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Modeling Spatial Sustainability: Spatial Welfare Economics versus Ecological Footprint

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Summary

A spatial welfare framework for the analysis of the spatial dimensions of sustainability is developed. It incorporates agglomeration effects, interregional trade, negative environmental externalities and various land use categories. The model is used to compare rankings of spatial configurations according to evaluations based on social welfare and ecological footprint indicators. Five spatial configurations are considered for this purpose. The exercise is operationalized with the help of a two-region model of the economy that is in line with the 'new economic geography'. Various (counter) examples show that the footprint method is not consistent with an approach aimed at maximum social welfare.

Keywords:. Agglomeration effects, Trade advantages, Negative externalities, Population density, Spatial configuration, Transport

JEL Classification: F12, F18, Q56, Q57, R12

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I. INTRODUCTION

In the large literature on sustainability and sustainable development, the aspect of spatial sustainability has not received much attention (Toman 1994; Pezzey and Toman 2005). Moreover, the literature on trade and environment refrains from dynamic sustainability issues. As a result, a firm basis for thinking about the sustainable development of regions, sustainable transport, sustainable location policy and sustainable trade policy is lacking. Here we offer such a basis, by performing a welfare analysis of alternative spatial configurations in a spatial economy with environmental pressure, land use, trade advantages and agglomeration effects.

The ecological footprint (EF hereafter) was proposed by Wackernagel and Rees (1996) as suitable to address questions about spatial sustainability. It has, however, been severely criticized on several grounds (e.g. Levett 1998; van den Bergh and Verbruggen 1999; Ayres 2000; Costanza 2000; van Kooten and Bulte 2000; Opschoor 2000; Lenzen and Murray 2001; Ferng 2002; Jorgensen, Vigsoe, Krisoffersen, and Rubin 2002). Notwithstanding its structural weaknesses, it has become a widely used indicator for assessing environmental sustainability. It has in fact been used to calculate the environmental sustainability performance of many nations, regions, cities, populations (e.g., Lenzen and Murray 2001; McDonald and Patterson 2004; Muñiz and Galindo 2004). The reason to revisit the EF is that the fundamental criticism has been neither refuted nor taken into account.

Our approach allows us to evaluate the robustness of the EF approach by examining how it ranks alternative spatial configurations of an economy in comparison with a spatial welfare economics analysis. Thus, we hope to fulfill two aims. The first is to contribute to a correct interpretation of the meaning of spatial sustainability. The second is to show in a formal manner that the EF is not a good guide to spatial sustainability.

The analysis of the spatial dimensions is relevant for two main reasons. First it enables the comprehension and operationalization of statements about sustainability, notably by distinguishing between sustainable and unsustainable land use, transport and trade. Second, it allows the linking of policy instruments and goals to concrete strategies concerning trade, locations and transport. The welfare analysis can cover both regional and global levels, taking into account positive externalities (namely, agglomeration effects), advantages from trade, and negative externalities (pollution, noise, etc.) related to the presence of economic activities. The inclusion of all these elements in a spatial welfare framework guarantees that outcomes are consistent with spatial sustainability. Our approach also generates information about various types of land use that allows the calculation of alternative ecological footprints. Comparison of these with (regional and global) social welfare (including environmental externalities) for a number of spatial configurations will permit a rigorous and systematic evaluation of the EF.

The remainder of this paper is structured in the following way. Section 2 outlines the methodological framework. This includes a description of alternative spatial configurations, i.e. spatial locations and interactions. Section 3 presents a formal spatial two-region economic model with land use, environmental externalities, agglomeration effects, and interregional trade. Section 4 presents an analytical solution to the reduced form model. Section 5 performs numerical exercises that compare welfare and EF for five spatial configurations. Section 6 concludes.

II. DESCRIPTION OF THE METHOD

Here we provide a general description of our approach. It involves a definition of the spatial configurations and a formal model. This takes the form of a general equilibrium welfare model of a two-region economy. The choice of a formal economic model is somewhat arbitrary. It is necessary to make sure that different spatial configurations are as much as possible consistent and mutually comparable. The general equilibrium model has the advantage that it includes behavioral responses and allows for indirect effects in terms of intermediate production, consumption, trade, income generation and welfare.

The model captures the environmental impacts from all activities, associated with particular land uses and translates these through externalities in welfare effects. Moreover, in contrast with EF approach, a number of notions that are important to the analysis of spatial sustainability are included. These are agglomeration effects, advantages from trade and negative externalities.

An agglomeration effect represents a certain type of positive externality. The term 'agglomeration' refers to the clustering of economic activities. Agglomeration occurs when all goods are produced in close proximity, so that the advantages of economies of scale, minimal transport and communication costs, common labor markets and technical know-how can be enjoyed (Brakman, Garretsen, and van Marrewijk 2001). As a result, many intermediate commodities and final goods are then available at low cost. Eberts and McMillen (1999) note that agglomeration effects are positive externalities caused by the fact that businesses share nonexcludable inputs, such as the labor pool and communication networks.

Trade advantages correspond to the benefits a region gets from trading its products with another region. This includes comparative advantage, which reflects that one region has a higher relative productivity in one good than another region, while the reverse holds for another good (Krugman 1991b). This mechanism causes trade which enhances international labor division and specialization. Trade further, leads to more competition between suppliers and therefore lower prices for consumers, thus enhancing social welfare (less market concentration or imperfections).

An externality arises when the production or welfare of one economic agent (consumer or producer) is directly influenced by the choices made by another agent. In the case of negative external environmental costs this influence is negative. Individual decisions will then not be in line with social welfare and environmental sustainability. The EF takes the negative effects of the economy on the environment into account but not as welfare changes through external effects. Moreover it omits issues of agglomeration effects and trade advantages.

