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Welfare measures and ecological footprint as spatial sustainability indicators

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Abstract:
The aim of this paper is to compare a social welfare (SW) indicator for sustainability with the ecological footprint (EF) indicator for measuring spatial sustainability. The framework applied follows the line of a core-periphery model of 'new economic geography' as put forward in Grazi, van den Bergh and Rietveld, EnvironResourceEcon, 38(2007) with interregional trade, agglomeration advantages and resource (land) use or environmental externalities. Welfare or sustainability indicators rely on quantitative relations between economic welfare, externalities and the integrity of (global) natural capital. We argue that these relationships, in order to be comparable, should be specified in a similar way in both indicator concepts (SW function and EF). The main difference between the two indicators is that the EF concept works with a binding resource constraint ('biocapacity') and therefore exclusively represents strong sustainability, while the SW indicator can be specified in a way to represent strong as well as weak sustainability. If the SW function is specified and parameterized as an indicator for strong sustainability, we get similar results for the welfare ranking of different land use configurations. If the SW function is specified and parameterized as an indicator for weak sustainability, we replicate the results of Grazi, van den Bergh and Rietveld (2007) that EF and SW lead to completely different welfare rankings of different land use configurations.

Key words: ecological footprint, social welfare measures, weak and strong sustainability
JEL-classification: F12, F18, Q56, R12

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1. Introduction

The ‘Ecological Footprint (EF) indicator’ - first proposed by Wackernagel and Rees (1996) – can be seen as a biophysical measure of natural capital and as a physical indicator of strong sustainability. The starting point of the paradigm of 'strong' sustainability is the observation of absolute scarcity of certain natural resources, that leads to binding resource constraints (Daly, 1990). This binding resource constraint represents a limit for the exploitation of non-renewable natural resources or for the carrying capacity of ecosystems to absorb emissions. The potential of substitutability between natural and man-made capital, which is the core of the 'weak' sustainability paradigm, is therefore limited, when resource constraints are binding.

As Neumayer (2002) has shown, the application of weak sustainability has advanced much more than the application of strong sustainability. Measures of strong sustainability are mainly based on physical indicators (like the EF and material flow accounts) and only partly on monetary indicators or measures of social welfare. The development of monetary measures of strong sustainability is limited to a few approaches, like for example the 'Sustainable National Income' (SNI, Hueting, et.al., 1992; Gerlagh, et.al., 2002). Another recent example of extending physical measures towards monetary measures of strong sustainability is Kratena (2008).

The EF concept has been extensively criticised for various reasons (see e.g. Lenzen et al. 2007; Wiedmann and Lenzen 2007; Wiedmann et al. 2006 and references therein),and the adequacy of the EF concept for policy guidance has been discussed very controversially among ecological economists (Ayres, 2000, Costanza, 2000, van den Bergh et.al., 1999 and Neumayer, 2002). One important shortcoming is the arbitrary spatial scale level at which the footprint is applied and measured (world, nation, region, city). As van den Bergh and Verbruggen (1999) have pointed out, the footprint contains an 'anti-trade bias' by implicitly assuming,that sustainability must be reached on the regional level without taking into account trade and comparative advantage. Especially for global environmental problems,like CO_2 emissions, the balancing between national land use and national biocapacity is meaningless from an environmental point of view. This critique has been partly considered recently in applications, which link EF accounts with input-output model systems and account for EF induced in other regions via imports and domestically induced EF for other regions via export. The conclusion in such a framework is, that ecological deficits need not necessarily to be compensated at the national level. The relevant policy question in such a setting is about the reduction of global EF and about the links between the social welfare increasing impact of trade and the international distribution of ecological deficits (see: van den Bergh and Verbruggen, 1999 as well as Ohl, Wolf and Anderson, 2008).

When the concept of static spatial sustainability is applied, the issues of the dynamic model (s.: Stavins, Wagner und Wagner, 2003), especially discounting, are absent, but the distinction between weak and strong sustainability is still upheld. Spatial sustainability is applied to different spatial configurations and takes local as well as global environmental externalities into account. Direct comparisons between social welfare (SW) indicators of weak sustainability and pure ecological indicators of strong sustainability like the EF are difficult. A recent paper by Grazi, van den Bergh and Rietveld (2007) carries out such comparisons of evaluations based on SW and EF indicators. The problem of incommensurability of social welfare accounting and pure ecological accounting is avoided by only comparing the ranking of different spatial configurations.

We take this modelling framework as a starting point and introduce the difference between weak and strong sustainability in new specifications for the SW function and the EF indicator. The SW function is specified in a way that allows for different parameterizations representing different concepts of sustainability (weak vs. strong sustainability). The main feature of strong sustainability is a binding resource constraint, which is identical in physical terms for both indicators. Emissions and externalities up to this level can easily be compensated by utility from consumption in the SW function. This treatment of environmental externalities in the SW function can be seen as consistent with the treatment of footprint in EF accounts. The footprint of a region is confronted with the available 'biocapacity' of this region yielding 'ecological deficit' as the balancing item. This 'ecological deficit' represents the overshoot of footprint over natural capital. Like Hueting and Reijnders (1998), we argue, that this concise treatment of environmental pressure compared to natural capital either in the form of externalities in a SW framework or as a physical indicator in EF accounts follows from the research results of natural science. It is the task of natural science to quantify the binding resource constraint for the anthropogenic environmental influence and to derive a standard for strong sustainability. The binding resource constraint can then be combined with environmental pressure in different specifications to derive an indicator for sustainability. In the EF indicator it is just the balance between both aggregates that defines sustainability. Therefore, if environmental externalities break the binding resource constraint, the EF indicator will always result in a deterioration of sustainability for any further increase of environmental externalities. In the SW framework we specify a function, in which the increase of environmental externalities above the binding resource constraint can either be compensated by the accompanying increase in utility from higher consumption (weak sustainability) or not (strong sustainability). The difference between these two forms of the SW function consists in the parameterization for the intensity of the environmental externality.

