2^{1-\varepsilon}h(1-h)} \end{cases} \tag{7bis}$$

Hence, the level of global emissions associated to a set $\{h,\phi\}$ is given by:

$$\begin{aligned} E(h,\phi) = {} & bL\frac{1-\delta}{1-\frac{\delta}{\varepsilon}} + \frac{a}{\alpha}\big(h\,x_1(h,\phi) + (1-h)x_2(h,\phi)\big) + \\ & + \frac{d}{2}\frac{\phi}{\phi^2-1}\left[\phi\big(x_1(h,\phi)+x_2(h,\phi)\big) - \left(\frac{\beta_1}{\beta_2}\right)^{\varepsilon} x_1(h,\phi) - \left(\frac{\beta_2}{\beta_1}\right)^{\varepsilon} x_2(h,\phi)\right] \end{aligned} \tag{19}$$

A sustainable configuration implies non-increasing cumulative pollution over the long term. This is addressed in our dynamic model through fixing a constant assimilation capacity A on global emissions and combining equations (17) and (18) to ensure that for a given configuration the following condition holds:

$$E(h,\phi) \leq A \tag{20}$$

By summarizing the insights from the two dynamics mechanisms in (15) and (20), we are now able to write down the general analytical functional form for the condition of sustainability of long-run spatial configurations of the economic system. For a given spatial configuration and a given assimilation capacity *A*, a certain pattern of population distribution h associated with a trade cost level ϕ defines a sustainable long-run equilibrium if one of the three following conditions is verified:

$$a)\ \begin{cases} h = 0.5 \\ \dfrac{\partial \Omega}{\partial h}(h,\phi) \le 0; \\ E(h,\phi) \le A \end{cases} \quad b)\ \begin{cases} 0.5 < h < 1 \\ \Omega(h,\phi) = 0,\ \dfrac{\partial \Omega}{\partial h}(h,\phi) \le 0\ ; \\ E(h,\phi) \le A \end{cases} \quad c)\ \begin{cases} h = 1 \\ \Omega(h,\phi) \ge 0 \\ E(h,\phi) \le A \end{cases} \tag{21}$$

If condition *a*) in (21) holds, the short-run equilibrium $h = 0.5$ is a sustainable long-run equilibrium for the spatial configuration considered. Clearly, with the global population evenly distributed across regions, the agglomeration effect and environmental pressure become the sole determinants of the economy's spatial structure and the dynamics of population migration, independently of any initial domestic endowment of production factors. If condition *b* (condition *c*) holds, a partial (full) concentration of skilled workers in region 1 is the sustainable long-run equilibrium. Finally, if none of the three conditions is satisfied, the spatial configuration is always unsustainable, for all possible trade costs and population distributions.

3. LONG-RUN EQUILIBRIA, SPATIAL SUSTAINABILITY, AND GLOBAL WELFARE

Providing insight into the spatial sustainability of regional and global economies requires a description of the long-term dynamics of the economic system considered. This section offers and discusses the outcomes of two types of analysis with the dynamic model developed in Section 2.2. First, we study the sustainability characteristics of the long-run equilibrium by varying the pollution assimilation capacity *A* and the trade parameter ϕ, which, we recall, is the core driver of geography in this type of economic modeling framework.[6] Subsequently, the long-term dynamics of global welfare is investigated for different spatial settings of the economy. This results in a derivation of a performance ranking of the sustainable spatial configurations according to global welfare. We start by discussing the values of the exogenous economic variables and parameters in the numerical analyses.

3.1. Values of model parameters and exogenous variables

In line with Grazi *et al.* (2007), the exogenous variable total unskilled labor availability *L* is set equal to 5. Moreover, since the number of individuals plays no independent role in our model, we normalize the global skilled population to 1, *i.e.* $H = H_1 + H_2 = 1$.

Values of the economic parameter have whenever possible been taken from the literature on spatial and trade economics (*e.g.*, Fujita *et al.*, 1999; Fujita and Thisse, 2002; Bernard *et al.*, 2003).

[6] In the New Economic Geography, transport costs allow one to study the extent to which space matters in affecting economic decisions by individual agents (consumers and producers) and how these decisions in turn drive the spatial distribution of economic activities.

The share of income spent on manufactured goods is set equal to $\delta = 0.4$, and the elasticity of substitution is $\varepsilon = 3$. Since the focus of this paper is on spatial sustainability, a more detailed analysis is required of the parameters that relate to the spatial and environmental dimensions of the model, notably the degree of economic agglomeration and the intensity of the environmental externality effect on individual utility.

The β-agglomeration parameter

As discussed in Section 2, the parameters β_j captures the agglomeration effect in region *j*. We consider spatial configurations where each of the two regions is characterized by a given spatial structure, *i.e.* constant over time, described by parameters β_j. Two types of regional agglomeration are considered: 'agglomerated regions' characterized by $0 < \beta_j < 1$ and 'spread-out regions' for which $\beta_j > 1$. We define a 'symmetric configurations' as characterized by both regions being identical from the agglomeration's point of view, *i.e.* $\beta_j = \beta_k$. In addition, we consider a 'non-symmetric configuration'; in this case, in line with Grazi *et al.* (2007), we set $\beta_j = 0.5$ for an 'agglomerated' region and $\beta_j = 2$ for a 'spread-out' region. Table 1 summarizes the possible combinations of the regional agglomeration parameter values, resulting in three spatial configurations.

TABLE 1.