The model we adopt is consistent with the EF in the sense that it covers the same land use and consumption categories as included in the EF. These are cropland, grazing land, forest, fishing ground, built-up environment and energy land. Our model is kept as simple as possible, by assuming that the world can be divided into two regions. This is sufficient to address the core features of (sustainable) trade, locations and transport.

We present alternative spatial configurations of the two-region economy. This economy consists of two activities, namely agriculture and manufacturing. In order to construct the spatial configurations for the two-region system, we distinguish between three possible spatial structures for each region. One assumes a sort of urban concentration (agglomeration) of manufacturing activities, a second is more rural in nature (agriculture-dominated), and a third is dominated by nature and has a relatively low intensity of economic activity. With these three possible regional structures we can in principle compose $3^2 = 9$ spatial configurations for the two-region system. However, some of these are just each others mirror images, so that only six configurations turn out to be relevant. Table 1 clarifies these in terms of the combinations of the spatial structures in each of the two regions. Note that all activities and pure nature are present to some degree in each region under all configurations.

TABLE 1

POSSIBLE SPATIAL CONFIGURATIONS

Spatial configuration	Region 1	Region 2
A	agriculture-dominated area	agriculture-dominated area
B	agglomeration	agriculture-dominated area
C	agriculture-dominated area	nature-dominated area
D	agglomeration	agglomeration
E	agglomeration	nature-dominated area
F	nature-dominated area	nature-dominated area

We omit from our analysis spatial configuration F (see Table 1), as it lacks a complete economy. This is not a moral judgment that such a system is less desirable, but a consequence of using a two-region economic model and assuring that the global (two-region) economies and populations under each configuration are identical in size. Under configuration F there is too little space available to host the economy and the population, so that a comparison with the other configurations would imply comparing apples and oranges. Table 2 shows for each of the five remaining configurations how they are characterized in terms of the three core spatial economic phenomena, i.e. agglomeration effect, negative externality and trade advantage. Figure 1 provides a schematic representation of these five configurations.

TABLE 2

ECONOMIC CHARACTERISTICS OF THE SPATIAL CONFIGURATIONS

Spatial configuration	Region	Agglomeration Effect	Negative Externalities	Trade Advantage
A	1	0	1	1
	2	0	1	
B	1	1	1	1
	2	0	1	
C	1	0	1	1
	2	0	1	
D	1	1	1	1
	2	1	1	
E	1	1	1	1
	2	0	1	

Notes: 1 = Present; 0 = Not present.