Like Grazi, van den Bergh and Rietveld (2007) we implement the reduced form of the model for numerical simulations of the welfare impact of different land use configurations. In the case of weak sustainability we get the result, that environmental externalities can partly be compensated by welfare from consumption. In a second simulation exercise we increase the parameter in the SW function that measures the intensity of the environmental externality. This increase in the parameter is very small and is calibrated with respect to estimates of the long-run economic impacts of environmental damage from climate change (Stern, 2006). This parameterization represents strong sustainability, as the economic disutility from environmental externalities is significant and cannot be compensated by welfare from consumption. An evaluation of different land use configurations with this specification of the SW function yields the same ranking as in the framework of physical footprint accounting. These results considerably differ from the results of a sensitivity analysis for the intensity of environmental externalities presented in Grazi, van den Bergh and Rietveld (2007). Their results indicate, that only for implausibly high values of the parameter in their SW function, the ranking of the different land use configurations becomes the same as in the EF concept. These differences in the results between our simulation and the sensitivity analysis in Grazi, van den Bergh and Rietveld (2007) are due to different specifications of the SW function. In our model the SW function reacts to the balance between the natural absorption capacity for emissions (derived from biocapacity in the EF concept) and actual emissions. This specification follows the concept of damage functions used in integrated assessment models of climate change (Nordhaus, 1992, 1998).

The paper is organized as follows. In section 2 the economic model of consumption, production and interregional trade is lined out. Section 3 presents and discusses the two indicators for spatial sustainability, namely the footprint and the SW function. In section 4 this model is used to evaluate the same land use configurations as in Grazi, van den Bergh and Rietveld (2007). The simulation results are presented and discussed. Finally section 5 draws some tentative conclusions.

2. The new economic geography model

In the following, we mainly rely on the core-periphery model of interregional trade in the tradition of Krugman (1991) as formulated in Forsild and Ottaviano (2003) and applied to spatial sustainability in Grazi, van den Bergh and Rietvald (2007). Agglomeration effects are not explained endogenously, but represented by certain parameter constellations as in Grazi, van den Bergh and Rietvald (2007). In general, agglomeration effects in this model lead to a reduction in transport costs and commodity prices and are therefore welfare relevant. The main 'ingredients' of the core-periphery model in Krugman's (1991) tradition are: imperfect competition in the manufacturing goods markets (Dixit-Stiglitz model), iceberg-transport costs as first laid down by Samuelson (1954) and positive externalities from agglomeration. Migration of labour is not considered in this simplified model. The model is enriched by taking into account environmental externalities from production and transport and land use linked to economic activity. The general structure of the model follows Grazi, van den Bergh and Rietveld (2007). Important differences can be found in the specification of consumers' utility and social welfare. That leads in a second step to a model formulation, where the environmental externalities are linked to the footprint accounting framework.

Consumption

We start from a formulation of consumer utility in region j, where the consumer can spend her income Y_j for agricultural (A_j) or manufactured (M_j) goods:

$$U_j = A_j^{(1-\delta)} M_j^{\delta} \Omega \tag{1}$$

This utility function allows for integration of environmental externalities as in Grazi, van den Bergh and Rietveld (2007). The term Ω contains the impact of externalities on utility, but is formulated in a different way from that in Grazi, van den Bergh and Rietveld (2007), as will be laid down in the next section.

The market for agricultural goods is fully competitive, whereas the market for manufactured goods follows the Dixit-Stiglitz model of imperfect competition. Consumption of manufactured goods produced in region k and consumed in region j and consumption in region j of domestic goods make up for total consumption of manufactures in j:

$$M_j = \left[\int_{i=0}^{n_k} c_{kj}^{(\varepsilon-1)/\varepsilon}(i)di + \int_{i=0}^{n_j} c_{jj}^{(\varepsilon-1)/\varepsilon}(i)di\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{2}$$

In (2) n_j and n_k is the number of varieties in both regions and we have $N = n_1 + n_2$ as the number of total varieties. The consumers' budget constraint states that income Y_j can be spent for agricultural goods A_j and for manufactures (c_{jj}, c_{kj}) with the corresponding prices (p_{jj}, p_{kj}) and the constant eleasticity of substitution ε. Total income is made up of compensation of unskilled labour L_j with the numéraire wage rate and skilled labour H_j with wage rate w_j :

$$Y_j = w_j H_j + L_j \tag{3}$$

From utility maximization under the budget constraint restriction the demand function in region j for a variety i produced in region k is derived as:

$$c_{kj}(i) = p_{kj}(i)^{-\varepsilon}\left(P_j^{\varepsilon-1}\delta Y_j\right) \tag{4}$$

In (4) $P_j^{\varepsilon-1}$ is the CES price index of all varieties i consumed in region j :

$$P_j = \left[\int_{i=0}^{n_k} p_{kj}^{1-\varepsilon}(i)di + \int_{i=0}^{n_j} p_{jj}^{1-\varepsilon}(i)di\right]^{\frac{1}{1-\varepsilon}} \tag{5}$$

Equations (2) to (5) describe the core of the standard Dixit-Stiglitz imperfect competition formulation used in the core-periphery model. As will be shown below, we also introduce the term containing externalities Ω in a standard formulation, usually applied in empirical models of integrated assessment of energy use and climate change.