Values of the agglomeration parameters across the spatial configurations

Spatial configuration	Region 1	Region 2
A (spread-out *vs*. spread-out)	$\beta_1 = 2$	$\beta_2 = 2$
B (agglomeration *vs* agglomeration)	$\beta_1 = 0.5$	$\beta_2 = 0.5$
C (agglomeration *vs*. spread-out)	$\beta_1 = 0.5$	$\beta_2 = 2$

The θ-environmental pressure parameter

As is clear from equation (13), the numerical value chosen for parameter θ influences the long-run equilibrium as indirect utility drives interregional migration of skilled workers. Indeed, high values of θ foster the homogenous distribution $h = 0.5$, whereas low θ-values (close to 0) encourage concentration of production activities (either partial: $0.5 < h < 1$ or full concentration $h = 1$). In the numerical analysis of the sustainability of the long-run spatial equilibria and corresponding welfare values we set $\theta = 0.1$. Such a low value of the environmental parameter is chosen to reflect the initially low influence of pollution externalities in shaping the spatial distribution of production (firms) and consumption (skilled workers) activities. That is to say, location decisions by (myopic) economic agents are assumed to be taken according to benefits from the agglomeration positive externalities, and are only marginally influenced by the negative pollution externalities.

3.2. Sustainable long-run equilibria

The distribution of the population in the stable long-run equilibria defined by condition (16) depends on the spatial configuration and the trade cost ϕ. Figure 2 plots the distribution of the population in the long-run equilibrium for different values of trade costs, for the three spatial configurations.[7]

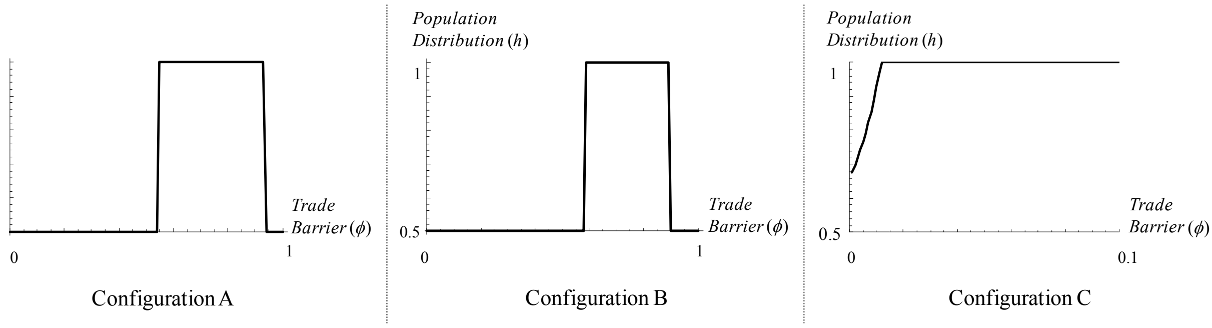

FIGURE 2**.** *The long -run equilibria for the three spatial configurations*

Except for very high trade costs (ϕ-values close to 0), configuration C always involves a full concentration of skilled workers in the agglomerated region. In other words, food production remains the only active sector in the spread-out region in the long run. This results from the advantages firms enjoy by choosing to locate in an agglomerated region, in terms of reduced production costs (see eq. 2). For symmetric configurations A and B, the homogenous distribution of skilled workers in the long run ($h = 0.5$) is preferred in the case of low and high trade costs ϕ. For intermediate ϕ-values (the corresponding value range of which depends on the specific spatial configuration considered), the long-run equilibrium has a full concentration of skilled workers in one region ($h = 1$). These equilibria result from the interplay between forces stimulating the concentration of activities and agents in a single region (reduced production costs due to agglomeration positive externalities and higher wages due to increased productivity) and forces pushing the world economy to homogenously spread across the two regions (higher trade costs and increased local environmental externalities due to more intense industrial activity).

The various equilibria are associated with different total pollutive emissions, and therefore spatial sustainability features. Indeed, for each spatial configuration, a long-run equilibrium identifies a certain regional endowment of production factors (namely, skilled workers), a certain interregional trade flow of goods, and some related regional and global environmental externalities, better identified here as pollution. The sustainability condition in (21) depends on the long-run spatial equilibrium (reflected by the set $\{h,\phi\}$) and on the assimilation capacity.

[7] For configuration C we only show values of ϕ that fall in the domain [0, 0.1], as for values $\phi > 0.1$ $h = 1$. If we would have shown the entire ϕ range [0,1], the details in the range [0, 0.1] would not be discernable.

For a given spatial configuration and a given assimilation capacity *A*, a range of ϕ -values may exist that satisfies the condition for sustainability in (21). We denote $\phi^*(A)$ as the highest of these values (lowest trade cost), which ensures a minimum constraint on the economy in terms of barriers on the intensity of trade activity. Let $\gamma \in \{A,B,C\}$ denote a specific spatial configuration, and $E_{\min}^{\gamma}$ and $E_{\max}^{\gamma}$ the minimum and maximum long-run levels of emissions in the domain over which the assimilation capacity *A* is defined for that configuration. If $A < E_{\min}^{\gamma}$, the level of long-run pollution is always larger than the assimilation capacity *A*, whatever the trade cost ϕ . This means that the spatial configuration considered is always unsustainable. The condition $\phi^*(A) = 0$ expresses unsustainability of the γ configuration.

For all different ranges of *A*-values, spatial sustainability in (21) is defined by the interplay between minimum trade barriers ($\phi^*(A)$), γ-specific pollution emissions (E^{γ}) and assimilation capacity (*A*), as follows:[8]

$$E^{\gamma}\left(h,\phi^*(A)\right) = \min\left(A, E_{\max}^{\gamma}\right) \tag{22}$$

Two cases need to be considered when it comes to assessing the actual value of $\phi^*(A)$. If condition $E_{\min}^{\gamma} < A < E_{\max}^{\gamma}$ holds, the relation in (22) becomes: $E^{\gamma}\left(h,\phi^*(A)\right) = A$. The corresponding solution in $\phi^*(A)$ is such that: $0 < \phi^*(A) < 1$. If, on the other hand, condition $E_{\max}^{\gamma} < A$ holds, the long-run equilibrium for the spatial configuration considered is always sustainable, whatever the value for the trade cost. This is expressed through $\phi^*(A) = 1$.