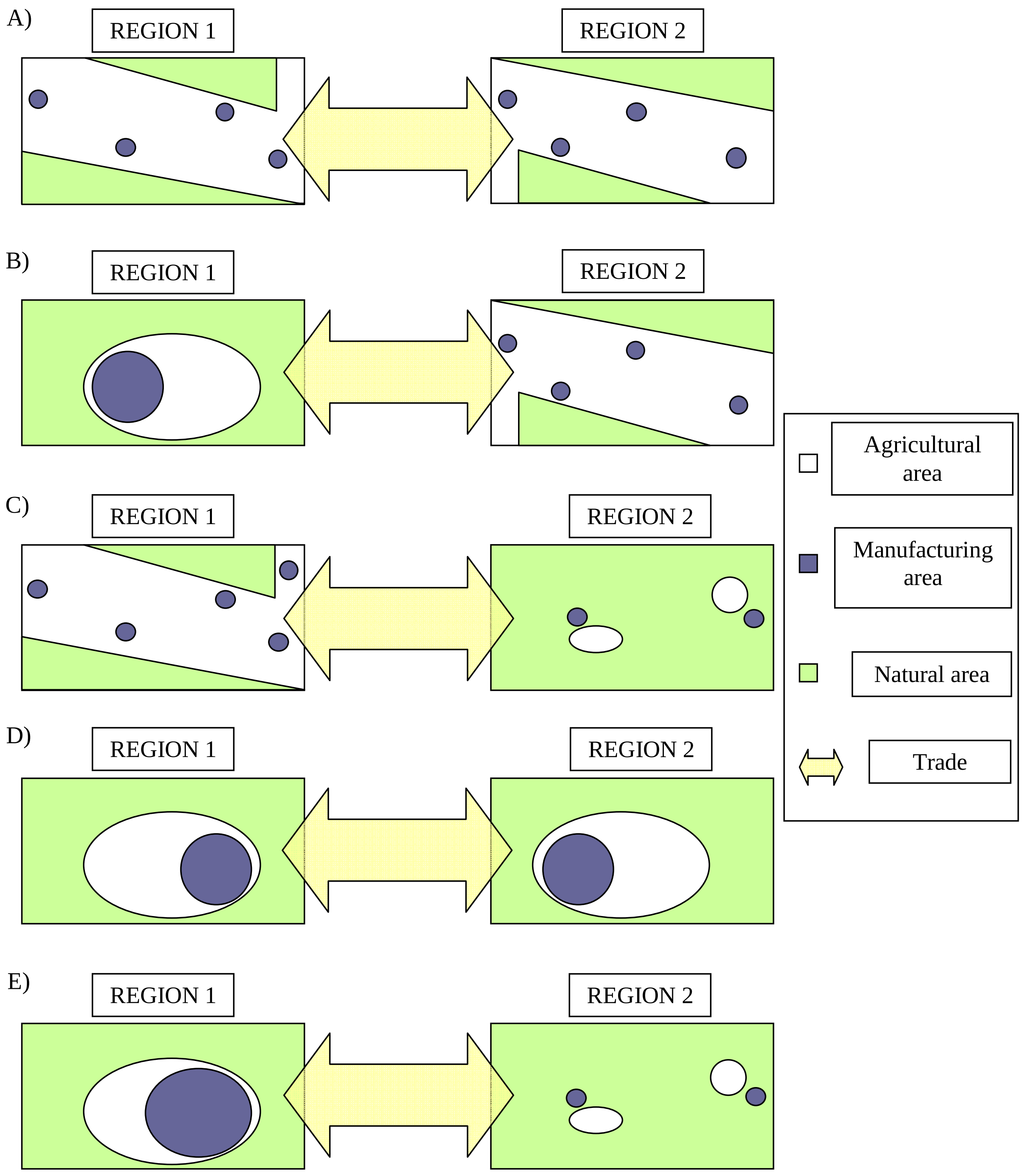

FIGURE 1

A SCHEMATIC REPRESENTATION OF THE SPATIAL CONFIGURATIONS

III. THE MODEL

Here we develop a general equilibrium model that includes all the elements as discussed in the previous section. Although it is not our explicit purpose to develop an entirely new model, our application requires a number of changes in existing models. Our main objective is to compare the EF with the spatial welfare approach in ranking different given spatial configurations.

To study the relationship between spatial concentrations at different scales (country, region, or urban) and environmental (un)sustainability in a way that is consistent with microeconomic theory, we develop a spatial trade model following closely models by Forslid and Ottaviano (2003) and van Marrewijk (2005). The first study enables us to use a model that can be analytically solved, while the latter suggests how to include negative externalities from pollution. These models are variations of a well known model by Krugman (1991a), which started a line of research that is known now as the ‘new economic geography’. In addition to the trade relations in these models we analyze the positive effects stemming from economies of agglomeration and (negative) environmental externalities.

This literature makes a distinction between short-run and long-run equilibria. Since we are interested in assessing static spatial configurations we only consider the short-run equilibrium, which means that migration between regions is not allowed. This comes down to assuming that the stocks of human capital and unskilled labor are exogenously given for each region. This restriction is motivated by the intention to stick as close as possible to the EF approach, which assumes a given population distribution in space or between regions (i.e., no migration).

The model captures agglomeration effects. The most significant advantage of the agglomeration of economic activities is reduced transport costs due to the reduced transport distances. We assume that intraregional trade covers such small distances relatively to interregional trade that intraregional transport costs are set equal to zero. We do therefore not model agglomeration effects endogenously (for example, depending on distances and transport costs), but include them as an exogenous factor that differs between the types of spatial configuration. This is no shortcoming, as our intention is to analyze the impact of agglomeration rather than explain or derive it theoretically.

We assume that the world is divided into two regions. Both regions produce two different types of goods: a homogeneous good F_j (agriculture) and a differentiated good M_j (manufacturing). Following Ottaviano (2001), we also assume that two production factors are available in the economy, namely unskilled labor (L) and human capital (H). In our two-region system the total amount of unskilled workers is $L = L_1 + L_2$, while the amount of skilled workers is $H = H_1 + H_2$.The production activities F_j and M_j (for regions, j = 1,2) generate a negative externality (E) that affects both regional and global welfare. Agriculture production is characterized by constant returns to scale and perfect competition, and is therefore the ideal candidate to represent the numéraire good (namely, we can fix the price of food equal to 1). In addition, we assume that transportation costs for food are zero, and that one unit of labor is needed to yield one unit of food. This guarantees that the wage of unskilled labor is equal to unity. We further assume that the manufacturing sector produces many varieties and that each manufacturing firm finds it useful to produce a single unique variety, under increasing returns to scale. Therefore, the number of available varieties in each region j, n_j, is equal to the number of firms that are active in the same region. We are able to define a price index (I) of manufactures, in order to treat the various products as a single group.

Demand Side

Given a certain income level (Y_j) that a consumer earns from working in the agriculture or manufacturing sector in region j, he has to decide whether to spend it on agricultural (in terms of demand, A_j) or on manufactured (M_j) goods. Utility is defined as:

(1) $$U_j = A_j^{(1-\delta)} M_j^{\delta} (1+E)^{-\theta}, \qquad j = 1,2, \qquad 0 < \delta < 1, \qquad \theta \geq 0$$

Here δ is the share of income Y_j spent on manufactures, E is the negative externality associated with domestic production and transport, and θ represents the intensity of the environmental externality in the utility function.

Concerning the demand for manufactures, let c_{jj} and c_{jk} be the consumption levels of a particular variety *i* that is sold in region *j* and produced in region *j* and in region *k*, respectively. Following Dixit-Stiglitz (1977), we define a constant elasticity of substitution (CES), ε, to write the aggregate consumption of manufactures *M* as a function of the consumption c_{jj}, c_{jk}, and the *N* varieties:

$$(2) \qquad M_j = \left[\int_{i \in n_j} c_{jj}(i)^{(\varepsilon-1)/\varepsilon} + \int_{i \in n_j} c_{kj}(i)^{(\varepsilon-1)/\varepsilon} \right]^{\varepsilon/(\varepsilon-1)}, \quad j,k = \{1,2\} \qquad \varepsilon > 1$$

Here n_j and n_k represent the total quantity of available varieties in region *j* and *k*, respectively, and *N* represents the total amount of available varieties in the two region system, so that $N = n_1 + n_2$.