Production

The supply side is characterized by firms producing varieties i with increasing returns to scale by inputs of skilled H_j and unskilled labour L_j in each region. In this setting a fixed proportion α of skilled labour H_j per unit of output necessary for the production of manufactures determines the number of varieties in each region n_j, as well as the fixed costs of production. The number of varieties becomes:

$$n_j = \frac{H_j}{\alpha} \tag{6}$$

Total costs $g_j(i)$ of producing a variety i comprise fixed costs of skilled labour inputs with wage rate w_j and variable costs of unskilled labour inputs with β_j as unit labour costs of unskilled labour (the wage rate for unskilled labour has been chosen as the numéraire):

$$g_j(i) = \alpha w_j + \beta_j x_j(i) \tag{7}$$

It must be noted, that this formulation of the core-periphery model corresponds to the model in Grazi, van den Bergh and Rietvald, (2007) as it does not allow for mobility of workers across regions, but uses different distributions of skilled workers across regions as inputs of exogenous variables for numerical simulations. Agglomeration effects are also treated as exogenous and captured in the parameters β_j, which can be changed for simulations. The β_j therefore can be defined independently for regions and are not set equal across the two regions like in Forsild and Ottaviano (2003). The impact of agglomeration effects on the economy consists of an increase in the firms' productivity and a decrease in unit costs of production. This lower unit cost is passed on to goods prices in the imperfect competition setting and thereby increases consumers' demand and utility.

For interregional trade Samuelson's traditional concept of 'iceberg'-transport costs is applied. Shipping a variety i from region j to region k implies that only a fraction $(1/T_{jk})$ arrives at k, with the rest 'melting away'. Consequently, the price of goods produced in j and shipped to k is augmented by a transport cost term:

$$p_{jk}(i) = p_{jj}(i) T_{jk} \tag{8}$$

Transport costs are only determined by the (economic) distance between regions and are therefore symmetric ($T = T_{jk} = T_{kj}$). At the same time transport costs have implications for quantities, as T times more quantities have to be shipped. Production in each region therefore also contains this transport cost term:

$$x_j(i) = c_{jj}(i) + T_{jk} c_{jk}(i) \tag{9}$$

Finally, profits of firms in a region ($\pi_j(i)$) are given by the difference between revenues and costs:

$$\pi_j(i) = p_{jj}(i)c_{jj}(i) + p_{jk}(i)c_{jk}(i) - \alpha w_j - \beta_j x_j(i) \tag{10}$$

The framework of imperfect competition with different varieties of goods incorporates the price setting mechanism of monopolistic competition, where the constant mark up firms charge on variable costs (β_j), is determined by the elasticity of substitution in demand (ε):

$$p_{jj}(i) = (1 - 1/\varepsilon)^{-1}\beta_j \tag{11}$$

In equilibrium profits are zero. That yields the equilibrium wage rate w_j by plugging in (9) and (11) into (10):

$$w_j = \frac{\beta_j x_j(i)}{\alpha(\varepsilon - 1)} \tag{12}$$

The equations for food supply and consumption in each region complement the new economic geography model. The unskilled labour force not employed in the manufacturing sector is available for agricultural production F_j and determines food production, given a unitary productivity of unskilled labour in this sector:

$$F_j = L_j - \beta_j n_j x_j \tag{13}$$

The difference between agricultural output F_j and agricultural consumption A_j in a region gives the volume of agricultural trade, z_j:

$$z_j = F_j - A_j \tag{14}$$

3. Spatial sustainability

The model is enlarged by measuring spatial sustainability at all different scales, i.e. for the two regions as well as for the global economy. As van den Bergh and Verbruggen (1999) have pointed out, applying the footprint concept at the regional level implicitly assumes that the footprint has to be compensated at the regional level and introduces an 'anti-trade' bias. Full regional mitigation of global environmental problems like CO_2 emissions (carbon footprint) is meaningless even from an ecological point of view. Therefore, in the following, spatial sustainability will be treated at the regional as well as the global level to analyze the interactions between regional environmental pressure and trade. Like Grazi, van den Bergh and Rietvald (2007), we use two different spatial sustainability indicators in the new economic geography model: (i) the ecological footprint (EF) and (ii) the social welfare (SW) function based on the utility function (1).

We further emphasize the difference between weak and strong sustainability at the spatial level. Strong spatial sustainability shall be defined as a state of a regional economy, where the total use of resources and the total pressure on the environment is in balance with total natural capital of this region. The regional natural capital represents the binding resource constraint, which is the main characteristic of strong sustainability. Weak spatial sustainability shall be defined as a state of a regional economy, where an overshoot of the total use of resources and of the total pressure on the environment can be compensated by higher utility from consumption. The 'anti-trade' bias of the footprint concept for spatial sustainability can be avoided by focusing on the global footprint. At this point, it is important to note that both for strong and weak sustainability only the relation between environmental pressure and natural capital determines spatial sustainability, not the environmental pressure itself. This is especially relevant for comparisons of different spatial configurations - as will be carried out in the next section - with different endowments of natural capital.