We now turn to consider the three spatial configurations together and for each of them study the sustainability characteristics of the final long-run spatial equilibrium as a function of the pollution assimilation capacity *A* and the trade parameter ϕ . We narrow the analysis to the range of values of the assimilation capacity *A* not associated with trivial outcomes, that is, for which the spatial configurations are all either never or always sustainable. To do that, we set $A_{\min}$ equal to the minimum value of $E_{\min}^{\gamma}$ across all spatial configurations, such that $A_{\min} = \min_{\gamma \in \{A,B,C\}} E_{\min}^{\gamma}$. For a certain assimilation capacity *A* satisfying the condition $A < A_{\min}$, this implies that $A < E_{\min}^{\gamma}$ for all spatial configurations. Moreover, we define $A_{\max}$ as the maximum value of $E_{\max}^{\gamma}$ across all spatial configurations, such that $A_{\max} = \max_{\gamma \in \{A,B,C\}} E_{\max}^{\gamma}$. For the assimilation capacity *A* satisfying the condition $A > A_{\max}$, this means that

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[8] Existence of extreme values for the global emission function in each spatial configuration is ensured by fixed amounts of available production factors (namely labor input *L* and *H*), which constrain the intensity of the economic activity in terms of both production and trade (and thus the extent of related externalities).

$A > E^{\gamma}_{\max}$ for all spatial configurations. To performing a non-trivial analysis of the sustainability of the configurations we then only consider values of A satisfying $A_{\min} < A < A_{\max}$.

We are interested in numerical values of the assimilation capacity A that identify the lowest trade cost $\phi^*(A)$ satisfying the sustainability condition in (21). This is done in two steps. First, by using equations (19) and (20), numerical values for the threshold values $E^{\gamma}_{\min}$ and $E^{\gamma}_{\max}$ are derived, shown in Table 2.

TABLE 2

Threshold values for emissions in the three spatial configurations

Spatial configuration	Emission threshold values	
	$E^{\gamma}_{\min}$	$E^{\gamma}_{\max}$
A	2.9	4.5
B	8.7	14.9
C	5.8	11.4

Second, the analysis supporting Table 2 gives the critical values for the assimilation capacity $A_{\min}$ and $A_{\max}$, as discussed above. Given the relations $A_{\min} = \min_{\gamma \in \{A,B,C\}} E^{\gamma}_{\min}$ and $A_{\max} = \max_{\gamma \in \{A,B,C\}} E^{\gamma}_{\max}$, we find that $A_{\min} = 2.9$ and $A_{\max} = 14.9$. The conditions for environmental sustainability of the three spatial configurations are then graphically summarized in Figure 3 through the dependence of the level of the assimilation capacity A on the minimum trade cost $\phi^*(A)$.

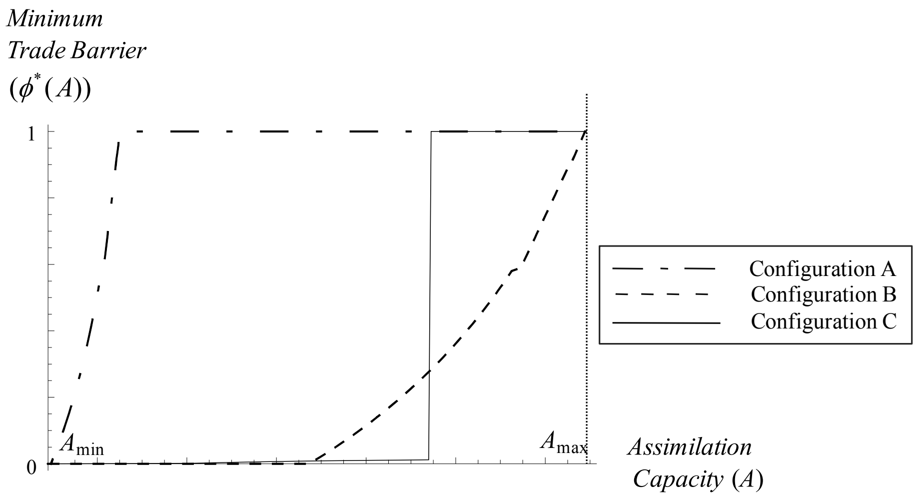

FIGURE 3. *Sustainability of the spatial configurations with respect to different levels of assimilation capacity and trade costs.*

For a given value of the assimilation capacity, Figure 3 shows that achieving sustainability is conditional on specific patterns of development of the world economy in terms of spatial organization and trade cost. The impact of the assimilation capacity on the long-run sustainability of the spatial configurations according to the trade costs for different A-range values is summarized in Table 3. Note that the range values for the assimilation capacity A are defined over minimum and maximum values of pollution emissions E for the three configurations (see Table 2). For each interval the dependence of $\phi^*(A)$ on A is studied.

TABLE 3

Sustainability of spatial configurations according to assimilation capacity

Spatial Configuration	Value of the assimilation capacity A				
	$2.9 < A < 4.5$	$4.5 < A < 5.8$	$5.8 < A < 8.7$	$8.7 < A < 11.4$	$11.4 < A < 14.9$
A	$\exists\phi$	$\forall\phi$	$\forall\phi$	$\forall\phi$	$\forall\phi$
B	–	–	–	$\exists\phi$	$\exists\phi$
C	–	–	$\exists\phi$	$\exists\phi$	$\forall\phi$

Legend:
Symbol '–' denotes that, since condition $A < E^{\gamma}_{\min}$ holds, condition for sustainability is *never* satisfied, that is, for any value of the trade barrier parameter. Symbol '$\exists\phi$' refers to the case $E^{\gamma}_{\min} < A < E^{\gamma}_{\max}$, which implies that $\phi^*(A) < 1$. In this case, the condition for sustainability is satisfied *only for certain* values of the trade barrier parameter (namely, $\phi \le \phi^*(A)$). Symbol '$\forall\phi$' finally refers to condition $E^{\gamma}_{\max} < A$, which implies that the condition for sustainability is *always* satisfied, for any value of the trade barrier parameter (namely, $\phi^*(A) = 1$).

