Spatial Externalities in an Open Environmental-Economic System

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1 Introduction

The United Nations Framework Convention on Climate Change and the associated Kyoto Protocol (KP) are examples of policy proposals which deal with transboundary environmental issues. Externalities, as was discussed in the introductory chapter of this book, are a nasty disease. For a better understanding of externalities in the case of transboundary environmental issues, a theoretical formulation for modeling the interactions between the economic actors and the environmental issues are needed. In the modeling of the fundamental relationships between the economic system and the ecological system, these systems are often treated as spaceless points (see e.g. Wang, Nijkamp and Verhoef, 2001). Important spatial characteristics – such as the distance between the individual consumers and producers, their living space, the location of the firms and households, the infrastructure, the geographical nature of the economic and the ecological systems (mountains, oceans, plains, forest, etc.) – are therefore ignored. However, in most real-world situations, spatial characteristics in fact are an important determinant of human behavior and ecological phenomena. Therefore, the inclusion of spatial characteristics in an analysis may lead to a better understanding of the real world (see Isard, 1956, Krugman, 1991a, Batten, 2001). Especially in the interaction between the economic and the ecological systems, spatial characteristics may cause additional complexities and complications for analyzing the impacts of environmental externalities (see Nijkamp, 1977, Siebert, 1985).

In the literature, we observe that most models that deal with the spatial characteristics reduce the complexities – which arise from adding spatial characteristics into the model – by ignoring some other aspects of real-world events. In addition to the simplified way that the ecological and the economic system are often represented in these models – i.e. as the interaction between both of these systems, and the interactions within each of these systems – spatial interaction models often simplify complexities concerning the issues of: (i) the determination of the borders of the regions; and (ii) the representation of the distance between two regions.

In this chapter, a taxonomy of models that have been developed for analyzing environmental-economic externalities in a spatial setting will be given. For this purpose, the interpretation of externalities in terms of framework of interaction between

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the economic and the ecological system, which was dealt in Wang, Nijkamp and Verhoef (2001), will be extended to include spatial characteristics. In this extended framework, the concept of spatial externality and forms of spatial interactions will be used.

This chapter is planned as follows. Section 2 formalizes the conceptual framework of interaction between the economic and the ecological system and extends this framework to include spatial characteristics. The issue of the determination of the borders of the regions is discussed in Section 3, by further elaborating on the formulation of the spatial landscape and on how this formulation gives rise to different kinds of spatial externalities, given the interaction between the spatial-economic and spatial-ecological aspects. The issue of the representation of the distance between regions will be discussed in Section 4, in order to categorize the set of models in terms of spatial interactions and spatial externalities. Section 5 summarizes the chapter.

2 Formalizing the Conceptual Framework

This section discusses the formalization of an extension of the conceptual framework of the interactions between the economic and the ecological system (as developed in Wang, Nijkamp and Verhoef, 2001) by the inclusion of spatial characteristics.

2.1 The spatial landscape

The spatial landscape (**L**) is a continuous Euclidean space of three dimensions, i.e. $\mathbf{L} \in \Re^3$. Both the economic system and the ecological system operate in this spatial landscape. A two-dimensional representation of this landscape may be found in Figure 1. This landscape may be divided into a discrete number of areas $\mathbf{L}_m = (L_1, ..., L_M)$, which may, as pointed out by von Thünen, Lösch and Isard (see Isard, 1956), be envisioned as a set of points or as a grid system (see also Siebert, 1985). For notational convenience, this chapter will use the bold lettertype to denote sets or subsets, and the normal lettertype to denote specific elements in the set.

2.2 The ecological system

In the ecological system, there are:

(i) a set **Z** of inputs[1], e.g. water, air, metal, fish and other ecological amenities; this set will also denote the amounts of inputs (also known as the stock of the ecological goods). The distribution of the amount of these inputs over the spatial landscape **L** may be denoted by the matrix $\mathbf{Z}^m$, where the superscript m signifies the column of the grid of areas ($\mathbf{L}_m$);

(ii) a set of ecological regeneration processes **R**, which transforms the set of inputs (**Z**) into a set of output factors (**S**). The distribution of the regeneration process over the spatial landscape is assumed to be dependent on the distribution of the presence of the amount of the inputs in the area;

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[1] We use the superscript 0 for the inputs and superscript ' for the outputs to denote that the sets of the inputs (**Z**) and the set of output factors (**S**) may coincide, but not necessarily. This also applies for the notation in the economic system.

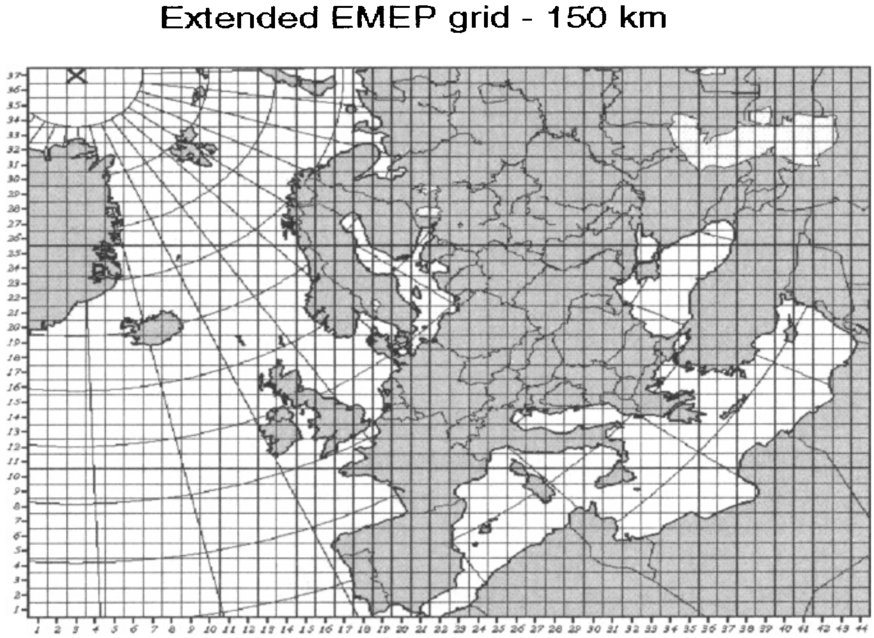

Figure 1: Example of a two dimensional landscape in a grid system
Source: EMEP grid-cell from the EMEP server (www.emep.int)

(iii) a set of outputs is defined as **S**. The amount of outputs is the result of the regeneration processes and depends on the amount of the inputs distributed in the grid of space. Furthermore, the amount of output in a specific region L_m may depend not only on the amount of ecological goods in that area, but also on the amount in other areas. Thus, the relationship is as follows[2], $\mathbf{S}^m = R^m_{S'}(Z^1, ..., Z^M)$. For example, in a river, we have the process related to the water that flows from area L_1 to area L_2, and the population of fishes that grows and regenerates.

(iv) the feedback in the ecological system implies that the set and the amount of outputs form the new inputs in the next phase. For an analysis in a temporal dimension, some relationships for the ecological feedback should be determined.

2.3 The economic system

The economic system operates in the same landscape **L**, and consists of:

(i) a set **K** of elements of inputs. The distribution of the amount of these inputs over

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[2] It should be noted that this notation only states that there is some kind of relationship. However, it does not assume an a priori functional relationship between the amount of input and the amount of output. The linearity of the system depends on the specification in a later phase.

the spatial landscape $\mathbf{L}$ may be denoted by the matrix $\mathbf{K}^m$, i.e. the amounts of each of the economic inputs $\mathbf{K}$ available in the grid of areas (L_m);

(ii) a set $\mathbf{J}$ of production processes, which describes the transformation of the amount of a set of inputs ($\mathbf{K}$) into the amounts of a set of outputs ($\mathbf{C}$). The distribution of the production process over the spatial landscape ($\mathbf{J}^m$) could either be homogenous or heterogeneous as well as being endogenously determined or exogenously given. It should be noted that for the production process, the inputs could be imported from other areas, i.e. $\mathbf{C}^m = \mathbf{J}^m(\mathbf{K}^1, ..., \mathbf{K}^M)$;

(iii) the set of outputs from the production process ($\mathbf{C}$) may be divided into intended – i.e. economic – outputs ($\mathbf{Q}$), and unintended – i.e. ecological – outputs ($\mathbf{E}$);

(iv) objective and feedback. The economic system functions in an environment partly created by goals determined by the economic subjects. In economic theories and in modeling terms, this is given by the preference or utility function of consumers $\mathbf{U}_I^m$, which stands for the matrix of the preferences ($\mathbf{U}$) of a set $\mathbf{I}$ of consumers in the grid of areas ($\mathbf{L}_m$). The utility function of consumers from a specific area L_m may depend on the amount of consumption of the outputs from all the areas and the presence of ecological goods which are not used as inputs in the economic system. However, the effective demand for the goods may depend on the economic inputs located in the area L_m ($\mathbf{K}^m$) and its production process ($\mathbf{J}^m$). Thus, we have preferences $\mathbf{U}_I^m(\mathbf{C}^m, \mathbf{S}^m | \mathbf{J}^m(\mathbf{K}), \mathbf{R}^m(\mathbf{Z}))$. In a temporal dimension, both the feedback in the economic system and the way the utility function evolves in time should be determined.