The two different spatial sustainability indicators shall be treated in a similar manner by linking emissions with footprint in the EF indicator and with externalities in the SW function. Additionally, we specify both sustainability indicators in the sense, that only the imbalance between environmental pressure and natural capital is relevant for sustainability.

3.1. Land use and ecological footprint

Concerning the formulation of footprint accounts, we stick to the notation of Grazi, van den Bergh and Rietveld (2007), which is in turn based on Wackernagel and Rees (1996) and the international EF accounts. We start with the land use from agricultural, forestry, and fishing activities defining these footprints by:

$$\ell_j^C = \gamma A_j^\varsigma \tag{15}$$

$$\ell_j^G = \eta A_j^\lambda \tag{16}$$

$$\ell_j^{FO} = \mu A_j^\nu \tag{17}$$

$$\ell_j^{FI} = \rho A_j^\sigma \tag{18}$$

The footprints of crops, ℓ_j^C , grazing land, ℓ_j^G , forestry, ℓ_j^{FO} , and fishing, ℓ_j^{FI} , are all directly linked to agricultural output in a region, A_j, by a scaling parameter as well as by a power function, allowing for non-linear relationships. These footprints from the agricultural sector are complemented by the footprint of built-up land, ℓ_j^B, which is linked to population in a region (Pop_j), and the footprint from air emissions due to energy use, also known as 'energy land', and called the 'hypothetical footprint', ℓ_j^H as in Grazi, van den Bergh and Rietveld (2007):

$$\ell_j^B = \xi Pop_j^{1/\beta_j^B} \tag{19}$$

$$\ell_j^H = \varphi E_j \tag{20}$$

The population is calculated by considering the labour force participation rate g for given labour forces of skilled and unskilled by region: $Pop_j = 1/g(L_j + H_j)$. The specification in (19) takes into account, that land use for building is linked to agglomeration, although the parameter β_j^B used here is not exactly the same as the one measuring the cost advantage of agglomeration in production (β_j).

As in the EF accounts, the 'hypothetical footprint' ℓ_j^H is directly linked to air emissions in region j by the fixed conversion factor φ. This conversion factor represents the necessary area of biocapacity (in ha) to absorb one unit of emissions (in tons). As we want to link the EF indicator concept to the SW indicator concept we define emissions by region E_j as Grazi, van den Bergh and Rietveld (2007) define externalities in the SW concept:

$$E_j = m(n_j x_j)^a (F_j)^b \left[1 + \frac{Tc_{jk}(i) + Tc_{kj}(i)}{2} + \frac{z_k + z_j}{2}\right]^d \tag{21}$$

Emissions which are the base for externalities are therefore linked to agricultural output (A_j), manufacturing output (M_j) and transport volume T. This function is based on the work of Ebert and Welsch (2004) on environmental indices and reveals the property $a + b + d = 1$. Like in Grazi, van den Bergh and Rietveld (2007), E_j comprises local externalities as well as global ones, like greenhouse gases. For these global externalities, the region, where they are released to environmental media, is irrelevant and only the sum of these externalities matters, so that:

$$E = \sum_j E_j \tag{22}$$

The total footprint is defined as the sum of all land use categories:

$$EF_j = \ell_j^C + \ell_j^G + \ell_j^{FO} + \ell_j^{FI} + \ell_j^B + \ell_j^H \tag{23}$$

This total footprint therefore represents the total pressure of economic activity on the environmental factor land, including actual land use as well as the land necessary to absorb emissions. This treatment of the total footprint is consistent with international EF accounts.

Differentiating between actual land use ℓ_j^{ACT} and hypothetical land use ℓ_j^{H} ('energy land') leads us to put all actual land use categories into one term $\ell_j^{ACT} = \ell_j^{C} + \ell_j^{G} + \ell_j^{FO} + \ell_j^{FI} + \ell_j^{B}$, so that total footprint might be written as:

$$EF_j = \ell_j^{ACT} + \ell_j^{H} \tag{24}$$

According to the footprint concept as outlined above, a region's total footprint is no direct measure for sustainability. As far as footprint in a region is balanced by biocapacity in (possibly a different) region, the economy is in a sustainable state (in the comparative static perspective applied here).

In the EF accounts, biocapacity is given partly by the same categories of land as the footprint (cropland, pastures, forestry, and fishery). Available biocapacity therefore is determined by the stock of natural capital as well as actual land use for agriculture, forestry, etc. The stock of biocapacity (or 'nature' land) ℓ_j^{N} therefore becomes endogenous and is defined as the difference between the total available land ℓ_j^{TOT} and the actual land use ℓ_j^{ACT}:

$$\ell_j^{N} = \ell_j^{TOT} - \ell_j^{ACT} \tag{25}$$

Total available land can be seen as the ultimate resource constraint from a perspective of strong sustainability. Grazi, van den Bergh and Rietveld (2007) also include such a definition in their model, but do not draw conclusions for different concepts of spatial sustainability from that.