For $A < 5.8$, only spatial configuration A can satisfy the sustainability condition. This means that for such a low value range of the assimilation capacity, fostering the sprawling pattern of the spatial organization in the two regional economies is a necessary condition to reach spatial sustainability. When instead $A > 5.8$, several spatial configurations potentially meet the spatial sustainability requirements summarized by condition $\phi < \phi^*(A)$. However the resulting constraint on trade costs depend on the spatial configuration considered. For example, for a value A such that $5.8 < A < 8.7$, two sustainable equilibria are possible: either production is spread-out in both regions (configuration A) and no constraint on trade cost is necessary for sustainability purposes (condition $\forall\phi$ in Table 3), or one of the two regions has an agglomeration of activities (the system moves to a C-like spatial configuration) and trade costs must be set high enough in order to satisfy condition $\phi \le \phi^*(A) < 1$ (condition $\exists\phi$ in Table 3). For $A > 8.7$, the three spatial configurations can satisfy the sustainability condition, but, similarly to the case $5.8 < A < 8.7$, associated constraints on trade costs should not be too low (as captured by high values of $\phi^*(A)$) and are strictly dependent on the spatial configuration considered. We recall that high values of $\phi^*(A)$ ensure a soft constraint on the economy in terms of barriers on the intensity of trade activity.

3.3. Welfare analysis of sustainable spatial configurations

As just described, several sustainable long-run equilibria that differ in the spatial organization and trade cost may exist for a given assimilation capacity A. To assess the most desirable sustainable long-run equilibrium, we compare the spatial configurations on the basis of how well they perform in terms of social welfare. Given the condition $A \geq E^{\gamma}_{\min}$, which assures sustainability of the long-run equilibrium, welfare is calculated for the long-run spatial configurations and different assimilation capacity levels.

Figure 4 shows the results. It includes a point R at which the welfare in the sustainable long-run equilibrium is identical for both configurations B and C. By defining the corresponding assimilation capacity level A_R, one can see that the welfare of sustainable long-run equilibria in configuration C exceeds the one obtained in configuration B as long as $A > A_R$. If $A = A_R$ configurations B and C perform equally well. For all smaller values of the assimilation capacity only one configuration performs best.

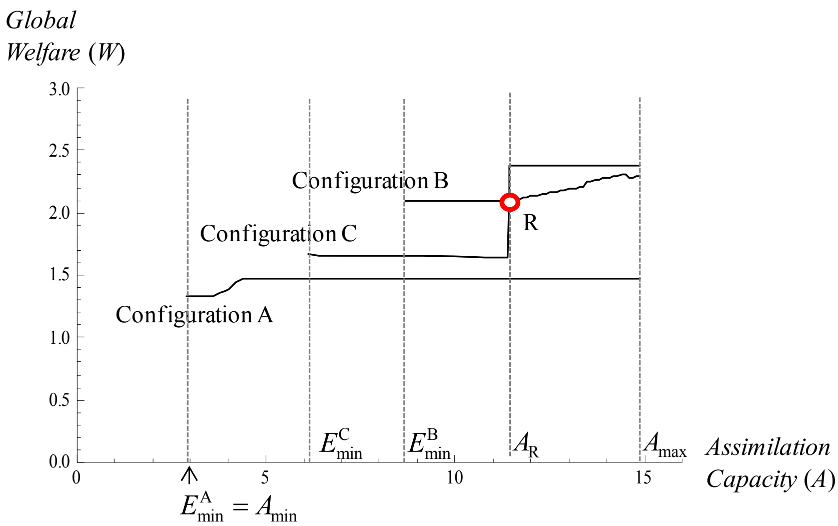

FIGURE 4. *Welfare of the long-run spatial configurations for different assimilation capacity levels.*

As shown, four ranges of A-values are identified for which the sustainability constraint has different spatial implications:

i. $A_{\min} \leq A \leq E^{C}_{\min}$: Only configuration A meets the sustainability constraint and thus performs best in terms of sustainable welfare (see Table 4).

ii. $E^{C}_{\min} \leq A \leq E^{B}_{\min}$: Both configurations A and C are sustainable in the long run. Yet, the welfare comparison highlights that for this range of values of the assimilation capacity configuration C performs better.

iii. $E^{B}_{\min} \leq A \leq A_R$: The three spatial configurations achieve sustainable long-run equilibria. Numerical analysis shows that configuration B reaches the highest level of welfare.

iv. $A_R \le A \le A_{max}$: Here all three spatial configurations are sustainable in the long run, while configuration C scores best in terms of welfare.

4. DOMESTIC AND GLOBAL IMPLICATIONS OF AGGLOMERATION AND ENVIRONMENTAL EFFECTS

The outcome of the ranking analysis performed in the previous section depends on the specific values of critical parameters of the model, notably β_j, which measures the positive agglomeration effect on the global welfare, and θ, which represents the intensity of the environmental externality in the utility function. In this section, we analyze the parametric dependence of the spatial economic variables to gain more insight into the spatial dimension of sustainability. In particular, we are interested in assessing the net benefits of regional agglomeration on the size of production activities, total consumption, and the domestic income distribution through comparative statics. Moreover, we test the dependence of the sustainability conditions and the welfare ranking derived in section 3 on the agglomeration and environmental parameters through a sensitivity analysis.