2.4 Economic-ecological interaction

Interaction, which is defined as a reciprocal action or influence, exists *within* the economic and the ecological system separately, as well as *between* the economic and the ecological system. The interaction between the economic and the ecological system may take place in the following ways (see also Wang, Nijkamp and Verhoef (2001)):

(i) a part of inputs in the economic system $\mathbf{K}_z \subseteq \mathbf{K}$ is retrieved from the elements of the ecological system, i.e. $\mathbf{K}_z \subseteq \mathbf{Z}$. Thus, $\mathbf{K}_z$ is the intersect of set $\mathbf{Z}$ and set $\mathbf{K}$ (or: $\mathbf{K}_z \subseteq (\mathbf{Z} \cup \mathbf{K})$);

(ii) a part of the outputs from the economic system, particularly the unintended output ($\mathbf{E}$), forms elements in the ecological system, i.e. $\mathbf{E} \subseteq S$; or,

(iii) a set of elements of the ecological system $\mathbf{S}_U \subseteq \mathbf{S}$ directly influences the utility $\mathbf{U}_\mathbf{I}$ of the consumers (set $\mathbf{I}$) in the economic system, i.e. $\mathbf{U}_\mathbf{I}(\mathbf{S}^m) \neq 0$.

Though the interaction between the economic and the ecological systems could be given in conceptual form, as has been formalized above (a summary is given in Table 1), it should be clear that the complexity is too great to permit the development of an applied model of the ecological and economic systems' interaction which takes into account the many characteristics of this interaction. As should be clear from this conceptual model, the number of interactions and their complexity increase according to (i) the number of inputs, i.e. the set $\mathbf{K}$ and the set $\mathbf{Z}$; (ii) the intersect between both these sets; (iii) the number of ecological and economic processes, i.e. the set $\mathbf{R}$ and

Description	Sets	Regional subset	Elements in the set
spatial landscape	$\mathbf{L}$	$\mathbf{L}^m$	$(L_1, ..., L_M, L_s)$
ecological system			
inputs	$\mathbf{Z}$	$\mathbf{Z}^m$	$(Z_1, ..., Z_Z)$
regenerative process	$\mathbf{R}$	$\mathbf{R}^m$	$(R_1, ..., R_R)$
outputs	$\mathbf{S}$	$\mathbf{S}^m$	$(S_1, ..., S_S)$
economic system			
inputs	$\mathbf{K}$	$\mathbf{K}^m$	$(K_1, ..., K_K)$
production process	$\mathbf{J}$	$\mathbf{J}^m$	$(J_1, ..., J_J)$
outputs	$\mathbf{C}$	$\mathbf{C}^m$	$(C_1, ..., C_C) =$ $(Q_1, ..., Q_Q, E_1, ..., E_E)$
intended outputs	$\mathbf{Q}$	$\mathbf{Q}^m$	$(Q_1, ..., Q_Q)$
unintended outputs	$\mathbf{E}$	$\mathbf{E}^m$	$(E_1, ..., E_E)$
consumers	$\mathbf{I}$	$\mathbf{I}^m$	$(I_1, ..., I_I)$
objective function	$\mathbf{U}$	$\mathbf{U}^m$	$(U_1, ..., U_I)$
E-E interaction			
inputs	$\mathbf{K_Z} \in (\mathbf{Z} \cup \mathbf{K})$	$\mathbf{K_Z^m}$	$(K_1, ..., K_K) \cup (Z_1, ..., Z_Z)$
outputs	$\mathbf{E_S} \in (\mathbf{E} \cup \mathbf{S})$	$\mathbf{E_S^m}$	$(E_1, ..., E_E) \cup (S_1, ..., S_S)$

Table 1: A summary of symbols and notations

J; and (iv) the number of consumers, i.e. the set (**I**). This complexity exists not only on the level of interaction between both systems, but also on the level of interaction within each separate system.

3 Spatial Landscape, Spatial Flow and Spatial Externality

3.1 Introduction

In this section, we will categorize various kinds of spatial externalities that arise from the conceptual framework of interaction between the economic and the ecological framework, with spatial characteristics. Roughly speaking, an externality exists if there is divergence between the marginal social costs and the marginal private costs for the economic subjects, i.e. if agents' actions that influence the utilities of other agents are not properly reflected in price signals. In the optimal case – i.e. no divergence exists between the marginal social costs and the marginal private costs for the economic subjects – climate change issues would not be so prominent, because, in the objectives of the economic subjects, the sustainability of the ecological system is already taken into account (assuming that marginal social costs would go to infinity if sustainability conditions were violated). However, due to the complexities of the ecological system and due to some characteristics of the ecological goods, i.e. the non-rivalry and the non-excludability properties of, for example, the air, these goods are not properly priced.

In essence, externalities apply to the level of economic decision units, which are the individual consumers and/or the individual producers. This implies that, strictly speaking, every externality has some spatial characteristics if spatial interaction is taken into account. However, if the objects of study are not the individual decision-makers – i.e. individual producers and individual consumers – but are at a more aggregated level, for example, on the sectoral or regional level, the characterization of an externality within the aggregated units of decision makers may complicate the taxonomy of spatial externalities.

In accordance with the description of externalities, as discussed in Wang, Nijkamp and Verhoef (2001), a *spatial externality* implies that (i) some agents' action from a spatial area L_m influences the utility of other agents in other spatial area(s) $L_{s \neq m}$, without this effect being reflected in price signals; and (ii) the necessary conditions for a socially-optimal situation (i.e. the Pareto-optimality conditions) are violated (see, for example, also Papageorgiou, 1978a, b). Furthermore, we will speak of a *localized externality* if the effect takes place in the same spatial area, given the spatial aggregation.

3.2 Spatial landscape and regional borders: exogenous or endogenous?

For applied research on spatial externalities, usually, it is necessary to define a set of borders that identify the set of spatial units distinguished (here called 'regions', see also e.g. Isard, 1956, Beckmann, 1978, Fujita, 1999). The issue of the determination of the borders of regions is an important one, as many natural borders may, as a result of economic and political processes, cease to exist; or may become either more or less relevant for economic purposes over time. Therefore, an important question is whether the border of a region should – based on some criteria – a priori be determined, or whether this regional border should – as a function of economic processes – be endogenously determined.

In reality, the landscape L is a continuous space covered by heterogeneous characteristics, e.g. geographical differences, differences in the distribution of ecological resources, cultural, political and economic differences. The heterogeneous landscape may be decomposed into various areas that are assumed homogenous in some respects. Difficulties will arise when the landscape is heterogeneous in a number of characteristics, such that the borders of the areas in these categories differ from each other and could not a priori be determined. This is what Mennes et al. (1969) called *defining the space units*. In the case of an exogenous determination of the borders, we normally take the political units, e.g. states, regions, cities, villages, as the areas.

For some research questions – e.g. the optimal market area or location questions – the borders and the areas should be endogenously determined by the economic decision processes (von Thünen, Launhard, Weber). Where a firm – either agricultural, industrial or service – locates and how firms interact with each other will determine the economic border. As Lösch (1938, 1953) pointed out, even in a vast plain with an equal distribution of raw materials and a complete absence of any other inequalities, spatial differences would still arise in a certain order, and a specific form of areas and borders is the most efficient one (i.e. a hexagon).