The sustainability indicator that can be derived from the footprint concept is the balance between total footprint EF_j and biocapacity or 'nature' land ℓ_j^{N} usually named as 'ecological deficit', ED_j:

$$ED_j = EF_j - \ell_j^{N} = 2\ell_j^{ACT} + \varphi E_j - \ell_j^{TOT} \tag{26}$$

The indicator therefore is a positive function of the term $\left(\ell_j^{ACT} + \varphi E_j - \ell_j^{TOT}\right)$, i.e. the difference between both types of footprint (actual land use and 'energy land'), and the total available area of land. Positive numbers of ED_j indicate an 'ecological deficit' and an unsustainable state of the region, whereas negative numbers of ED_j indicate an 'ecological surplus', i.e. a state of spatial sustainability.

3.2. Social welfare and environmental externalities

In equation (1) the term Ω stands for the inclusion of environmental externalities into the utility function of the representative consumer. In Grazi, van den Bergh and Rietvald, (2007), environmental externalities are specified as in (21) and directly enter the utility function. They are given an impact by a parameter measuring the intensity of environmental externalities (θ). We take this specification of emissions as a starting point for specifying the term Ω. Spatial sustainability shall be measured in an analogous form as in the footprint concept, i.e. by the balance between environmental pressure and natural capital. Environmental pressure is again measured as in (21) and externalities arise from the overshoot of environmental pressure over certain thresholds. This treatment of environmental externalities is similar to the one in the "Integrated Assesment Models" (IAMs) of climate change (Nordhaus 1992, 1998), where the concept of damage functions is applied. These functions assume that climate change leads to damages which are proportional to the increase of temperature above a certain level, mostly the pre-industrial temperature. This pre-industrial temperature level represents the standard of strong sustainability as it describes an environment without anthropogenic climate change. Again, it is therefore not emissions itself, like in Grazi, van den Bergh and Rietvald (2007), which directly lead to a deterioration of the state of the environment, but the overshoot of emissions above the natural capacity of absorption. In a dynamic framework, this balancing between emissions and the natural capacity of absorption would have to take into account stock/flow interactions (Kraev, 2002) or different rates of reaction of aggregates (Hofkes, 1996). These aspects are absent in this purely static sustainability framework. Excessive emissions in this static framework lead to an increase in atmospheric concentration of greenhouse gases and then in turn to an increase in temperature. An operational world model that captures the influence of greenhouse gases and atmospheric CO_2 concentration on temperature increase as well as the feedback on the economy by damages can already be found in Nordhaus (1992). We adapt this damage function-concept for the model here by dealing with emissions and natural capacity of absorption instead of temperature levels. It is assumed that environmental externalities in region j, Ω_j, can be approximated by the following quadratic function:

$$\Omega_j = \left[1 + \theta_1 \left(E_j + E - \ell_j^N / \varphi\right)\right]^{\vartheta_2} \tag{27}$$

with $\theta_1 > 0$ and $\theta_2 < 0$. E_j is the regional and E the global externality as above and ℓ_j^N corresponds to 'nature land' as in (25). The parameter φ is the same conversion factor of footprint accounts as in (20). The treatment of spatial sustainability is similar to the footprint concept, as only the imbalance between environmental pressure and natural capital matters. The two sustainability indicators are linked via a common definition of emissions and by the resource constraint from 'nature land', ℓ_j^N. We want to emphasize the point that this similar treatment of externalities and sustainability follows from natural science and corresponds to the concept of 'strong' sustainability with a binding resource constraint. The binding resource constraint simply stems from total available land in each region, ℓ_j^{TOT} .

The externality (27) can then be plugged into the utility function (1) to derive the welfare level of the representative consumer in a region:

$$U_j = A_j^{(1-\delta)} M_j^{\delta} \left[1 + \theta_1 \left(E_j + E + \left(\ell_j^{ACT} - \ell_j^{TOT}\right) / \varphi\right)\right]^{\theta_2} \tag{28}$$

We get the same property for the disutility from externalities in social welfare as for the ecological deficit above, namely that it is a positive function of the term $\left(\ell_j^{ACT} + \varphi E_j - \ell_j^{TOT}\right)$.

The SW index is then derived as the sum of these regional welfare levels weighted by population:

$$W = \left[U_j^{(H_j + L_j)} U_k^{(H_k + L_k)}\right]^{1/(H+L)} \tag{29}$$

Although the two indicators of spatial sustainability are linked now by a common concept of defining overshoot of environmental pressure over natural capital, there are still important differences between them. The ecological deficit only measures environmental spatial sustainability and does not allow for confronting economic welfare gains with environmental externalities. Therefore it is only a measure for strong sustainability. The SW index combines environmental externalities accompanying agglomeration with economic welfare from agglomeration effects and could represent strong as well as weak sustainability. That depends on the relation between the disutility of externalities above the binding resource constraint and the utility from consumption. For strong sustainability, the compensatory potential of utility from consumption in an economy that is in overshoot over the binding resource constraint is limited or even ruled out.

Additionally, the population weighting and the addition of local and global environmental externalities in the SW indicator, introduce a bias against the impact of global environmental externalities. This is especially relevant for spatial configurations, where one of the two regions is nature dominated and not densely populated (see next section), so that the low environmental impact in this region gets a low weight for the overall social welfare.