4.1. Economic gains in agglomeration: a comparative statics analysis

To what extent are variations in firm productivity and consumption due to agglomeration? And what are the underlying mechanisms through which these variations occur? To keep track of the impact of the agglomeration on the core economic variables of the model, a comparative static analysis is performed here. In what follows, we take the first-order approximation of the model in the short-run equilibrium, with labor input fixed and assumed internationally immobile: $h(t=0)=0.5$, and then consider the economic effects of variations in the key model variables as a result of the variation in the value of the agglomeration parameter β_j. The variables tested are: the local production size x_j (eq. (7)), aggregate manufacturing consumption M_j (eq. (1)) and domestic income generation Y_j (eq. (4)),. Table 4 reports their response mechanisms.

TABLE 4

Comparative statics – changes in the agglomeration parameter β_j (β_k = costant)

$$\frac{\frac{\partial x_j}{x_j}}{\frac{\partial \beta_j}{\beta_j}} = -\frac{1}{h}\frac{2\beta_j^{3(1-\varepsilon)}\phi^2 + \beta_j^{2(1-\varepsilon)}\beta_k^{1-\varepsilon}(2+\varepsilon)\phi + \beta_j^{1-\varepsilon}\beta_k^{2(1-\varepsilon)}(\Xi^2 + (4\varepsilon-2)\phi^2) + \beta_k^{3(1-\varepsilon)}\Xi\varepsilon\phi}{\left[2\beta_k^{1-\varepsilon}\Xi + 4\beta_j^{1-\varepsilon}\phi\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi + (\beta_j^{2(1-\varepsilon)} + \beta_k^{2(1-\varepsilon)})\phi\right]} \leq 0\,,\quad \Xi = 1 - \frac{\delta}{\varepsilon} + \phi^2\left(1 + \frac{\delta}{\varepsilon}\right). \quad (23)$$

$$\frac{\frac{\partial M_j}{M_j}}{\frac{\partial \beta_j}{\beta_j}} = -\beta_j^{1-\varepsilon}h^6\left\{\begin{array}{l}\dfrac{\beta_j^{4(1-\varepsilon)}\left[(\varepsilon+\delta)\phi^2\right] + \beta_j^{3(1-\varepsilon)}\beta_k^{1-\varepsilon}\left[\Xi(\delta+2)\varepsilon\phi\right] + \beta_k^{2(1-\varepsilon)}\beta_j^{2(1-\varepsilon)}\left[\Xi^2\varepsilon + \Xi\delta\phi^2(\varepsilon-1) + \phi^2(2+4\delta(\varepsilon-1))\right]}{\left[\beta_j^{1-\varepsilon} + \beta_k^{1-\varepsilon}\phi\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi + \phi(\beta_j^{2(1-\varepsilon)} + \beta_k^{2(1-\varepsilon)})\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi\varepsilon + \beta_j^{2(1-\varepsilon)}(\delta+\varepsilon)\phi + \beta_k^{2(1-\varepsilon)}(\varepsilon-\delta)\phi\right]} + \\ + \dfrac{\beta_k^{3(1-\varepsilon)}\beta_j^{1-\varepsilon}\left[\phi(4\delta(\varepsilon-1)\phi^2 + \Xi(2(\varepsilon-\delta)+\delta\varepsilon))\right] + \beta_k^{4(1-\varepsilon)}\left[\varepsilon-\delta+\Xi\delta(\varepsilon-1)\right]}{\left[\beta_j^{1-\varepsilon} + \beta_k^{1-\varepsilon}\phi\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi + \phi(\beta_j^{2(1-\varepsilon)} + \beta_k^{2(1-\varepsilon)})\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi\varepsilon + \beta_j^{2(1-\varepsilon)}(\delta+\varepsilon)\phi + \beta_k^{2(1-\varepsilon)}(\varepsilon-\delta)\phi\right]}\end{array}\right\} \leq 0. \quad (24)$$

$$\frac{\frac{\partial Y_j}{Y_j}}{\frac{\partial \beta_j}{\beta_j}} = -\frac{\beta_j^{(1-\varepsilon)}\beta_k^{1-\varepsilon}\delta(\varepsilon-1)\phi\left[(\beta_j^{2(1-\varepsilon)} + \beta_k^{2(1-\varepsilon)})\Xi + 4\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\phi\right]}{\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi + (\beta_j^{2(1-\varepsilon)} + \beta_k^{2(1-\varepsilon)})\phi\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi\varepsilon + \beta_k^{2(1-\varepsilon)}(\varepsilon-\delta) + \beta_j^{2(1-\varepsilon)}(\varepsilon+\delta)\phi\right]} \leq 0. \quad (25)$$

Assessing the feedback between agglomeration and the spatial structure of the economy comes down to studying the signs of equations (23) to (25). We find that these signs are always negative. This means that the considered endogenous variables always tend to increase in value for a decrease in the value of the agglomeration parameter, *i.e.* an increase in the magnitude of the agglomeration effect ($0 \leq \beta_j \leq 1$). The mechanism through which this trend occurs is quite clear from the individual firms' production size in (23), where the agglomeration effect acts on the variable component of a *j*-firm's production structure by dragging down the curve of the total costs of producing in location *j*, hence increasing the amount of output a domestic firm's supplies (see eq. (2)). The equilibrium reaction of local consumption trends of the industrial good and income generation in (24) and (25) are ambiguous. As for the aggregate manufacturing demand M_j in (24), ambiguity of results is due to the structure of the function: the increased consumption trend in the more agglomerated region can in fact be due to larger quantities demanded of either the domestically produced good or the imported good. Concerning the growth of domestic income in the agglomerated region (eq. 25), an ambiguous interpretation of the model results is due to a twofold simultaneous mechanism: as a consequence of an increase in the agglomeration degree, the unskilled labor input in the manufacturing sector decreases (as captured by a drop in the value of β_j), thus influencing the cost structure of a *j*-firm when choosing to produce in a more agglomerated region (through eq. 2). This in turn may lead to enlarging the share of available unskilled workers for the agricultural sector, thus affecting the size of regional food production (through eq. 3). Which mechanism dominates in raising domestic income is *a priori* not evident.