Thus, the operational determination of the space units depends, as Nijkamp (1987) pointed out, on the research questions. When, as in our study, data availability dictates

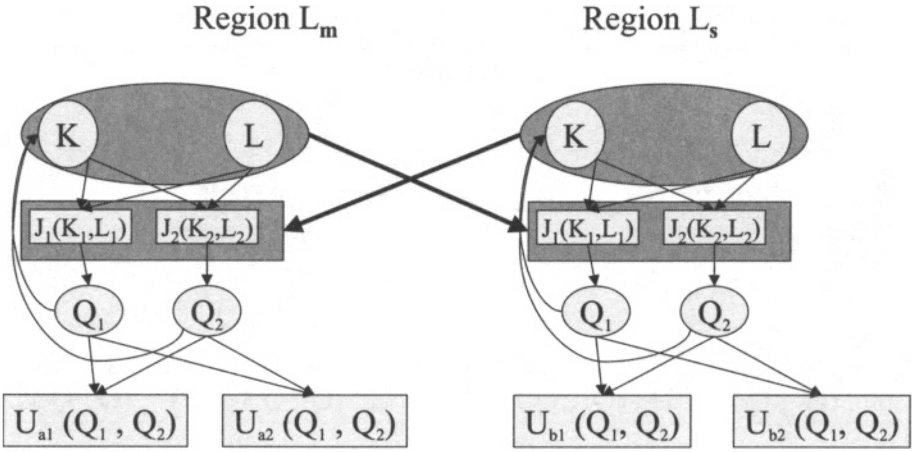

Figure 2: Spatial-economic interaction at input

the definition of space units, there is not much scope for the endogenization of borders. Nevertheless, one ought to be aware that issues of endogenous borders then cannot be captured in the modeling framework, which may imply limitations on the level of generality of the work carried out.

3.3 Spatial-economic interaction

Spatial interaction in the economic system, which is broadly defined in the literature as the flow of goods, people, or information between places that results from a decision process (Fotheringham and O'Kelly, 1989), plays an important role in analyzing spatial externalities.

In terms of the conceptual model, we may categorize spatial interaction in the economic system as follows:

(i) interaction at the level of inputs (**K**), i.e. the input $\mathbf{K}^m$ from region L_m is demanded by the producers $\mathbf{J}^s$ at other locations $L_{s \neq m}$. This is addressed by the migration theories and international resource-use literature, as shown in Figure 2;

(ii) interaction at the location of the prodution process (**J**), i.e. the location of producers $\mathbf{J}^m$ at the location L_m results from economic decision processes. This is shown in Figure 3 and is addressed by locational choice literature in the spatial economics and game-theoretic literature;

(iii) interaction at the level of outputs (**Q**) or the objective (consumer's utility **U**), i.e. the same amount of outputs of the products $\mathbf{Q}^m$ from region L_m is demanded by the consumers $\mathbf{I}^s$ from other regions $L_{s \neq m}$. This is shown in Figure 4 and is addressed by, for instance, the international trade theories;

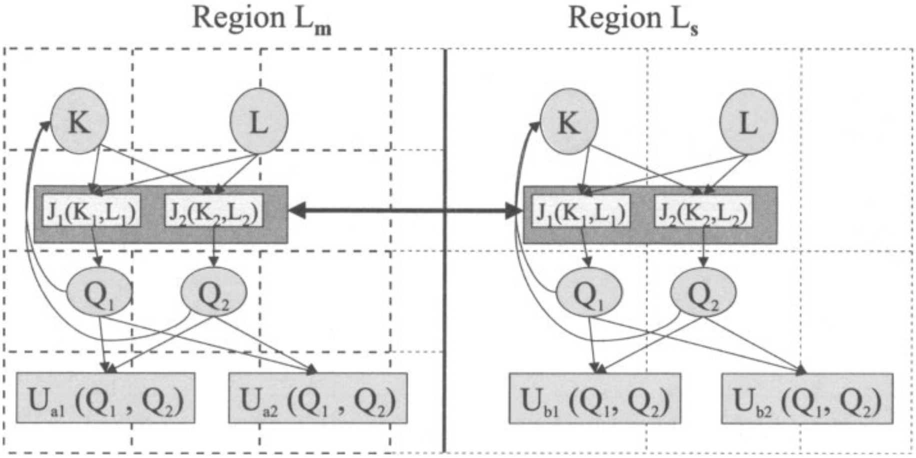

Figure 3: Spatial-economic interaction at the production level

(iv) a combined interaction of these factors (i-iii above). This is addressed by, for instance, the economic geography and spatial economics literature.

In the spatial economics literature, the ideal approach is, given an initial situation, to determine the spatial constellation of the economic system by considering interactions at the level of inputs, at the location of the production process, and the level of outputs in the context of general locational theory (Isard, 1956). From the traditional spatial-economic literature, which mainly concerns the locational behavior (e.g. von Thünen, Weber, Lösch, Isard, and, for an overview, see Beckmann and Thisse, 1986, Birkin and Wilson, 1986a, b, Isard, 1956, 1990a, Kilkenny and Thisse, 1999, Nijkamp, 1976, Sohns, 1978), it was also recognized that, after the firms have determined the location of the production process, the location itself would in its turn then affect the prices and flows of commodities which are important in the interaction of the inputs and the interaction of the outputs.

This influence is taken into account in the spatial general equilibrium model (Takayama and Labys, 1986, van den Bergh et al., 1996), which models complete and complex spatial interaction of the economic system in a spatial setting. However, analytical results sometimes may not easily be interpreted and empirically tested, e.g. because of a chaos-type of outcome, i.e. bifurcation of the results (see e.g. Nijkamp, 1987, Nijkamp and Reggiani, 1998).

3.4 The nature of spatial-ecological interaction

The ecological system relating to the aspect of climate change is a complex system and the diversity of interactions within this ecological system is also the reason for the complexity in the study of climate change: on the one hand, there is human action so that the dynamics in the ecological system could be characterized as interac-

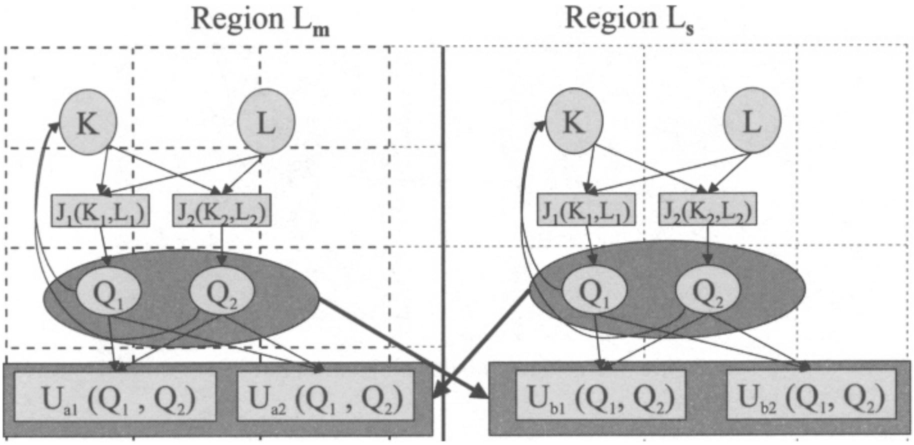

Figure 4: Spatial-economic interaction at output level

tion between the ecological and the economic system; on the other hand, there are some internal dynamics of the ecological system itself: the interaction within the subsystems of the ecological system has its own dynamics. For example, it covers not only the carbon cycle and external solar influences, but also the atmospheric process, the ocean, the terrestrial vegetation and the inland glaciers (IPCC, 1997). The study of interactions between both systems is a considerable study which is carried out by international programs (see e.g. Hibbard et al., 2001).

From a spatial point of view, we may, by generalizing the interacting processes of several subsystems within the ecological system, divide the spatial interaction of the ecological subprocesses in terms of:

(i) a localized ecological subprocess, i.e. there is no interaction between any part of the ecological subprocess in region L_m and regions $L_{s \neq m}$. This concerns immobile ecological systems, such as a mountain area, a forest, a lake, or an island;

(ii) a uni-directional ecological subprocess, i.e. the ecological subprocess in region L_m will have effects on the ecological process in other regions ($L_{s \neq m}$). This is depicted in Figure 5. An example of this is the waterstream in a river, which could be interpreted as flows in the perspective of spatial areas L_m and $L_{s \neq m}$; and

(iii) a multidirectional ecological subprocess, i.e. the ecological subprocess in regions L_m and $L_{s \neq m}$ are spatially interrelated, such that the ecological subprocess in both regions may be perceived as one common ecological subprocess. This is depicted in Figure 6.