4. Numerical simulations of different land use configurations

In a first step, we derive the reduced form model as in Grazi, van den Bergh and Rietveld (2007). First, we derive a new expression for manufacturing output x_j in a region by inserting the price equations (8) and (11) into the CES price index (5) and both into the output equation (9). This together with the number of varieties (6), the equilibrium wage rate (12) and the income constraint comprises the reduced form model:

$$x_j = \frac{\delta}{\varepsilon}\frac{\varepsilon - 1}{\beta_j^{\varepsilon}}\left[\frac{Y_j}{n_j\beta_j^{1-\varepsilon}n_k\beta_k^{1-\varepsilon}} + \frac{T^{1-\varepsilon}Y_k}{T^{1-\varepsilon}n_j\beta_j^{1-\varepsilon}n_k\beta_k^{1-\varepsilon}}\right] \tag{30}$$

$$n_j = \frac{H_j}{\alpha} \tag{6}$$

$$w_j = \frac{\beta_j x_j(i)}{\alpha(\varepsilon - 1)} \tag{12}$$

$$Y_j = w_j H_j + L/2 \tag{3a}$$

In (3a) we have assumed that the unskilled labour force L is divided evenly between the two regions. Consumption in both regions, agricultural output and trade volumes directly follow from the solution of this reduced form of the model. The model is then complemented by the equation for emissions, from which the two indicators for spatial sustainability are derived:

$$E_j = m(n_j x_j)^a (F_j)^b \left[1 + \frac{Tc_{jk}(i) + Tc_{kj}(i)}{2} + \frac{z_k + z_j}{2}\right]^d \tag{21}$$

$$ED_j = EF_j - \ell_j^N = 2\ell_j^{ACT} + \varphi E_j - \ell_j^{TOT} \tag{26}$$

$$U_j = A_j^{(1-\delta)} M_j^{\delta} \left[1 + \theta_1 \left(E_j + E + \left(\ell_j^{ACT} - \ell_j^{TOT}\right) / \varphi\right)\right]^{\theta_2} \tag{28}$$

$$W = \left[U_j^{(H_j + L_j)} U_k^{(H_k + L_k)}\right]^{1/(H+L)} \tag{29}$$

The global measure in the EF indicator is given by the sum of the ecological deficits of both regions. This model has been used to simulate the same spatial configurations as presented in Grazi, van den Bergh and Rietveld (2007) with the same parameterization for those functions which have specifications identical to Grazi, van den Bergh and Rietveld (2007). Table 1 shows the five different spatial configurations for region j and region k and their definition via agglomeration effects. The spatial configurations are combinations of regions with agglomeration, agriculture-dominated regions, and nature-dominated regions. As has been lined out, agglomeration effects are captured in this model via the (exogenous) parameter β_j that directly influences productivity and thereby costs and commodity prices. On the other hand a similar parameter β_j^B also influences land use for built up-land, linked to population by region. The model does not contain the endogenous movement of labour, but assumes instead that nature-dominated regions are less densely populated than both agriculture-dominated regions and regions with agglomeration. For all other spatial configurations the population of high-skilled labour is equally distributed across regions.

The agriculture-dominated region is characterized by no specific agglomeration advantages and is normalized by setting the 'agglomeration parameter' β_j equal to unity. In this region no specific impact on productivity is at work that would lead to lower unit costs and commodity prices. Also no specific driving force for land use by built up-land is active in this spatial configuration and β_j^B is also equal to 1. In a region with agglomeration massive cost saving impacts are generated in production leading to a doubling of productivity and therefore to lower costs and output prices. Use of built up-land is also extended massively in the agglomerated region though not with the same multiplier as the economic advantages of agglomeration compared to the agriculture-dominated region; the corresponding parameter β_j^B is only lowered to 0.65 instead of 0.5. For the nature dominated region, disadvantages of non-agglomeration are at work at the production side by assuming only half of the productivity as in the agriculture-dominated region leading to higher costs and output prices. Equally, the pressure by use of built up-land is only half that of the agriculture-dominated region.

>>>>>>>> Table 1: Spatial configurations and agglomeration effects

Most of the economic and land use parameters shown in Table 2 have been taken from Grazi, van den Bergh and Rietveld (2007). The parameters describing the consumption and production side of the model (including labour endowment and labour force participation) are identical. The only different parameterization in the economic model concerns the different specification of environmental externalities in the utility function. In general the configuration

B (agglomeration/agriculture dominated) has been chosen to calibrate the model to the existing data from EF accounts and from long run economic impacts of environmental damage, especially due to climate change. This configuration can be seen as the correspondence to the theoretical structure of the core-periphery model lined out in section 2. Taking into account the work of Nordhaus on the parameterization of damage functions and the most recent research on the long-run economic damages of climate change (Stern, 2006) we choose parameter values of $\theta_1 = 0.2$ and $\theta_2 = -0.1$ in a baseline specification of the model. The Stern Review gives an exhaustive overview of potential long-run economic costs of climate change and puts an emphasis on introducing uncertainty about extreme events into model simulations. The main result from that is a range of long-run costs of climate change between 5% and 13% of GDP.

In order to make that consistent with EF accounts we also had to deviate from Grazi, van den Bergh and Rietveld's specification concerning the impact of population on built up-land measured by the term ξ^{1/β_j^B}. The value of this term is fixed at 0.5, in order to get values for global footprint due to built up-land, that are consistent with global EF accounts.