Each consumer has to satisfy the following budget constraint:

$$(3) \qquad \int_{i \in n_j} p_{jj}(i) c_{jj}(i) + \int_{i \in n_j} p_{kj}(i) c_{kj}(i) + A_j = Y_j, \qquad j,k = \{1,2\}$$

Maximizing utility given in (1) subject to (3) gives consumer demand in region *j* for a variety *i* produced in region *k:*

$$(4) \qquad c_{kj}(i) = p_{kj}(i)^{-\varepsilon} \left(I_j^{\varepsilon-1} \delta Y_j \right), \qquad j,k = \{1,2\}, \qquad i = 1,.....,N$$

Here I_j is the local price index of all the *i* manufactures in region *j:*

$$(5) \qquad I_j = \left[\int_{i \in n_j} p_{jj}(i)^{1-\varepsilon} + \int_{i \in n_k} p_{kj}(i)^{1-\varepsilon} \right]^{1/(1-\varepsilon)}, \qquad j,k = \{1,2\}$$

Given skilled workers H_j with the relative wage rate w_j, and unskilled workers L_j with the numéraire wage as input factors, the income in each region *j* is generated as follows:

$$(6) \qquad Y_j = w_j H_j + L_j \qquad , \qquad j = \{1,2\}$$

Supply Side

In this part of the description of the modeling framework, we are interested in defining the supply side for manufactures (*M*) and agriculture goods (*F*). Each variety of manufactures is produced under increasing returns to scale using both unskilled labor *L* and human capital *H*. The quantity H_j in each region *j* is only used in fixed amount in the manufacturing sector, while the unskilled variable labor L_j intervenes either in agriculture or in manufactured production. Fixed costs are based on α units of *H* and variable costs on β_j units of *L* per unit of manufactured goods. Letting w_j be the wage rate for *H* in region *j*, we find the total cost $\chi_j(i)$ of producing $x_j(i)$ of variety *i* in region *j* as follows:

$$\chi_j(i) = \alpha w_j + \beta_j x_j(i), \qquad j = \{1,2\}, \qquad i = 1,.....,N$$

We choose the unit of skilled labor, *H*, such that α = 1. Due to the fixed input necessity α, the number of firms in region *j*, n_j, which is exogenously determined in our approach is, proportional to its skilled workers:

$$(7) \qquad n_j = \frac{H_j}{\alpha} = H_j, \qquad j = \{1,2\}$$

In order to provide the model with a spatial dimension, the assumption that manufactured goods can be freely shipped between the two regions is introduced, and that in shipment transport costs occur. To avoid modeling a separate transportation sector we use the 'iceberg' form of those kinds of costs, which has been introduced by Samuelson (1952). In particular, if one variety *i* of manufactured goods is shipped from region *j* to region *k*, only a fraction, $1/T_{jk}$ will arrive at the destination: the reminder will go 'melt' during the shipment. This means that if a variety produced in location *j* is sold in the same region at price p_{jj}, then it will be charged in consumption location *k* a price p_{jk}, which equals:

$$(8) \qquad p_{jk}(i) = p_{jj}(i) T_{jk}, \qquad j,k = \{1,2\}, \qquad i = 1,.....,N$$

Here k is the other region of j in a two-region system, and $T_{jk} > 1$ represents the amount of manufactured good sent per unit received. We hereafter refer to T to mean that amount.

Each manufacturing firm is assumed to produce a single variety under internal returns to scale. Given its monopoly power, having set α = 1, it is clear that the firm acts as to maximize profit:

$$\pi_j(i) = p_{jj}(i)c_{jj}(i) + p_{jk}(i)c_{jk}(i) - w_j - \beta_j x_j(i), \qquad j,k = \{1,2\}, \quad i = 1,\ldots.,N$$

The total production x_j (i) of a firm located in region j is defined by:

(9) $$x_j(i) = c_{jj}(i) + Tc_{jk}(i), \qquad j,k = \{1,2\}, \qquad i = 1,\ldots.,N$$

Here $Tc_{jk}(i)$ represents the supply to region k of variety i produced in region j. This total production corresponds to that x_j appearing above, in the total cost of production function.

Recalling that $p_{jj}(i)$ is the price of a variety i that is both produced and sold in region j, under Dixit-Stiglitz monopolistic competition we have that a profit maximizing firm sets its price as a constant mark-up on variable cost:

(10) $$p_{jj}(i) = (1 - 1/\varepsilon)^{-1}\beta_j \ , \qquad j,k = \{1,2\}, \qquad i = 1,\ldots.,N$$

The parameter β_j captures the agglomeration effect. It is exogenous and may differ between spatial configurations, as has been explained above within this section. A lower value means more agglomeration in the respective region. That is, each firm's productivity increases and thus the total cost of producing varieties falls, given a lower β_j. Note that this deviates from the approaches followed by Forslid and Ottaviano (2003) and by van Marrewijk (2005), in which β_j is equal among the regions.

As a consequence of the profit maximization behavior, in both the regions firms will entry and exit the manufacturing sector until the point at which profits are zero, as monopolistic competition states as an equilibrium condition. Therefore, recalling that the parameter for fixed input labor α is assumed to equal unity, by substituting (10) into the profit function $\pi_j(i)$ and setting $\pi_j(i) = 0$ we find the wage rate w_j at the equilibrium:

(11) $$w_j = \frac{\beta_j x_j}{\varepsilon - 1} \quad , \qquad j = \{1,2\}$$

Production of agricultural good is based on a linear production function in labor. Since $\beta_j n_j x_j$ unskilled workers are required in the production process, the level of food supply in each region *j*, F_j, is:

(12) $$F_j = L_j - \beta_j n_j x_j \, , \qquad j = \{1,2\}$$

The total amount of manufactures that is shipped from region *j* to region *k* equals Tc_{jk}, while the shipped amount of agricultural goods z_j that is transferred between regions is given by the difference between the supply for agricultural goods, F_j and the demand for agricultural goods, A_j, in each region *j:*