From the perspective of economic subjects in an individual area, for example $\mathbf{I}^m$, both the unidirectional and multidirectional ecological subprocesses may cause spatial

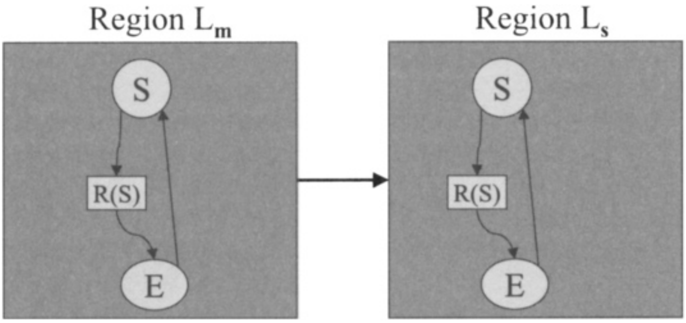

Figure 5: Uni-directional ecological subprocess

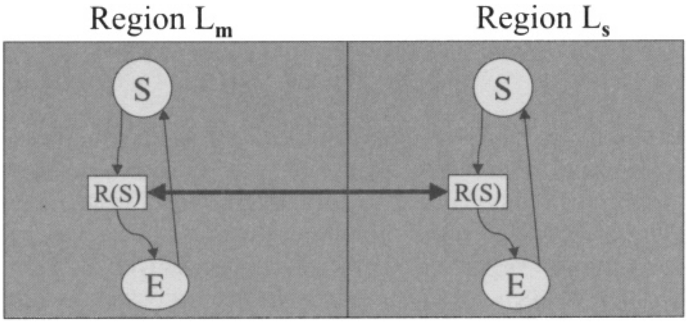

Figure 6: Spatially-interrelated ecological subprocess

externalities for economic subjects from other spatial areas, i.e. $\mathbf{I}^{s \neq m}$. This will be further discussed in the next subsection.

3.5 A taxonomy of spatial externalities

One of the main elements of the spatial aspects of the interaction between the ecological system and the economic system is that the mapping of borders in spatial area L_m differs for each system. In other words, an ecological process does not necessarily observe the borders between the regions or countries in the economic systems. Given that (i) the intersecting elements in the interaction between the ecological and the economic systems are known, and that (ii) the border of spatial areas L_m are determined, we have the following taxonomy of spatial externalities:

(i) spatial-localized effects

Spatial-localized effects are environmental externalities within region L_m itself and these externalities do not affect other regions. This form of externality arises as a result

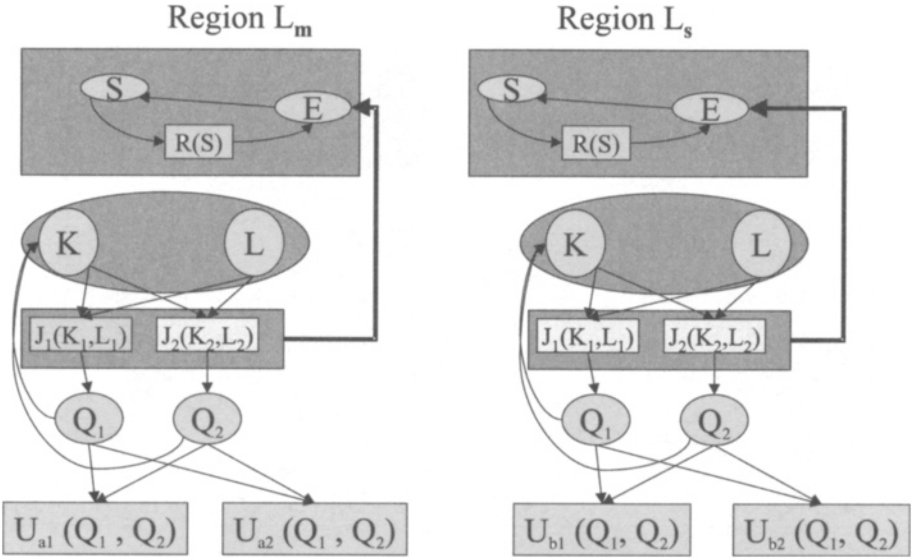

Figure 7: Localized externalities

of the aggregation of individual consumers and individual producers into a regional decision level. Figure 7 presents a graphical description of this form of externality.

(ii) spatial-economic environmental externalities

Spatial-economic environmental externalities are environmental externalities which are intensified by spatial-economic spillovers. This is known as 'point-externality' and is depicted in Figure 8. This may be subdivided into the following two categories:

(ii.a) localized environmental externalities in one (source) region.

In this category, environmental externalities occur only in the source region, i.e. localized ecological factors which are not properly priced in region L_m. For the source region, spatial-economic interaction may exacerbate environmental degradation, e.g. trade in garbage and waste disposal (see e.g. van Beukering, 2001). In this case, the source region (L_m) bears the impacts of spatial interaction because of localized environmental externalities.

For other region(s), i.e. $L_{s\neq m}$, spatial-economic interaction will cause a pecuniary environmental externality, as spatial-economic interaction with localized externality in region L_m may disturb the existing equilibrium in region(s) $L_{s\neq m}$. However, the market in region(s) $L_{s\neq m}$ would adapt and result in an optimal outcome in region(s) $L_{s\neq m}$ For example, in the case of tropical wood, a local environmental externality in region L_m results in a lower market price for this good, which, because of the spatial economic interaction, will in turn result in a higher demand for the import of tropical wood from region L_m in other region(s) $L_{s\neq m}$. As a consequence, region(s) $L_{s\neq m}$

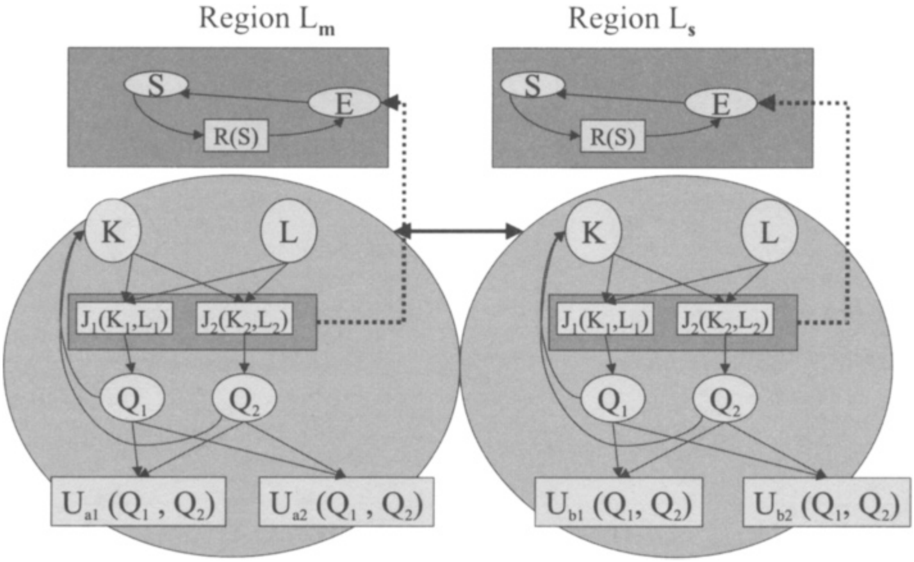

Figure 8: Spatial-economic environmental externalities

face a higher amount of waste caused by the higher demand for tropical wood. Then, because there is no externality in region(s) $L_{s \neq m}$, either a higher price for waste will cause a lower demand for tropical wood, or there will be trade-off between more waste and more demand for tropical wood.

(ii.b) localized environmental externalities in more regions

In this category, localized environmental externalities occur in both the source region (L_m) and in the other region(s) ($L_{s \neq m}$). In this case, the destination region(s) would also be faced with the impacts of the local environmental externality in the source region (L_m) – i.e. localized ecological factors which are not properly priced in region L_m – causing environmental degradation in region(s) $L_{s \neq m}$ through spatial-economic interaction.

The former example of tropical wood and waste illustrates this: the environmental externality in waste, for example, will not lead to a re-evaluation in the destination region(s). This environmental externality exacerbated by spatial-economic interaction is no longer a pecuniary externality, but a technological externality. Because of the higher amount of waste in region(s) $L_{s \neq m}$, the market in region(s) $L_{s \neq m}$ will not adapt and, hence, the result will not be an optimal outcome, i.e. the higher waste will cause environmental degradation. Thus, the environmental externality caused by spatial-economic interaction is a technological one and we will call this category of spatial externality 'spatial-economic environmental externality'.