For the conversion of emissions (in tons of CO_2) into 'energy land' ´(in ha) measured by the parameter φ we use the value of 5 from the methodology underlying the EF accounts (Wackernagel, et.al., 2005). All the other land use parameters have been taken from Grazi, van den Bergh and Rietveld (2007).

That gives for spatial configuration B a baseline solution, where the ecological deficit is about 20 for a given total land endowment of about 43, implying a relationship close to the global EF accounts. At the same time the spatial configuration B does not show significant global environmental externalities, which lower global social welfare. The average value of the term $\left[1+\theta_1\left(E_j+E+\left(\ell_j^{ACT}-\ell_j^{TOT}\right)/\varphi\right)\right]^{\theta_2}$ is almost unity, and does not lower social welfare (it is insignificantly below zero in region j with agglomeration and insignificantly above zero in agriculture-dominated region *k*). Conversely, in spatial configuration D (agglomeration/agglomeration), both regions are characterized by agglomeration and the term $\left[1+\theta_1\left(E_j+E+\left(\ell_j^{ACT}-\ell_j^{TOT}\right)/\varphi\right)\right]^{\theta_2}$ is about 6% below unity. This can be seen as consistent with the lower bound of the range of long-run costs of climate change (5% to 13% of GDP). The parameterization with θ_2 = -0.1 therefore sets economic costs (damages) of environmental pressure in all spatial configurations at the lowest level consistent with the existing literature. Additionally this parameterization represents a low intensity of externalities in the SW function and makes it very probable, that utility gains from higher consumption levels will compensate for higher disutility from externalities. Therefore, this parameterization might be seen as an application of the paradigm of weak sustainability.

>>>>>>>>>>> *Table 2: Parameter values of the model*

We reaffirm the results of Grazi, van den Bergh and Rietveld (2007) for this situation of weak sustainability (θ_2 = -0.1), that the ranking of the spatial configurations under the SW criterion is almost completely opposite from the ranking under the ecological deficit (EF) criterion, as shown in Table 3. In our view, this expresses the main postulate of weak sustainability, that in a situation where environmental externalities can be balanced by economic advantages of higher consumption (in that case due to agglomeration advantages), the economy is in a sustainable state.

>>>>>>>>>>> *Table 3: Ranking of different spatial configurations for weak (θ_2 = -0.1) and strong (θ_2 = -0.4) sustainability (welfare measure vs. ecological deficit)*

This is achieved here despite the fact that in spatial configuration D, where both regions face agglomeration, the environmental costs amount to about 6% of total welfare. The overall impact on total welfare, when moving from configuration B to D, is positive, because the economic agglomeration advantages in configuration D compared to B more than compensate for the increase in externalities.

As shown in Table 4, the ecological deficit increases from about 20 units in configuration B to over 100 units in configuration D, clearly indicating global spatial un-sustainability of this configuration. The land-use configuration C (agriculture dominated/nature dominated) is characterized by the existence of a global ecological surplus. This spatial configuration ranks least favourable from a social welfare point of view in the case of weak sustainability. It might also be argued that from an EF point of view, a global ecological surplus is sub-optimal, and it is plausible, that it might be accompanied by economic disadvantages lowering overall welfare.

>>>>>>>>> *Table 4: Sustainability indicators for weak sustainability (θ_2 = -0.1)*

>>>>>>>>> *Table 5: Sustainability indicators for strong sustainability (θ_2 = -0.4)*

The only similarity in the results of both indicators in the case of weak sustainability (θ_2 = -0.1) is, that land-use configuration A (agriculture dominated/agriculture dominated) ranks better than land-use configuration E (agglomeration/nature dominated). This similarity, though, is due to very different balancing mechanisms between utility from consumption and environmental externalities in both indicator concepts. Moving from A to E induces economic advantages from agglomeration and higher land use and emissions (externalities) in region *j*. Region *k* faces economic disadvantages by moving to a nature-dominated economy and lower land use and emissions (externalities). These changes bring about a larger global footprint and higher global economic utility from consumption, thereby improving both indicator values.

In order to represent strong sustainability in the SW indicator, the parameter value for θ_2 is changed to -0.4 leading to about 9% of economic impact of environmental externalities in spatial configuration B in region j. This value can be seen as an average of the range for long term economic impacts of climate change as reported in the Stern Review (Stern, 2006). We argue that this increase in the impact of environmental externalities represents a change towards the paradigm of strong sustainability, as it is possible, that high levels of consumption lead to an overshoot of externalities over the binding resource constraint. This can in turn produce a large increase in disutility from externalities, which might outweigh the utility increase. The change in the parameter value for θ_2, in general, decreases disutility from environmental externalities for all regions without agglomeration, as shown in Table 5. That means that those land-use configurations, where none of the two regions is characterized by agglomeration, i.e. A, C and E, face higher social welfare than with a parameter value of $\theta_2 = -0.1$. For land-use configuration B, social welfare in the agglomeration-region j is lower for $\theta_2 = -0.4$ than for $\theta_2 = -0.1$, whereas social welfare in the agriculture-region k is higher. The result of these two opposite changes for the SW indicator is an overall global increase in social welfare in B for $\theta_2 = -0.4$ compared to the weak sustainability case ($\theta_2 = -0.1$). This is due to the fact, that the social welfare gains from low environmental pressure in region k get a higher weight in the SW indicator.