(13) $$z_j = F_j - A_j \, , \qquad j = \{1,2\}$$

Externalities and Welfare

Negative externalities (*E)* are associated with production and transport. Therefore, the negative externality can be written as a function of agriculture production (*F*), manufacture production (*M*), and transportation (*t*), in the following way:

(14) $E = \sum_j E_j$, is the global level of environmental degradation,

where $E_j = E(F_j, M_j, t)$, $\qquad \partial E_{F_j} / \partial F_j > 0, \; \partial E_{M_j} / \partial M_j > 0, \; \partial E_{t_j} / \partial t_j > 0$

Noting that externalities from transport are related to the quantity of agriculture and manufacturing products that are shipped between the two regions, we can write:

(15) $$E_j = m(n_j x_j)^a (F_j)^b \left[1 + \left(\frac{Tc_{kj}(i) + Tc_{jk}(i)}{2} + \frac{z_k + z_j}{2} \right) \right]^d , \; a,b,d > 0 \, , \; a + b + d = 1$$

Here *m* is a constant, and *a,b,d* represent the measurement of the relative externality burdens of manufacture, agriculture and transport. This approach is more general than van Marrewijk

(2005), who only considers pollution (externalities). Our approach can address any type of environmental externality (e.g. noise, biodiversity loss due to fragmentation of nature, etc.).

The welfare function in region *j* is identical to regional utility (1):

(16) $$W_j = A_j^{(1-\delta)} M_j^{\delta} (1+E)^{-\theta}, \qquad j=\{1,2\}, \qquad 0<\delta<1, \qquad \theta \geq 0$$

Global social welfare can then be defined as a weighted geometric mean of the welfare for each region, where the weights reflect population size of each region:

(17) $$W = \left(\prod_j W_j^{\,(n_j + L_j)} \right)^{1/2} \qquad j=\{1,2\}$$

The choice of multiplicative factor is suggested by the presence of environmental components in determining the global welfare (Ebert and Welsch 2004).

Land Use

Since the EF is expressed in terms of land area (ha), a final step of our approach will be to translate activities in the economy into land units. This step guarantees that the comparison between our approach and the EF is feasible. We adopt a sort of Leontief production function, which does not allow for substitution between land on the one hand and other production factors (labor and capital) on the other. This is not severely restrictive given that we exclude dynamic processes, notably technical progress. The latter is conform the EF procedure, which considers sustainability scenarios based on available technologies, leaving out considerations of advanced or hypothetical technologies (e.g., solar PV rather than land-intensive forestation to solve the problem of global warming).

Given that our two production sectors completely cover the EF categories as explained in section 2, we can establish the following set of relationships defining land use:

(18) $$l_{crops,j} = \gamma A_j^{\,\eta}, \qquad \eta \leq 1 \qquad j=\{1,2\}$$

(19) $$l_{grazing,j} = \zeta A_j^{\,o}, \qquad o \leq 1 \qquad j=\{1,2\}$$

(20) $l_{forest,j} = \lambda A_j^{\mu}$, $\mu \leq 1$ $j = \{1,2\}$

(21) $l_{built,j} = \nu Pop_j^{aggl_j}$, $\nu = 2$, $aggl \in \{0.5,1\}$, $j = \{1,2\}$

(22) $l_{fishing,j} = \xi A_j^{\psi}$, $\psi \leq 1$ $j = \{1,2\}$

(23) $l_{hypothetical,j} = \varphi F_j + \sigma M_j + \omega Pop_j^{aggl_j}$, $\varphi, \sigma, \omega > 0$ $j = \{1,2\}$

Here the terms $l_{category,j}$ on the left-hand-side of each equation represents the land used to produce those goods expressed by each sub-index in the EF. Instead, the first indexes on the right-hand-side are parameters that homogenize the units of measure, while the power indexes show the non-linear trend of the function. Concerning (21), *aggl* is the agglomeration effect, and takes values equal to 1 when agglomeration occurs, and equal to 0.5 when it does not. Pop_j represents the size of region *j* and is calculated as follows: $Pop_j = 3(L_j + H_j)$.

Equation (23) represents 'energy land' use. The first two terms on the right-hand side of this equation represent the energy use by production, while the last term refers to residential energy use. We assume in line with Wackernagel and Rees (1996) that energy land is the land required to capture CO_2 emissions of fossil fuel combustion by forestation. As it does not deal with real land use, we call it hypothetical land.

The set of equations (18) to (22) corresponds to 'real' – as opposed to 'hypothetical' – land use. The sum of all 'real' land uses gives us total 'real' land use $l_{R,j}$ in region *j*, as follows.

(24) $l_{R,j} = l_{crops,j} + l_{grazing,j} + l_{forest,j} + l_{built,j} + l_{fishing,j}$, $j = \{1,2\}$

We assume that a fraction of natural land is always present in both regions:

(25) $l_{nature,j} > \underset{spatial\ configurations}{Max} \bar{l}_{R,j}$, $j = \{1,2\}$, $l_{nature,j} > 0$

Here $l_{nature,j}$ is the area covered by nature in each region j. This in fact defines the total land use of region j (namely as equal to the maximum of $l_{R,j}$ + $l_{nature,j}$ over all spatial configurations).[1]

The sum of all land uses, including therefore energy land, gives the EF_j, ecological footprint of region j (in ha), as from Wackernagel and Rees (1996). We refer to it as EF_j^1 to distinguish it from an alternative EF approach, EF_j^2 (van Vuuren and Bouwman 2005).