One important issue here involves the causality of spatial-externality. As we may deduce from the illustrations above, spatial-economic interaction is not the cause of

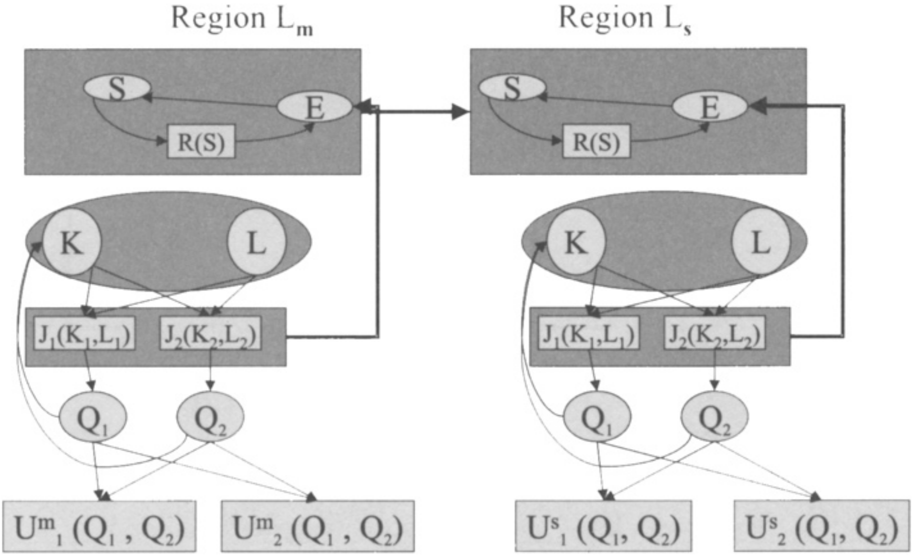

Figure 9: Transfrontier spatial-ecological environmental spillover

the externality, but it serves as an intervening variable for the spillover of the environmental externality. If the destination region has no localized externality, spatial-economic interaction will not cause technological spatial externality in the destination region(s), while if there is localized externality in both regions, there will be technological spatial-externality.

(iii) spatial-ecological environmental externalities

Spatial-ecological environmental externalities are environmental externalities intensified by spatial-ecological spillover. This category is the best-known form of spatial environmental externality. The term 'transboundary pollution' is mostly used in international trade literature, i.e. an internally inefficient price system in region L_m causes, because of the ecological system, environmental degradation in other regions. This category may be subdivided into the following subcategories (see e.g. Siebert, 1985):

(iii.a) unidirectional spatial-ecological environmental externalities

In this category, the ecological system is transfrontier, i.e. it transports pollutants from one region (L_m) to (an)other region(s) ($L_{s \neq m}$). This involves uni-directional ecological systems, e.g. the pollution from one region at the source of a river will affect a few other regions downstream. This is depicted in Figure 9.

(iii.b) multidirectional spatial-ecological environmental externalities

In this category, the ecological system of the regions is a spatially-interrelated system. Other terms are: global environmental system or common resource system. The environmental goods in this system have non-exclusive and non-rival characteristics. This

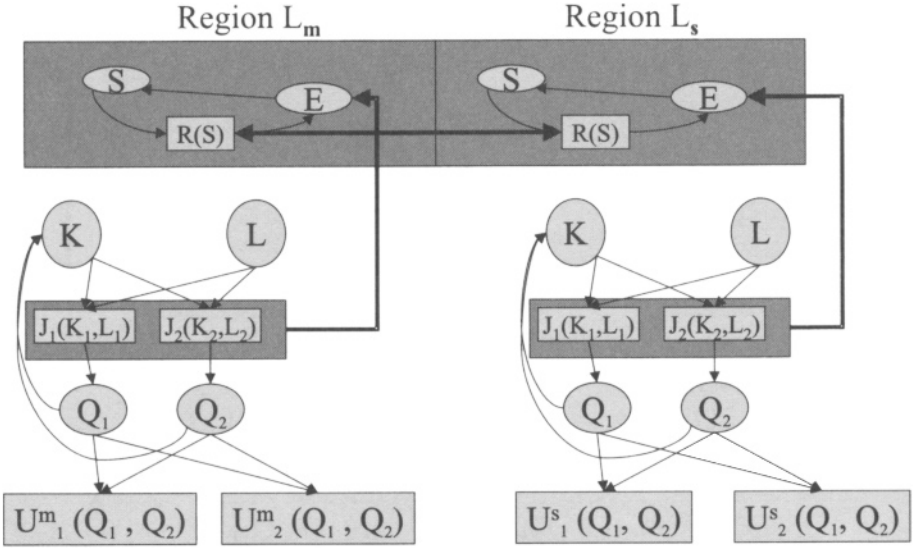

Figure 10: Multidirectional spatial-ecological environmental externalities

is called a global public good, e.g. clean air. This category of spatial-externality may be depicted as in Figure 10.

(iv) general spatial environmental externalities

General spatial environmental externalities are environmental externalities intensified by both spatial-economic interaction and spatial-ecological interaction. In this category, environmental externality in region L_m causes environmental degradation in other region(s) $L_{s \neq m}$, through both spatial-economic interaction (e.g. trade in energy) and spatial-ecological interaction (e.g. carbon emission).

The externalities may, as known from the environmental economic literature (Baumol and Oates, 1987, Opschoor and Vos, 1989, Opschoor et al., 1994), be internalized through (i) the equalization of the marginal private costs to that of the marginal social costs using a Pigouvian tax; or (ii) a property rights system, such that the equalization of both costs could be achieved by the parties involved themselves. Both instruments have their own shortcomings and restrictions (see e.g. Cropper and Oates, 1992). For the tax instrument, for example, a Pigouvian tax in the case of public goods is not easy to formulate and the willingness to pay and willingness to accept as compensation may differ for the same amount of pollution (see e.g. Bishop and Woodward, 1995, Bockstael and McConnell, 1993, Hanemann, 1991). Property rights also work badly for public goods because of their non-exclusivity and non-rivalry characteristics (see Baumol and Oates, 1987, Hanley et al., 1997, Samuelson, 1952). However, in the complete information case, both instruments result in the same equilibrium (see Baumol and Oates, 1987, Mas-Colell et al., 1995). Externalities characterized by spatial-economic or spatial-ecological spillover are, however, even less easily internalized. Though the instruments are the same, spatial environmental externalities require cooperation between areas with different political orientations and objectives. In the next section, we categorize the literature that investigates these instruments and a priori presumes that such cooperation may arise.

4 Categorizing Spatial Externalities in Spatial Interaction Models

In this section, the literature on spatial externalities in spatial-economic interaction models will be categorized. Section 4.1 discusses the differences between a few approaches in terms of the way of linking the regions and the representation of the spatial characteristics in the models. Section 4.2 treats the spatial-interaction via the output. In this subsection, we consider the international trade approach (distance-less) as well as the spatial-price equilibrium approach (with transport costs). Spatial-interaction via the production process is treated in Section 4.3 by discussing locational choice and locational competition theories. However, for analyzing the internalization of the spatial externalities, the locational competition (or strategic interaction) models assume a distance-less space. Section 4.4 gives a review of interaction via the inputs; special attention is paid to the consumer-labor location and the literature on capital flight. Section 4.5 discusses a few multi-region models and the associated literature for internalizing spatial externalities.

4.1 Linking the regions: distance and transport costs

Before discussing the models of spatial-economic interaction, it is important to stress the treatment of space and distance in the literature. The decomposition of the continuous space of landscape **L** into homogenous units does not necessarily mean that there is no distance left between the areas L_m. In other words, (i) the connection between two areas may not only take place at the border, and (ii) the activities between both areas may be linked with each other through one or more routes from somewhere in the area L_m (Isard, 1990a).

This aspect is one of the major differences between the international trade literature and that of spatial economics (see Isard, 1956, Krugman, 1990, 1993, Fujita et al., 1999). In the traditional theories of international trade, where the spatial interaction, i.e. the flow of commodities between countries, is analyzed, the spatial landscape is typically decomposed, i.e. each nation is represented as a spot in the landscape **L** without measurable distance between the nations/regions. In such a distance-less representation of the economic system in a spatial setting, the inputs and the outputs from each area should necessarily be different, otherwise these goods will be perfect substitutes (see Isard, 1956, Krugman, 1990, 1993).

This spaceless treatment by international trade theory is criticized by Isard (1956), i.e. the distance between each nation/region is assumed to be equal and negligible. According to Isard (1956), distance affects the ultimate costs in the case of spatial-economic interactions. In this sense, the commodities produced in different regions would become imperfect substitutes: the characteristics of the goods are the same, but not their location. Commodities from different space-areas could be substituted, and international trade may result in specialization. However, transport costs may prevent this from happening.

Armington (1969) tried to incorporate the imperfect substitute characteristics between the commodities from different countries, without explicitly taking the transport costs and distances between the countries into account in the model, by using substitution elasticities. A more explicit modeling of distance between two regions is represented by the gravity type of models, in particular, and the spatial interaction models, in general. These models assume that distance will directly affect the magnitude of interaction between the regions. The analogy is drawn from physics where masses attract each other (Isard, 1972). In the trade analyses in terms of gravity models, the trade flow between regions L_m and L_s is a positive function of the mass of the region, e.g. measured by the GDP, but is negatively correlated to the distance between both regions (see Fotheringham and O'Kelly, 1989, Isard, 1990b, Reggiani, 1990).