Major changes can be seen in the strong sustainability case for land-use configuration D. Environmental costs are very significant in configuration D amounting to about 20% of total global welfare. In an agglomerated world, therefore, environmental externalities are in imbalance with binding resource constraints to such an extent that economic utility from higher consumption is completely crowded out by the large disutility from environmental externalities. The general result in the strong sustainability case is, that when θ_2 is changed to -0.4 the model yields the same ranking for the spatial configurations from both indicators.

These results are in contrast to a sensitivity analysis reported in Grazi, van den Bergh and Rietveld (2007), where they only get this result of identical rankings for implausibly high values of their parameter θ, measuring the intensity of environmental externalities. This discrepancy in results is due to our specification of the SW function in line with the EF concept, so that externalities cause increasing disutility, if the economy is in overshoot over the binding resource constraint.

5. Conclusions

This paper compares two different concepts and indicators for spatial sustainability, namely the ecological footprint (EF) and the social welfare function (SW). The analysis heavily relies on the work of Grazi, van den Bergh and Rietveld (2007), and sets up a similar core-periphery model in the spirit of 'new economic geography' with measures for spatial sustainability. The economic specification of the model is identical with Grazi, van den Bergh and Rietveld (2007), but the specification of spatial sustainability differs considerably. We argue, that the distinction between weak and strong sustainability is also valid for spatial sustainability without any dynamic perspective. The EF indicator is specified as in the EF accounts, where the excess of footprint over 'biocapacity', i.e. the ecological deficit, is taken as the indicator for sustainability. As 'biocapacity' or total available land is a binding resource constraint in the EF indicator, it is a pure measure of strong sustainability. If natural science can identify binding resource constraints for anthropogenic environmental impact, then– as Hueting and Reijnders (1998) propose - this should be taken as the standard for strong sustainability. The SW function we propose also integrates a binding resource constraint and measures disutility from environmental externalities as a function of the overshoot, similar to the EF indicator. Both indicators are therefore linked by a common equation for emissions, which in the SW indicator determine externalities and in the EF indicator enters as 'energy land'. Conversion factors from global EF accounts are used to flexibly convert emissions into land use and vice versa. The ultimate binding resource constraint is total available land, which is by actual land use (agriculture, forestry, built up-land) reduced to natural land. The amount of natural land is then the resource constraint for emissions and 'energy land' and is a common resource constraint in both indicator concepts (EF and SW).

This common base for both indicators leads to a SW function, which can be parameterized in a form to represent weak or strong sustainability alternatively. Numerical simulations with the model show that the SW indicator and the EF indicator yield opposite results for the ranking of different land-use configurations only in the case of weak sustainability. This is the case analysed in Grazi, van den Bergh and Rietveld (2007). In the case of strong sustainability, the SW indicator and the EF indicator yield identical results for the ranking of different land-use configurations. This is achieved by only small changes in one parameter value and is in contrast with the findings in Grazi, van den Bergh and Rietveld (2007).

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Table 1: Spatial configurations and agglomeration effects

	region j	region k	β_j	β_k	β_j^B	β_k^B	H_j	H_k
A	agric.-dominated	agric.-dominated	1	1	1	1	0.5	0.5
B	agglomeration	agric.-dominated	0.5	1	0.65	1	0.5	0.5
C	agric.-dominated	nature-dominated	1	2	1	2	0.8	0.2
D	agglomeration	agglomeration	0.5	0.5	0.65	0.65	0.5	0.5
E	agglomeration	nature-dominated	0.5	2	0.65	2	0.8	0.2

Table 2: Parameter values of the model

economic parameter		land use parameter	
α	5	ζ	1
β_j	0.5 ; 1 ; 2	β_j^B	0.65 ; 1 ; 2
δ	0.4	γ	0.17
ε	1.7	λ	1
θ_1	0.2	η	3.76
θ_2	-0.1 ; -0.4	ν	1
a	0.5	μ	4.86
b	0.3	$\xi^{1/\beta j}$	0.5
d	0.2	σ	1
L	5	ρ	17.7
T	1.79	φ	5
g	0.45	ϕ	0.00011
		ω	0.11

Table 3: Ranking of different spatial configurations for weak (θ_2 = -0.1) and strong (θ_2 = -0.4) sustainability (welfare measure vs. ecological deficit)

	Ranking: 1 = most favourable ; 5 = least favourable				
	1	2	3	4	5
θ_2 = -0.1					
welfare measure	D	B	A	E	C
ecological deficit	C	A	B	E	D
θ_2 = -0.4					
welfare measure	C	A	B	E	D
ecological deficit	C	A	B	E	D

Table 4: Sustainability indicators for weak sustainability (θ_2 = -0.1)

θ_2 = -0.1	utility measure region *j*	utility measure region *k*	welfare measure	ecological deficit
A	1.63	1.63	1.63	5.51
B	1.94	1.60	1.76	21.89
C	1.71	1.11	1.41	-8.78
D	1.94	1.94	1.94	107.65
E	1.97	1.12	1.52	39.31

Table 5: Sustainability indicators for strong sustainability (θ_2 = -0.4)

θ_2 = -0.4	utility measure region *j*	utility measure region *k*	welfare measure	ecological deficit
A	1.85	1.85	1.85	5.51
B	1.82	1.83	1.82	21.89
C	1.84	2.23	2.01	-8.78
D	1.60	1.60	1.60	107.65
E	1.62	1.90	1.74	39.31

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