(26) $$EF_j^1 = l_{R,j} + l_{hypothetical,j} , \qquad j = \{1,2\}$$

(27) $$EF_j^2 = EF_j^1 - l_{hypothetical,j} - l_{fishing,j} , \qquad j = \{1,2\}$$

This completes the model.

IV. ANALYTICAL RESULTS

In this section, we provide an analytical solution to the model described in the previous section. We start by arguing that the Dixit-Stiglitz monopolistic competition imposes that each firm's profits equal zero at equilibrium. Therefore, recalling that the parameter for fixed input labor α is assumed equal to one, by substituting (10) into profit function π_j (i) and setting π_j = 0 we find the wage rate w_j at the equilibrium, as shown in equation (20):

(28) $$w_j = \frac{\beta_j \varepsilon}{\varepsilon - 1} x_j + \beta_j x_j = \frac{\beta_j x_j}{\varepsilon - 1} \quad , \qquad j = 1,2$$

Then we define the analytical equations for the equilibrium. We introduce it by showing the market clearing condition for the production of a variety of manufactures in region j.

By substituting (8) and (10) in (4) the price index I_j can be written as follows:

(29) $$I_j = \frac{\varepsilon}{\varepsilon - 1} \left(n_j \beta_j^{1-\varepsilon} + T^{1-\varepsilon} n_k \beta_k^{1-\varepsilon} \right)^{1/(1-\varepsilon)}, \qquad j,k = \{1,2\}$$

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[1] The presence of agriculture land use in both regions is based on Forslid and Ottaviano's work (2003), which imposes the restriction $\delta < \varepsilon/(2\varepsilon - 1)$ to warrant that food production is present in both regions.

By substituting (4), (8), (10), and (29) in (9) the level of production of firms located in region *j* can be determined as follows:

$$(30) \qquad x_j = \frac{\varepsilon - 1}{\beta_j^{\varepsilon}\varepsilon}\left(\delta \frac{Y_j}{n_j \beta_j^{1-\varepsilon} + T^{1-\varepsilon} n_k \beta_k^{1-\varepsilon}} + T^{1-\varepsilon}\delta \frac{Y_k}{T^{1-\varepsilon} n_j \beta_j^{1-\varepsilon} + n_k \beta_k^{1-\varepsilon}}\right), \qquad j,k = \{1,2\}$$

Here *k* is the other region of *j* in the two-region system (*j*, *k*).

We assume unskilled workers to be evenly spread between the two regions, so that

$$(31) \quad L_j = L/2, \qquad j = 1,2$$

Using (7) and recalling that in our model the number of firms in each region *j*, n_j, is exogenously determined, income Y_j in region *j* is calculated from equation (6), as follows:

$$(32) \quad Y_j = w_j n_j + L/2 \qquad j = 1,2$$

The reduced form model can now be expressed as follows:

$$(10) \quad p_{jj}(i) = (1 - 1/\varepsilon)^{-1}\beta_j, \qquad j,k = \{1,2\}$$

$$(11) \quad w_j = \frac{\beta_j x_j}{\varepsilon - 1}, \qquad j,k = \{1,2\}$$

$$(30) \quad x_j = \frac{\varepsilon - 1}{\beta_j^{\varepsilon}\varepsilon}\left(\delta \frac{Y_j}{n_j \beta_j^{1-\varepsilon} + T^{1-\varepsilon} n_k \beta_k^{1-\varepsilon}} + T^{1-\varepsilon}\delta \frac{Y_k}{T^{1-\varepsilon} n_j \beta_j^{1-\varepsilon} + n_k \beta_k^{1-\varepsilon}}\right), \qquad j = 1,2$$

$$(32) \quad Y_j = w_j n_j + L/2, \qquad j = 1,2$$

By substituting (32) into (30) and the resulting into (11) we obtain two linear equations in two variables, w_1 and w_2, which can be analytically solved. The solutions are:

$$(33) \quad w_j = \frac{\delta/\varepsilon}{1-(\delta/\varepsilon)}\frac{L}{2}\frac{2T^{1-\varepsilon}\beta_j^{2(1-\varepsilon)} n_j + \left[1-(\delta/\varepsilon)+(1+(\delta/\varepsilon))T^{2(1-\varepsilon)}\right]\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon} n_k}{T^{1-\varepsilon}\left(n_j^2\beta_j^{2(1-\varepsilon)} + n_k^2\beta_k^{2(1-\varepsilon)}\right) + \left[1-(\delta/\varepsilon)+(1+(\delta/\varepsilon))T^{2(1-\varepsilon)}\right]\beta_j^{1-\varepsilon}\beta_k^{1-\varepsilon} n_j n_k}.$$

Now we have an explicit solution for w_j in the exogenous parameters. Substituting this in (32) gives a solution for Y_j, while substituting it in (11) gives a solution for x_j. In turn, all other model variables can be solved as functions of exogenous parameters.

V. NUMERICAL ANALYSIS

Although we have achieved an analytical solution for the model, a generalized analytical comparison of EF and spatial welfare is not possible. The reason is that the explicit expressions in parameters of both EF and spatial welfare are extremely complicated. We are therefore forced to employ numerical methods of further analysis. This is no problem as we intend to find one or more counter examples, i.e. inconsistent rankings of spatial configurations according to EF and spatial welfare. Note that the analytical model solution obtained in the previous section allows us to perform numerical analysis without having to solve a complex, nonlinear system of equations. To numerically assess the ranking of different configurations we use realistic ranges – as motivated below – of parameter values, for both economic and land use parameters. Nonetheless, it is not our purpose to perform real world application. The following sub-sections provide information on the exact procedure followed.