In the spatial economic literature, transport costs and distance are used in the models to reflect the spatial character. One often-used approach is the 'iceberg transportation costs'-approach (Samuelson, 1952). In this approach, transportation costs between the regions are represented as increasing functions of the distance. In the standard formulation, it is assumed that for every unit of distance, a given proportion of the (remaining) quantity of the good shipped 'evaporates' to reflect transportation costs. This is used, for example, by Krugman (1991a, b) in economic geography, where the agglomeration effect of regions is analyzed. Isard (1956), on the other hand, also introduced the term 'transport-unit', which directly includes transport as an input in the production process. Consequently, more transportation, keeping other inputs fixed, would result in a higher output.

4.2 Interaction through output

The international trade approach

The traditional international trade theories, such as the Ricardian comparative costs advantage and the Hecksher-Ohlin (HO-)model of trade, treat the output from the production process as mobile between the 'regions', while the production factors are assumed to be immobile between the regions. With respect to the initial location of the production process, the Ricardian approach assumes different (heterogeneous) production technologies between the regions, while the HO-model assumes identical (homogenous) production technologies across the regions. In both approaches, the endogenous character of locational behavior is implicitly assumed. In Ricardian models, differences in the production technologies lead, in the case of international trade, to specialization of that industry which has a comparative cost advantage. In other words, agglomeration in Ricardian models implicitly takes place in that industry which has a comparative cost advantage over another industry. In HO-models, relative factor endowments work, through price mechanisms in the output market, to produce an optimal allocation of factor endowments in the sectors. In other words, agglomeration depends on factor endowments and the relative preferences of the consumers for the outputs (see Obstfeld and Rogoff, 1996).

The standard textbook examples are two-country models with two production factors (labor and capital). However, by including the environment as a production factor, Siebert (1981) extended the HO-model and argued that a country with relatively rich environmental endowments (e.g. natural resources) will have a comparative advantage in environmental intensive products and will thus produce and export these commodities. Van Beers and van den Bergh (1999) have discussed possible ways of extending the standard trade model for environmental research, including adding the role of utility and technological issues.

The impact of internalizing the spatial externality in the presence of trade

In the presence of spatial externalities – in the form of spatial-economic spillovers or spatial ecological spillovers – as a result of free trade, the generally accepted insight that international trade will have mutual benefits for all free-trade countries could be reversed, as this insight would implicitly assume that the environmental prices are incorporated in the market prices, i.e. that the externalities are internalized. The literature on this subject is enormous (see e.g. Rauscher, 1991, 1997, Siebert, 1981, van den Bergh and Nijkamp, 1995, Withagen, 1998, 1999). Therefore, our discussion only highlights some important conclusions on this subject.

The environmental effects of international trade could, according to the NAFTA Commission for Environmental Cooperation (1996), be boiled down into three effects: (i) product effects, (ii) scale effects, (iii) structural effects. The first of these effects could occur in the home market, if it gets environmentally superior goods that would not be supplied if there were no international trade (e.g. low-pollution engines), or – conversely – if it gets some environmentally harmful products, such as 'polystyrene' packaging for fast foods. The scale effect has to do with the expanded market when international trade occurs. The lower costs as a result of scale effects could lead to an ever-increasing use of natural resources, such that economic development becomes unsustainable. The structural effect concerns the patterns and processes of production that could be affected by the specialization process that will unavoidably arise after international trade: this could – like the product effect – be positive or negative.

Theoretically, in the case of spatial-economic environmental externalities – i.e. spatial economic spillover because of local environmental externalities – international trade would not necessarily be beneficial for countries that have not internalized the environmental externalities (Verbruggen, 1991, 1999). The 'first-best' assumptions that underlie the benchmark result of the positive effects of trade are violated, as an environmental externality exists. It turns out that, because of the existence of negative domestic environmental externality, the country would seemingly have comparative advantage in the environmental goods causing the externality. Consequently, Copeland (1994) analyzed the policies for a small, already polluted country in the case where the environment is a local public good and concludes that there would be environmental degradation.

In the absence of technological progress, the 'pollution-haven hypothesis' (Copeland and Taylor, 1999) may occur, as some countries would set too low a standard for environmental policy in order to strengthen the competitiveness. However, it is also possible that the 'ecological dumping hypothesis' or the 'pollute-thy-neighbor strategy' (see e.g. Dean, 1992) is relevant, i.e. countries would dump the polluted industries in other countries. An example is the already-mentioned study on waste-disposal (van Beukering, 2001). In this example, it is shown that a developing country attracts polluting industries as it is 'competitive' in the pollution-intensive sector.

In the case of spatial-ecological spillover, singly or unilaterally internalizing the externalities is more difficult, as the loss of competitiveness (if we keep assuming that there will be no technological progress) is still present, while the gains from this policy would, to a certain extent, flow away as the result of spatial-ecological flow. Transboundary pollution may be analyzed in cases that where the pollution affects (i) the utility of the consumers (e.g. Rauscher, 1997); (ii) the ecological system as it is (e.g. Copeland and Taylor, 1995); and, (iii) the productivity of the producers (e.g. Benarroch and Thille, 2001).

The trade-based literature considers the effect of free trade on the quality of the environmental system[3]. On the one hand, because of the pollution-haven hypothesis or ecological dumping possibilities, there is the argument that trade would adversely affect the ecological system of some countries and allow rich countries to export their environmental problems to poor countries (see e.g. Baumol and Oates, 1987, Siebert, 1985). The 'trade-induced degradation hypothesis' suggests that international trade can play a key role in initiating a vicious cycle, in which trade-induced environmental degradation could lead to income losses (Copeland and Taylor, 1999). Moreover, these income losses can then lead to further degradation (Daly, 1995). On the other hand, Grossman and Krueger (1991) argue that growth may improve environmental quality, as trade promotes income growth and thus could lead to a cleaner environment. This is, in short, also the relationship that is studied by the empirically oriented studies on the environmental Kutznets curve (see de Bruyn, 1997, de Groot, 1999). Copeland and Taylor (1999) show that, in situations where the costs of pollution are small in the short run, but large in the long run the environmental degradation hypothesis would prevail.

However, technological progress would play an important role in overcoming environmental degradation in general (see e.g. van den Bergh and de Mooij, 1997). If there is environmental degradation as a result of spatial externalities, the Porter-hypothesis (Porter and van der Linde, 1995) argues that as a result of environmental regulations in the home country, firms could gain comparative advantages as they are forced to implement more advanced production technologies. Although technological progress is important in the endogenous growth literature, trade-based technological models are still rare[4].

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[3] See Copeland and Taylor (1995) for further references on debates, empirical work, and theoretical issues on this subject.

[4] In a static model, it is straightforward to incorporate technological differences between the countries (see van Beers and van den Bergh, 1999).

Spatial price equilibrium

In addition to the international trade approach, the spatial price equilibrium models (see Samuelson, 1952, Takayama and Judge, 1964, Takayama and Labys, 1986) take transport costs into account. The spatial price equilibrium models are partial equilibrium models which analyze the equilibrium of prices in the interaction between the producers of goods, the consumers of goods and the shippers or traders of these goods in spatially-separated areas. The literature on environmental policy in a multi-regional context uses the spatial price equilibrium models to analyze the potential first-best or second-best policy rules (see Verhoef and Nijkamp, 2000, Verhoef and van den Bergh, 1995). In Verhoef and Nijkamp (2000), the spatial externality as a result of both economic and ecological spillover is discussed.

4.3 Interaction through decision process units: locational choice?

Generally speaking, the regional science-oriented literature explicitly analyses locational behavior from the viewpoint of spatial-economic interaction. The most intuitive way to analyze the interaction in a spatial context is to focus on firms that are settled or may settle in a certain area. The questions in this context are then: 'Where would a firm locate?' and 'Given the locations of some firms, how would these firms interact with each other?'.

In the most simplified locational analysis, the spatial diffusion of both the inputs and the demand for the output is assumed to be exogenously given. Then, the locational choice of an individual firm could be interpreted as the choice of a producer j for a location in the spatial area L_m which would maximize his objective, i.e. his profit.

Von Thünen analyzed the locational behavior and spatial distribution of agricultural firms in a homogenous area and came up with concentric rings of agricultural firms around a center. In his model – among other things – transport costs, distance and the input – viz. land – are immobile. These are important assumptions for a firm's location decision (see e.g. Beckmann and Thisse, 1986, Kilkenny and Thisse, 1999).