To gain insights on the findings from equations (24) and (25), we first decompose the aggregate consumption M_j in (1) and consider the share of local consumption of domestically produced manufacturing goods: $s_{M_j} = \frac{n_j c_{jj}^{\frac{\varepsilon-1}{\varepsilon}}}{M_j^{\frac{\varepsilon-1}{\varepsilon}}}$. We then look at the macroeconomic effect of increasing the agglomeration degree in driving individuals' consumption choices by studying the sign of the following equation:

(24bis)

$$\frac{\partial s_{M_j} / s_{M_j}}{\partial \beta_j / \beta_j} = -2\beta_k^{1-\varepsilon} h\phi(\varepsilon-1) \cdot$$

$$\cdot \frac{\beta_j^{4(1-\varepsilon)}\phi^2(\varepsilon+\delta)+\beta_j^{3(1-\varepsilon)}\beta_k^{1-\varepsilon}\Xi\phi(2\varepsilon+\delta)+\beta_j^{2(1-\varepsilon)}\beta_k^{2(1-\varepsilon)}\varepsilon(2\phi^2+\Xi^2)+\beta_j^{1-\varepsilon}\beta_k^{3(1-\varepsilon)}\Xi\phi(2\varepsilon-\delta)+\beta_k^{4(1-\varepsilon)}\phi^2(\varepsilon-\delta)}{\left[\beta_j^{1-\varepsilon}+\phi\beta_k^{1-\varepsilon}\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi+(\beta_j^{2(1-\varepsilon)}+\beta_k^{2(1-\varepsilon)})\phi\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi\varepsilon+\beta_j^{2(1-\varepsilon)}\phi(\delta+\varepsilon)+\beta_k^{2(1-\varepsilon)}\phi(\varepsilon-\delta)\right]} \leq 0$$

The function of the share of domestic consumption by domestic production of the manufacturing good in (24bis) is negatively responding to an increase in the agglomeration intensity of region *j*'s spatial structure (*i.e.* a decrease in the β_j value), indicating that the agglomeration effect acts in favor of the home market. This trend reflects firms' productivity gains of producing in a more agglomerated region as a result of a decrease in the marginal production costs (see eq. (23)). These gains in turn benefit consumers via lower consumption prices.

Second, to explain the macroeconomic effect of an increase in the *j*-agglomeration degree on the distribution of domestic income studied in (25), we need to determine the shares of revenue by the industrial and agriculture sectors. By using (3) and (4), the share of domestic income generated by the industrial sector is: $s_{Y_{M_j}} = \frac{w_j H_j + \beta_j n_j x_j}{Y_j}$. We consider the effect of a marginal change in the agglomeration on this share, as follows:

$$\frac{\partial s_{Y_{M_j}} / s_{Y_{M_j}}}{\partial \beta_j / \beta_j} = -4\beta_j^{1-\varepsilon} h^2(\varepsilon-1) \frac{\beta_j^{2(1-\varepsilon)}\beta_k^{1-\varepsilon}\Xi\phi + \beta_k^{3(1-\varepsilon)}\Xi\phi + 4\beta_j^{1-\varepsilon}\beta_k^{2(1-\varepsilon)}\Xi\phi^2}{\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi + \phi(\beta_j^{2(1-\varepsilon)} + \beta_k^{2(1-\varepsilon)})\right]\left[\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon}\Xi + 2\beta_j^{2(1-\varepsilon)}\phi\right]} \leq 0. \quad \text{(25bis)}$$

The sign of the function in (25bis) is negative. Hence, our model predicts an increase in industry-related domestic income in response to the agglomeration of firms, which in turn raises regional wages and domestic consumption because of individuals' increased purchase power.[9]

All in all, by increasing the agglomeration degree of the domestic market, macroeconomic response mechanisms not only foster an increase in firms' production size, but also boost

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[9] An earlier version of the paper presented a comparative statics analysis on the variation of the domestic wage w_j associated to a change in the agglomeration parameter β_j. Results, which are not reported here due to space constraint, showed a negative trend of the differential function.

consumption preferences for locally produced manufacturing goods and make a region's industry-related income rise. These insights are in line with what is known in trade theory as the 'home market effect' (Krugman, 1980; Helpman and Krugman, 1985), but so far has not been formalized through a specific agglomeration-effect parameter.[10]

4.2. Alternative settings for sustainability and welfare: a sensitivity analysis

How much do the findings so far change if we increase (decrease) the intensity of the impact of agglomeration and environmental externalities, as captured by a fall (rise) in β_j and a rise (fall) in θ? To answer this question, we perform a sensitivity analysis on these two model parameter. In particular, we test the welfare ranking of the alternative spatial configurations in response to changes in the values of the agglomeration and environment parameters.

Sensitivity analysis of parameter β

Results from the long-run analysis have been investigated when β_j takes different values with respect to its default ones set as $\beta_j = 0.5$ for an agglomerated region. This sensitivity analysis has been undertaken for β_j covering its whole range of definition for an agglomerated region: $0 < \beta_j < 1$. Figure 5 illustrates results from the welfare analysis for two specific β-values in this range: $\beta_j = 0.25$ and $\beta_j = 0.75$ that are representative of the general trends observed.