Economic Parameters

The base economic parameter values are chosen to fall in realistic empirical ranges. Most of them are based on van Marrewijk (2005). Only the parameters that relate to the concentration of manufacturing firms in each region *j*, namely n_j and β_j, assume arbitrary values (without harming the generality of our counter example). The parameter β_j is set equal to 1 in the case of de-concentration of firms, while it equals 0.5 if agglomeration occurs in region *j*. For the nature-dominated region (in configurations C and E), β_j is assumed equal to 2. This value is arbitrarily chosen to reflect the higher costs a firm incurs in producing goods in region 2 due to the absence of agglomeration of production activities. Concerning the total number of firms that are active in both the regions 1 and 2, we use the normalization factor, such that $N = n_1 + n_2 = 1$. The parameters n_1 and n_2 are both equal to 0.5, except for configurations that involve a nature-dominated region, in which case n_1 = 0.8 and n_2 = 0.2. Furthermore, the total number of unskilled workers L is normalized to 1, such that L_j = 0.5 represents the number of the available unskilled workers in each region j.

Land Use Parameters

Next we set the exogenous parameters appearing in the land use equations, (18) to (23). Two types of parameters characterize each land use equation. A first type of parameters is the set of superscript parameters. A second type refers to the first parameters on the right-hand side of each land use equation.

The parameters of the first type express the non-linearity of the relationship between the volume of production for a particular consumption category and the land needed to support it. Concerning the second type, they have to be interpreted as the efficiency rate of (agricultural or manufacturing) production. In order to derive their values, we follow Wackernagel and Rees (1996). We first estimate world production (in metric tons, Mt) for each of the food products associated with particular land use categories. Data from FAOSTAT (FAO 2002) are used. Then we proceed to calculate the land required to support the production of one metric ton of food products for these same categories, based on data from WWF (2002). The obtained value is in ha/Mt. Similarly, the value of parameter ν in equation (21) is calculated dividing the global built-up surface through the world population, in order to find the per-capita land use of this type (in ha/capita).

Concerning the estimate of parameter values for the hypothetical land in (23) (i.e φ,σ,ω), we utilize data from the FAOSTAT (FAO 2002) for world agricultural production (expressed in million dollars per unit of world GDP), from the World Development Indicators (World Bank 2004) for world manufacturing production (expressed in million dollars per unit of world GDP), and from World Energy Outlook (IEA 2002) for estimates of CO_2 emissions from fuel combustion by sector of production (i.e. emissions from agricultural, manufacturing and residential sectors, all expressed in million tons of CO_2). By dividing CO_2 emissions caused by agriculture, manufacturing and residential sectors through world agricultural production, world manufacturing production and the world population, respectively, we obtain three coefficients expressing the emissions associated with normalized production units for each sector (i.e. in tons of CO_2/dollars, tons of CO_2/dollars, and tons of CO_2/capita, respectively). To derive the land needed to absorb the emissions per unit of output from the economic sectors, we apply the conversion factor by Wackernagel and Rees (1996), which is equal to 0.56 (i.e. 1/1.8) ha per ton of CO_2. Finally, the values for φ,σ,ω in (23) are derived by dividing the conversion factor through the emissions generated by each sector's production activity (φ,σ,ω are then expressed in ha/dollars, ha/dollars, and ha/ capita, respectively).

The resulting values of economic and land use parameters are shown in Table 3.

TABLE 3

OVERVIEW OF PARAMETER VALUES

Economic Parameter	Value	Land use Parameter	Value
θ	0.1	H	0.5
δ	0.3	ζ *(ha/tons^{o})*	3.76
ε	3	o	1
a	0.5	λ *(ha/tons$^{\mu}$)*	4.86
b	0.3	μ	1
d	0.2	v *(ha/capita^{aggl})*	0.1
β	> 0	*aggl*	0.5; 1
α	1	ξ *(ha/tons$^{\psi}$)*	17.7
T	1.79	ψ	1
n_j	$0 \leq n_j \leq 1$	σ *(ha/dollars)*	0.00011
L	1	φ *(ha/dollars)*	0.00054
		ω *(ha/capita)*	0.10999

Results and Discussion

This sub-section is aimed at comparing rankings of the five spatial configurations on the basis of welfare and EF (for two types of EF). We determine the results at both the regional and the world level. The configuration showing the highest value of welfare and the lowest value of EF is ranked as first (i.e. higher welfare and lower footprint are desirable). The results are reported in Table 4.

TABLE 4

RANKING OF THE SPATIAL CONFIGURATIONS ACCORDING TO WELFARE AND FOOTPRINT

Approach	Spatial configuration ranking (1: most favorable; 5: least favorable)				
	1	*2*	*3*	*4*	*5*
SWE	D	B	E	C	A
EF^1	C	A	B	E	D
EF^2	C	A	B	E	D

The most important finding is that the welfare evaluation ranks alternatives differently than evaluation based on the two EF indicators. A second finding is that the two EF approaches give rise to identical rankings, even though the (absolute) values of EF^1 and EF^2 differ (see Appendix 1 for an example of the magnitude of these differences). This outcome is remarkable, given that the second EF indicator (EF^2) is the result of an effort to improve the original (Wackernagel and Rees) EF method (EF^1). We have examined whether this result holds for different parameter values, and it turned out to be a very robust result. One explanation is that hypothetical land use and real land use are very much correlated in the configurations considered, which is also true for industrialized countries in the real world.

Further insights can be obtained by interpreting the specific rankings according to welfare and EF criteria. This shows that – under limited externality effects – starting from any configuration, changing a region structure to an agglomeration contributes positively to global welfare and negatively to global ecological footprint.[2] The reason is that in terms of the welfare criterion the extra positive externality of agglomeration dominates the extra negative environmental externality associated with it. When the externality effect becomes large relative to the agglomeration effect, then we obtain the case which is examined below under 'sensitivity analysis'.