On the other hand, for the industrial firms, the location of the inputs need not necessarily be fixed. Weber analyzed the locational choice of such a firm, which is able to transport the input and the output. In this situation, locational choice is not bounded by the spatial distribution of the inputs; the transport costs and distances of both input and output also play an important role. In Weber, as the location of the inputs and the demand for the output are given, the problem boils down to a minimization of the transport costs (see Birkin and Wilson, 1986b, Isard, 1956).

Hotelling analyzed the locational behavior of more firms (see e.g. Birkin and Wilson, 1986a, Greenhut et al., 1987, Isard, 1956). A well-known example is the competition between the location of two ice-cream sellers on a beach. Under certain conditions, it seems that agglomeration may prevail, i.e. both sellers would locate near each other to serve the whole market, while, under other conditions, location at both ends of the market may be the equilibrium. The result also depends on the strategy that is chosen by the sellers.

The precursor of city models may also be found in Lösch (1953), who sought the optimal locational structure of firms, given some forms of strategic behavior of the firms, and given the initial situation of the spatial distribution of input factors as well as of the consumers. According to Lösch (1953), the optimal locational structure of a number of firms in a homogenous plain is a hexagonal structure. This structure may, given other settings of spatial distribution of inputs, be adjusted (Greenhut et al., 1987).

The result of a firm's locational decisions would affect the spatial economic behavior, such as the price of the input and output as a result of rent-seeking behavior. In this sense, Lösch's idea of optimal locational structure may be seen as a step prior to the analysis performed by the network models (van den Bergh and Nijkamp, 1995). It is, however, a challenge to integrate both approaches, as, in reality, a homogenous plain on a large scale is difficult to find, so that it is difficult to test whether the network structure is optimal or not.

Given the optimal locational structure, the network models represent the whole spatial constellation by a network of nodes, for which the interaction is accomplished by links. As van den Bergh and Nijkamp (1995) pointed out, in the modern network models, the nodes and links "*. . .may reflect the real transportation infrastructure consisting of a complex network with ports and cargo terminals*". In the network models, an important role is assigned to the transportation sector. In this sector, the shippers and carriers will determine the equilibrium outcome. The shipper is a decision-making entity that desires a particular commodity to be delivered to a particular destination and the carrier is a decision-making entity that actually executes the transport of freight.

Result of internalizing the locational spatial externalities: strategic interaction

In the literature, strategic interaction models that incorporate both distance and locational choice are still rare. Therefore, the studies in this subsection only discuss strategic interaction models on locational choice as a result of environmental policy or in the case of transboundary pollution.

'Strategic interaction' forms a part of the game theoretic literature[5], which analyses the strategies of the economic agents – which could be an individual, a firm, a government or some other groups – to which some economic conditions (rules) apply. As there are some imperfections in the market structure – e.g. market power, externality, increasing returns to scale, incomplete information – strategic considerations become important. In the studies of environmental policy, the object of study is mostly the strategic interaction between governments and/or between firms. In the first case, governments in both countries will choose their tax rates knowing that the

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[5] The works in this subsection differ from the 'modern' trade theory, which applies game theory to imperfect competition within the international trade system. Elements of imperfect competition could be: monopolistic or oligopolistic competition (thus the firms are no longer price takers); increasing returns to scale; multinational enterprises, etc. A unifying work on game theory and perfect competition may be found in the model of Keyzer and van Wesenbeeck (1999) that incorporates the game-theoretic elements of the imperfect competition in a general equilibrium framework in order to have a better understanding of the welfare effects of various environmental policies.

choice of the domestic tax rate will affect the world price and therefore affect production both in the home country and in the foreign country. In the second case, firms will decide whether to locate in some places or not, given some environmental policy set by the government. Some examples of the literature are: Kennedy (1994), Barrett (1994), Copeland and Taylor (1995), Markusen (1997), Ulph and Ulph (1994).

Kennedy (1994) analyzed a symmetric two-country model with a homogenous polluting product and symmetric oligopolistic industries with sunk costs for new entrants in the industries. He came to the conclusion that imperfect competition will lead to inefficient distortions of pollution taxes in the case of free trade. He decomposed these distortions into a rent-capture effect and a pollution-shifting effect. The first effect lowers the equilibrium taxes as each country attempts to gain a competitive advantage over its trading partner, and the second effect raises the equilibrium taxes as each country attempts to transfer production and its associated pollution to the other.

Markusen (1997) also analyzed a symmetric two-country model (so that the specialization effect is neutralized) with imperfect competition, extending that of Kennedy (1994) with two goods: one competitive and one imperfectly competitive with increasing returns to scale and imperfect competition. Furthermore, his attention is focussed on the locational choice of the multinational firm that could decide to have a plant in one or both countries. The conclusion is that when these multinational firms are confronted with free trade (by lower transaction costs from the removal of trade barriers), there will be a regime shift away from multinationals toward national firms. Furthermore, the firms headquartered in the home country have an incentive to close plants in the foreign country.

Barrett (1994) analyzed government strategy in the case of environmental policy in terms of weak environmental standards for industries that compete for business in imperfectly competitive international markets. He concluded that when the domestic industry consists of one firm, the foreign industry is imperfectly competitive, and competition in international markets is of the Cournot-type, then the domestic government has an incentive to impose a weak environmental standard. 'Weak' in this sense means that the marginal damage from pollution exceeds the marginal cost of abatement. However, this conclusion is not robust, because when the international competition is of the Bertrand-type, then the conclusion would be just the opposite. In addition, other kinds of policy, e.g. reduction of subsidy, would then function better.

Also interesting are Ulph and Ulph (1994) and Ludema and Wooton (1997). The first combines both the firms' and the government's perspective in a three-stage game. It also incorporates the R&D investments by the firms and thus allows both the government and the producers to act strategically. Ludema and Wooton (1997) took another perspective by analyzing situations where the importing countries are faced with negative externalities and try to find international trade rules to prevent 'trade wars' relating to the setting of environmental standards.

Though these models analyze the locational behavior of the firms in the presence of environmental externalities and/or as a result of policies aimed at internalizing the environmental externalities (either local or spatial externalities in the form of spatial-ecological spillover), they also have the shortcoming of treating space in a distanceless manner.

4.4 Spatial interaction through inputs

Spatial interaction through inputs may be interpreted as international trade in resources. In general, this may be analyzed in terms of comparative cost theory, where demand for the inputs depends on the price and availability of the goods. Therefore, pure interaction on the level of inputs is not widely studied, though we may interpret modern trade theory which analyzes the trade in intermediates as models analyzing the interaction through inputs. Despite this, there are three important elements of inputs which deserve our attention.

Consumers and labor location

Consumers play a dual role in the spatial-economic interaction analysis. On the one hand, consumers provide labor and other inputs (i.e. endowments) for the firms, which may be viewed as inputs in the production process. On the other hand, consumers exercise demand for the output of the firms. Both roles could, of course, be separated. In the commuter-traffic analysis, consumers are assumed to have choices concerning spatial distribution for the demand role and the labor role. The labor market and the migration literature, on the other hand, analyse the mobility of this input-factor in spatial areas.

Though this literature is very broad and covers urban economic research, the main focus is not on the spatial effects of environmental externalities (Verhoef and Nijkamp, 2000). Therefore, we will not discuss this literature in detail. However, from the consumers' perspective, there is a vast body of literature on environmental externalities. The problem is that most of this literature is not directly related to spatial externalities per se.

Capital mobility and capital flight

Another important area is the literature on 'capital flight' or 'foreign direct investment'. In the presence of environmental externalities, these studies investigate the implications of mobility of the production factors, notably capital. Some survey papers on foreign direct investment are: Beghin et al. (1994), Beghin et al. (1996), Copeland and Taylor (1995), Dean (1992), and Jaffe et al. (1995). In this literature, the industrial-flight and the pollution-haven hypotheses are tested. In the case of relocation of industries, there is a fear that the relatively low environmental standards in developing countries compared with industrialized nations will lead 'dirty' industries to shift their operations to these LDCs, i.e. the industrial-flight hypothesis. In addition, LDCs may purposely undervalue the environment in order to attract new investment, i.e. the pollution-haven hypothesis (see Dean, 1992). Although theoretically very interesting, the general empirical conclusion is that the capital-flight effect is quite small (see e.g. Dean, 1992, Bouman, 1998).

Land use and the ecological footprint

Another important input is the land. Spatial interaction concerning this input is, except in terms of rent differences, difficult because of the immobility of land in a spatial context. Because of this characteristic of land, we may interpret the literature on land use in terms of location theory, i.e. the function of some piece of land in terms of the kinds of firms located on the land.