It indicates that the numerical values of the threshold parameters ($E^{\gamma}_{\min}$, $E^{\gamma}_{\max}$ and A_R) as well as the absolute values of associated global welfare strongly depend on the agglomeration parameter. In particular, the welfare gap between different spatial configurations, as measured by the vertical distance between the curves, is reduced when increasing β_j. In addition, it is found that whatever the numerical value of the agglomeration parameter and the level of assimilation capacity considered, configuration A, which lacks agglomerations, performs less well on welfare than the two other configurations. This is logical since configuration A does not benefit from positive externalities arising from agglomeration.

The welfare ranking depends on β_j. Indeed, for low β_j-values, positive agglomeration externalities are so intense that configuration B, which features two agglomerated regions, is always performing the best in terms of welfare. For high values of β_j, agglomeration externalities are offset by the negative impact on utility due to increased production-induced pollution in agglomerated regions. This explains why, in this last case, the welfare ranking is reversed, leading to C as the best performing spatial configuration.

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[10] An exception is Grazi *et al.* (2007). They perform a numerical analysis of the macroeconomic impact of a change in the agglomeration parameter.

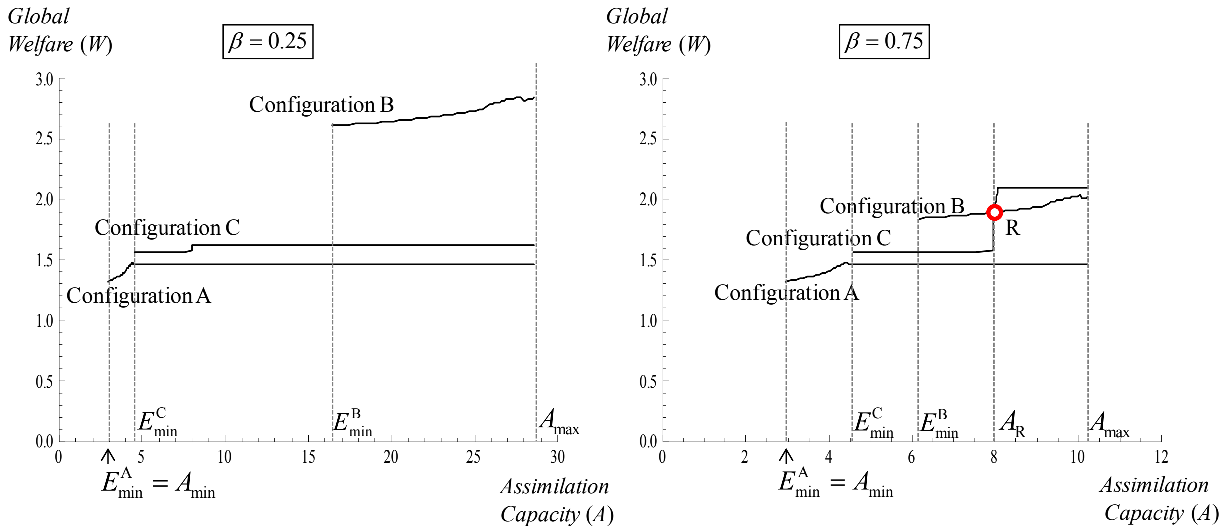

FIGURE 5. *Sensitivity of the welfare ranking to the β_j agglomeration parameter:* $\beta = 0.25$ *(left panel) and* $\beta = 0.75$ *(right panel).*

Sensitivity analysis of parameter θ

We now turn to assess the impact of changes in the value of parameter θ on the long-run development of the welfare trends. The default value was set at a low level to study the general case in which the negative environmental externalities play a small role in migration decisions and welfare. The underlying rationale was that myopic economic agents base their location decisions on the economic benefits arising from spatially positive externalities. Here we explore conditions under which the intensity of utility losses due to pollution is initially relevant, as captured by higher values of θ in the utility function given in (1).

This parameter can take any positive values. We increase its value from 0.1 through 1-50. We find that increasing the environmental parameter beyond $\theta = 1$ adds nothing to the relative importance of the environmental effect in driving migration and welfare and making the agglomeration effect relatively less influential. This is due to the structure of the indirect utility function in (13), in which the environmental effect dominates over the wage one as soon as $\theta \geq 1$. Figure 6 therefore presents results obtained for values $\theta = 0.5$ and $\theta = 1$. This provides the following insights. First, increasing θ from the default value $\theta = 0.1$ to $\theta = 0.5$ reduces the absolute value of welfare for all spatial configurations, consistent with the increased harmful impact of negative environmental externalities on social welfare. Second, the welfare ranking is strongly modified: the higher the degree of regional agglomeration, the more its long-run welfare is reduced. Hence, welfare in configurations B and C is more impacted than in configuration A. This is caused by agglomerated regions incorporating a higher level of production, which goes along with a higher level of pollution.

An increase in the environmental burden parameter up to $\theta = 1$ results in configuration A performing best under all the assimilation capacity levels. This corresponds to a case in which the environmental effect has become so important that production- and trade-related environmental external costs fully dominate the benefits of production in an agglomeration.