Regional Analysis

Above we have focused the attention on global evaluation of welfare and EF. However, many footprint studies have focused the attention on regional rather than global analysis of EF.

TABLE 5

RANKING OF THE SPATIAL CONFIGURATIONS AT A REGIONAL LEVEL

Approach	Region	Spatial configuration ranking per regional performance (1: most favorable; 5: least favorable)				
		1	*2*	*3*	*4*	*5*
SWE	Region 1	E	B	D	C	A
	Region 2	D	B	A	E	C
EF^1	Region 1	A	D	B	C	E
	Region 2	E	C	B	A	D
EF^2	Region 1	A	D	B	C	E
	Region 2	E	C	B	A	D

[2] For example, from an EF perspective, configuration A performs always better than B, while the opposite holds for performance in terms of welfare.

What can we on the basis of our results say about this. The results in Table 5 show that in general regional and global welfare evaluation will not render the same rankings.[3] This indicates that regional evaluation is partial in nature from an overall welfare perspective. Global evaluation is therefore to be preferred. [4]

Sensitivity Analysis

Next we perform a sensitivity analysis. The two crucial parameters to be examined are n_j, the number of firms that are active in each region j, and the parameter θ, which represents the intensity of the environmental externality. With regard to the first parameters, we consider as an alternative setting $n_1 = 0.6$ and $n_2 = 0.4$ for configurations C and E, to reflect a different degree of concentration in the nature-dominated region. This evidently is an important element of the debate on spatial sustainability. This changes the global rankings according to welfare and EF, as shown in Table 6, below.

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[3] By the way, the rankings based on the global and regional EF's differ as well. To see this for EF^1: Configuration A is regarded as optimal for region 1, and configuration E for region 2. However, configuration C is optimal from the global EF perspective.

[4] Our findings do not exclude that isolated regions function as autarkic economic systems. In fact, certain isolated islands on an (un)sustainable track behave as 'global systems', and have for this reason been suggested – rightly or not – to be exemplatory for the (un)sustainability of the world as a whole (e.g. Erickson and Gowdy 2000).

TABLE 6

RANKING OF THE SPATIAL CONFIGURATIONS, NEW SCENARIO

(n_1=0.6; n_2=0.4, IN CONFIGURATIONS C AND E)

Approach	Spatial configuration ranking (1: most favorable; 5: least favorable)				
	1	*2*	*3*	*4*	*5*
SWE	D	E	B	A	C
EF^1	C	A	B	E	D
EF^2	C	A	B	E	D

In particular we find completely opposed rankings between the two approaches, when the regions are less asymmetric in terms of degree of concentration. Moreover it changes rankings based on regional EF (not regional welfare). So the results have proved fully robust with regard to the values set for these parameters.

TABLE 7

RANKING OF THE SPATIAL CONFIGURATIONS, NEW SCENARIO (θ=120)

Approach	Spatial configuration ranking (1: most favorable; 5: least favorable)				
	1	*2*	*3*	*4*	*5*
SWE	C	A	B	E	D
EF^1	C	A	B	E	D
EF^2	C	A	B	E	D

We then increase the value of θ from 0.1 through 0.9 to 120, which changes the intensity of the environmental externality. The results reported in Table 7 show that welfare and EFs rankings converge. This makes sense as for sufficiently high θ environmental externalities completely dominate welfare. Under these circumstances environmental externalities are no longer kept in balance by agglomeration and trade effects. The welfare analysis thus boils down to a one-dimensional environmental EF analysis.

VI. CONCLUSION

In the large literature on sustainability and sustainable development the aspect of spatial sustainability has not received much attention. As a result, thinking about the sustainable development of regions, sustainable transport, sustainable location policy and sustainable trade policy has tended to be *ad hoc.*

The ecological footprint is a good example of this, as follows from our comparative analysis. Using a formal model it has been shown with a number of counter examples that welfare rankings can be inconsistent with rankings based on the ecological footprint (for two specific types of footprint indicator). It has been argued that the spatial model should be regarded as a quite reliable theoretical guide to spatial sustainability, as it covers trade advantages, agglomeration effects, and environmental externalities. By implication, the ecological footprint is not a reliable guide to spatial sustainability.

The conclusion is that global welfare evaluation is preferred when analyzing spatial sustainability and sustainable trade issues. The global and especially regional ecological footprint do not provide information that is useful from the perspective of welfare enhancing sustainable development. It has further been shown that only in the case in which environmental externalities dominate agglomeration and trade, EF and spatial welfare evaluation are identical. Evidently, this is not a very realistic depiction of a reality that is characterized by various agglomeration and trade advantages.

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APPENDIX

APPENDIX 1

OVERVIEW OF THE RESULTS FOR THE THREE ALTERNATIVE APPROACHES

Spatial configuration	Region/World	SWE (*Meu*)[5]	EF[1] (*ha*)	EF[2] (*ha*)
	1	0.24	10.82	3.59
A	2	0.24	10.82	3.59
	1+2	0.241	21.64	7.18
	1	0.30	11.70	3.89
B	2	0.25	10.30	3.42
	1+2	0.27	22.02	7.31
	1	0.27	11.70	3.90
C	2	0.20	9.89	3.28
	1+2	0.243	21.60	7.18
	1	0.29	11.20	3.72
D	2	0.29	11.20	3.72
	1+2	0.29	22.40	7.44
	1	0.33	12.50	4.13
E	2	0.23	9.77	3.25
	1+2	0.25	22.20	7.38

[5] *Monetary equivalent unit*

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