Exactly because of this characteristic of land, the 'ecological-footprint approach' (Wäckernagel, 1998, Wäckernagel and Rees, 1996) uses land to indicate the magnitude of ecological degradation in a spatial context, i.e. the use of other natural resources causing environmental externality as if it were related to land use. The ecological-footprint approach uses the idea that there is spatial interaction of inputs worldwide. Thus, the economic processes in each area affect scarce environmental resources anywhere in the world. This approach is, however, a normative one (see e.g. Nijkamp and Finco, 2001) as the ecological footprint is measured as the ratio of the use of the scarce environmental resources in a particular area in comparison with a normalized amount of land for the resource concerned. Thus, a country's land use according to the ecological footprint may be far larger than the actual area of that country. This happens, for example, if the country uses many natural resources. This approach is, however, criticized by van den Bergh and Verbruggen (1999) because the procedure for measuring the ecological footprint is aggregated and biased. Furthermore, it does not recognize the advantages of spatial specialization and concentration. Finally, the ecological-footprint approach uses a hypothetical optimal land use.

4.5 Spatial interaction through multiple levels: input-output, spatial interaction and general equilibrium modeling

Multi-regional input-output models

The input-output model was first proposed by Leontief and assumes a fixed technological coefficient (and fixed production process) for the transformation of the amount of inputs and intermediates into the amount of outputs. Isard (1956) operationalized the input-output analysis for spatial-economic research by using the interregional and regional input-output table. Since then, multi-regional input-output model analysis is one of the standard methods of empirical spatial economics (Bröcker, 1998). For this approach, the border should, as in all other multi-regional models, be exogenously determined. Furthermore, this approach requires stability in the relative supply prices of each output produced by several regions, as the substitution effects (for the inputs) are not incorporated (Isard, 1990b). This also implies that the 'economic' distance between two regions should not change, i.e. that the transport routes and costs would not change between the regions. Bröcker (1998) furthermore raised the following objections: (i) multi-regional input-output models do not sufficiently take account of income-expenditure interdependencies; and (ii) multi-regional input-output models are one-sidedly demand-driven, such that effects coming from the supply side can not be modeled appropriately.

The input-output analysis is applied in environmental studies by treating, for example, carbon emission as an input. The interaction between the ecological and the economic system is realized by treating the natural resources as inputs provided by the environment (see e.g. Isard, 1972, Siebert, 1981, 1985).

Multi-regional general equilibrium models

The same interregional input-output tables may also be used by the general equilibrium models. The additional advantage of general equilibrium models compared with the input-output approach is that there is a theoretical foundation for the behavioral rules. In the general equilibrium models, the transformation of input into output is not only a result of a fixed technological coefficient such as in the input-output approach, but allows for substitution effects too. In this approach, competitive markets, utility-maximizing behavior of the consumers and profit-maximizing behavior of the producers are assumed to influence the relationship between the input and the output. As in input-output analysis, general equilibrium analysis typically assumes that the production function in the regions is given. Thus, the location of the production is predetermined, although the equilibrium production levels can change and can become equal to zero (Bröcker, 1995, Göttinger, 1998, Truong, 1999).

The internalization of the spatial environmental externalities in general equilibrium models may be realized in two ways: (i) via the price mechanism through taxes which will affect the demand for the taxed goods; or (ii) in the quantity space, which will give a shadow price comparable to the tax.

Spatial interaction models

Spatial-interaction models may also use data from input-output tables. However, the assumed causality and theoretical focus is rather different (Pooler, 1994a, b, Openshaw, 1998, Diplock, 1998). Though the spatial interaction models can also be related to some utility-based models, such as the general equilibrium models, with the additional characteristic that the distance is measured in terms of transportation costs (see e.g. Nijkamp and Reggiani, 1987, 1990, 1998, van Lierop and Nijkamp, 1978), we may see the difference more clearly in the gravity models, which, as Isard (1990a) already pointed out, may be perceived as a special case of spatial interaction models. In the gravity models, the focus is on the spatial flow of the commodities (input and or output) between two regions, which – in analogy with physics – is positively dependent on the mass, measured by indicators such as regional income, output or other macroeconomic quantity-variables of the regions, and negatively related to the distance between the regions. The transportation costs are thus implicitly incorporated.

Other multi-regional models

Multi-regional systems are a generic term for models that have an explicit regional element (Beckmann, 1978, Isard, 1956, Hafkamp, 1984, Hordijk and Nijkamp, 1980, Nijkamp, 1976, 1987). In a sense, the input-output and the multi-regional general equilibrium models are a subset of the multi-regional systems. In a survey of multi-regional economic models, Nijkamp et al. (1982) have already pointed out a wide range of possibilities. Hafkamp (1984), for example, designed a triple-layer multi-region model for analyzing the impact of internalizing the environmental externalities in a multi-regional context. Currently, except for the models mentioned in the previous sections, multi-regional models which analyze the spatial ecological-economic interaction consider regions as open systems, both in terms of economic and environmental processes. This is done, among others, by Rembold (1975), van den Bergh and Nijkamp (1998), and Inoue (1998). Considering the contribution of each of these authors in turn, first, Rembold (1975) analyzed a regionalized multi-sector model, combining a trade, an environmental, a demand and a production model. Without endogenous knowledge accumulation, which is assumed to be the basis for technological progress, the raw material or pollution is the limiting factor for economic growth. In van den Bergh and Nijkamp (1998), growth could be engined by 'international' trade as well as technological progress (as in endogenous growth theory). However, in this approach the state of economic development is limited by the carrying capacity of the environmental system.

The sustainability issue is analyzed in van den Bergh and Nijkamp (1995) through the interlinkage of both the environmental and the economic system of two regions. In this two-region model, endogenous technological progress is engined in one of the regions and the process of knowledge diffusion occurs through mutual trade. On the basis of this approach, Inoue (1998) studied the sustainability of economic development when knowledge diffusion came through aid instead of trade and the emphasis is on the abatement technology.

5 Conclusion

By extending the conceptual framework, which was developed in Wang, Nijkamp and Verhoef (2001), to the spatial landscape, this chapter has categorized the existing literature on spatial interaction models that concern environmental externalities. It was shown that the literature may be subdivided into model categories focussing, on the location and transportation of the inputs, the outputs, and the location of the production possibilities, respectively.

In this categorization, it is evident that the models become more general the more factors they include. In this sense, a pure partial model would be one which, according to the framework developed in Section 2, considers, as given, all the inputs, outputs and production possibilities in all regions, except for one: for example, one of the input, output or production possibilities in one of the regions. A general model of spatial interaction would then assume that, given some initial situation, all the inputs, outputs and the production possibilities would be endogenously determined. In this sense, even the spatial general equilibrium models, which include the markets for all inputs and the outputs, are not truly general models of spatial interaction, as they presuppose a fixed location of the production possibilities across the regions. In other words, an operational 'generalized theory' of spatial interaction, as expressed by Isard (1956), is, given the complexities, not yet available in the literature.

From the point of view of reality, another important aspect is the time that is involved in the interactions between the economic and the ecological system. The inclusion of time in the analysis may have quite an important influence on the interpretation and the method for analyzing the underlying system: when time plays a role, the feedback may become even more complex. Therefore, some additional assumptions about the feedback process (or the movement of the variables of interest) have to be made. In the optimal control literature – for example, Chiang (1992), and Kamien and Schwartz (1978) – this is typically expressed by the smooth growth or decline of the variables, such as capital accumulation, which presupposes rational or adaptive expectations of the economic subjects.

Despite the fact that the issues of dynamics and statics have been considered by many economists, there is a wide variety of definitions of dynamics and statics (for a comprehensive review of the definitions, see Machlup, 1963). To have a better understanding of the concepts of statics and dynamics and to clarify the differences between the various definitions, consider the case in which the system could move towards one or more states. Theoretically, each period (e.g. a generation, an economic cycle, or even a second) may be perceived as one state. Then, statics studies the system within one state, while comparative statics compares two or more states of the system, and dynamic analysis studies the transition of the system from one state to another state (or more states).

Schumpeter (1948) illustrated the relationship between dynamics and statics by the following two, different points of view. First, static theory involves a higher level of abstraction: while dynamic patterns ignore a good many things, the static patterns drop even more features of reality, for example technological progress, and statics is, therefore, still nearer to a pure logic of economic quantities than dynamics. Secondly, statics may be seen as a special case of a more general dynamic theory: as we may derive static patterns from dynamic ones by the simple process of equating the 'dynamizing factors' to zero. As the history of economic thought starts with static analysis, Schumpter stated that, when using dynamic analysis, under all conditions, it must be possible to restate the dynamic model as a static one (of course, with additional simplifications).

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