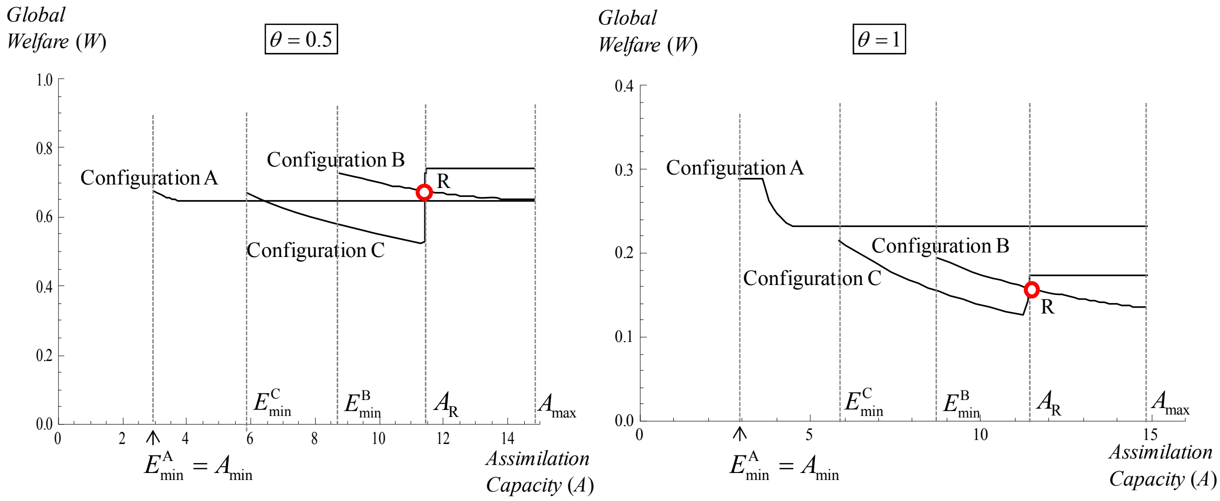

FIGURE 6. *Welfare in the sustainable long-run equilibria for* $\theta = 0.5$ *(left panel) and* $\theta = 1$ *(right panel).*

6. CONCLUSIONS

This paper has presented a theoretical framework to study the impact of particular spatial configurations of economic activities and (labor) population on the (un)sustainability of the global economy in the long run. The starting point for the analysis was the notion of 'spatial sustainability', which denotes a combination of spatial organization and dynamics of production and consumption activities that meets the conditions of environmental sustainability. We operationalized the framework in a general equilibrium setting *à la* Dixit-Stiglitz and Krugman, which describes agglomeration and trade in a two-region system. Our approach then results in the integration of three important factors of influence on both welfare and (un)sustainability, namely agglomeration economies, advantages of international or interregional trade, and environmental externalities at regional as well as global scales. Two possible spatial structures for each region are defined, involving a spatial distribution of manufacturing activities, agricultural and non-productive (nature-dominated) land. One spatial regional structure describes an urban agglomeration of manufacturing activities, and a second a spread-out structure. The model includes two innovations versus an earlier version. First, migration responds to differences in regional welfare. Second, the level of pollution assimilative capacity influences the sustainability of economic equilibria.

The model is numerically analyzed to examine long-run spatial-economic equilibria under different settings for the three determinants of spatial sustainability. First, the sustainability characteristics of the long-run equilibrium are studied by varying the pollution assimilation capacity and the trade parameter, which is a core driver of spatial structure. In addition, a ranking of sustainable spatial configurations is derived according to their performance in terms of global welfare. For a sufficiently low assimilation capacity, only spatial configuration A (no agglomeration, *i.e.* a spread-out spatial structure in both regions) can satisfy the sustainability condition and thus performs best in terms of sustainable welfare. For slightly higher values of the assimilation capacity, both configurations A and C meet the sustainability requirement in the long run. Spatial configuration C (one region agglomerated) is sustainable as long as trade costs are high enough and performs better on spatial welfare than configuration A. Sufficiently high values of trade cost mean a soft constraint on the economy in terms of barriers on the intensity of trade activity, and thus a small impact on global welfare. For an even higher assimilation capacity and sufficiently high trade costs, all three spatial configurations can satisfy the sustainability condition, while configuration B (two regions agglomerated) reaches the highest level of welfare. Finally, for the highest values assimilation capacity and trade costs all three spatial configurations include sustainable long-run equilibria, while configuration C scores best in terms of welfare.

Next, we studied whether results altered much if parameters capturing the intensity of the impact of environmental and agglomeration externalities change. In particular, we tested how the welfare ranking of the alternative spatial configurations responds to changes in the values of these parameters. Concerning the environmental parameter, even a moderate increase in the initial value reduces the absolute value of welfare for all spatial configurations and induce modifications in the welfare ranking. In particular, welfare under configurations B and C is more influenced than under configuration A. For very high values of the environmental parameter, configuration A performs best under all the assimilation capacity levels. As for the agglomeration-effect parameter, low values (*i.e.* a high impact of positive agglomeration externalities on domestic welfare) imply that configuration B is always performing the best in terms of welfare. For high values of the agglomeration parameter (a low impact on utility) the welfare ranking is reversed, leading to C as the best performing spatial configuration. Moreover, a comparative statics analysis on the agglomeration parameter has been performed to reveal the underlying economic feedbacks between agglomeration patterns and the spatial structure of the economy. This showed that the macroeconomic response mechanisms to an increase in the agglomeration intensity of the domestic market not only cover an increase in firms' production size, but also a sharp change in consumption preferences to favor locally produced manufacturing goods, which in turn causes the region's industry-related income to rise. These results are relevant as they formalize what is known in trade theory as the 'home market effect' through a specific agglomeration-effect parameter.

Our approach and results provide a novel contribution to the current debate on sustainable development of spatial economies, by giving attention to local or regional and urban (agglomeration) aspects. This is relevant to sustainability policy, including those strategies associated with climate change. Here the international global perspective and technical solutions so far has been unable to provide a satisfactory solution. Spatial re-organization of economic activities needs attention here as well, and the current framework can help to study relevant questions. In comparison with an earlier version of the framework (Grazi *et al.*, 2007), the dynamics analysis offered here has enabled the study of the interaction between individuals' location behavior, spatial patterns of development, and patterns of trade when pollution assimilation capacity levels of the system are accounted for. By means of a general equilibrium modeling framework in the spirit of the new economic geography, the current study has aimed at widening the spectrum of possible effective approaches to study sustainability. In particular, our approach provides a specific and policy-relevant tool to examine the notion of spatial sustainability.

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