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Concentration, Separation, and Dispersion: Economic Geography and the Environment

Abstract

The paper investigates the spatial patterns of industrial location and environmental pollution in a new-economic-geography model. Factors of production and their owners are mobile, but factor owenrs are not required to live in the region in which their factors are employed. Under laissez faire, a chase-and-flee cycle of location is possible: people, who prefer a clean environment, are chased by polluting industries, which want to locate geographically close to the market. Locational patterns under optimal environmental regulation include concentration, separation, dispersion and several intermediate patterns. Moreover, it is shown that marginal parameter changes may induce discrete changes in locational patterns.

1 Introduction

Economic geography deals with the allocation of economic activity in geographical space. With the publication of his small monograph "Geography and Trade", Paul Krugman (1991) revived the interest in this field of economic research, which had been largely neglected for a long time. Using the tools of modern trade theory, in particular Krugman's (1979, 1980) intra-industry trade models based on Dixit-Stiglitz (1977) monopolistic competition, a "new economic geography" (NEG) was established NEG is a theory that does not rely on ad-hoc arguments and heuristics to explain spatial patterns of economic activity but instead builds on a consistent micro-founded modelling framework. General features of the NEG are the interaction of centripetal and centrifugal forces (which explain agglomeration and spatial dispersion of economic activities, respectively), bifurcations, and path dependencies. Small parameter changes may drive an economy from agglomeration to dispersion and vice versa and adjustment paths towards long-term equlibria are not unique such that the outcomes of dynamic allocation processes in space are indeterminate and may depend on historical pre-conditions or self-fulfilling expectations. The state of the art is summarized in books and survey papers such as Fujita et al. (1999), Brakman et al. (2001), Neary (2001), and Baldwin et al. (2003).

Geographical space is an important category in environmental economics, too. With the exception of greenhouse gases, CFCs, and possibly some other global pollutants, emissions generate more environmental harm in the geographical proximity of their source than far away.

Catastrophic vents like the London smog disaster of 1953 and the accidents in Seveso (1976), Bhopal (1984), and Chernobyl (1986) tragically testify this relationship. Nevertheless, the environmental-economics literature on the geographical dimension of pollution and, in particular its interaction with the spatial patterns of economic activity is surprisingly small. An early paper is Siebert's (1985) handbook article, which was written before the arrival of the NEG and is by and large based on traditional models of foreign-trade. Markusen et al. (1992), Rauscher (1995), and Hoel (1996) look at interjurisdictional competition for mobile polluting firms and find that, depending on the severity of environmental harm, the outcome of this competition is either a "race to the bottom" or "not in my backyard". Pflüger (2001) adds NEG elements to the interjurisdictional competition model by introducing Dixit-Stiglitz monopolistic competition and "iceberg" transportation costs. However, since the model set-up is that of the footloose-capital model (see Baldwin et al., 2003, Chapter 3) there are no agglomeration effects in this model. Like in Markusen et al. (1995), Rauscher (1995) and Hoel (1997), the emphasis is placed on the "race to the bottom" vs. "not in my backyard". Kanbur et al. (1995) look at interjurisdictional competition, too, but they model space as a continuous variable and look at the impact of environmental regulation on the location of polluting industries. They show that small jurisdictions have incentives to charge lower environmental taxes than larger ones. Issues of agglomeration, which is the central issue of the NEG, are not addressed. Papers explicitly addressing issues of economic geography are Rauscher (1998) and van Marrewijk (2005). Rauscher (1998) looked at a variety of NEG models and derived optimal environmental policies only for a world in which factors are immobile whereas residents can change their locations. The genuine NEG models with mobile factors of production, however, are only sketched in this paper. Van Marrewijk (2005) investigates a core-periphery NEG model in which centrifugal and centripetal forces do exist and derives the result that agglomeration forces are mitigated by environmental externalities. The consumers' desire to reside in agglomerations is weakened if these agglomerations are polluted.

Similar issues are discussed in the present paper. In particular, I am interested in three geographical patters:

- concentration, i.e. a geographical pattern where the most populated regions are the most polluted ones, e.g. big cities like Shanghai, Mexico City, or Los Angeles,
- the separation of pollution and population, the example being nuclear power stations, which are often located in peripheral regions with low population densities, and
- dispersion, i.e. pattern where people and pollution are (more or less) evenly distributed in space.

In order to address these issues, I use an economic-geography model based on the ingredients, i.e. Dixit-Stiglitz (1977) preferences and "iceberg" transportation costs. Moreover, like in many other NEG models, regions are symmetric. The main difference compared the standard core-periphery model of the NEG literature, which was extented by van Marrewijk (2005) to deal with environmental externalities, is that factor owners do not have to live where their factor is employed. This is related to the footloose-capital model used by Pflüger (2001), where the factor is mobile whereas its owners are not. I go one step further by assuming that factor owners are mobile as well, but that they can choose their location of residence independently of where the factor is employed. With this assumption, two new patterns that cannot be found in other NEG models are detected. The first one is the "chase-and-flee" phenomenon: residents try to avoid pollution and leave agglomerations, but the industry wants to be where the market is and follows the consumers. The second one is separation: residents and the industry agglomerate in different regions if environmental damage is large.

The paper is organized as follows. The next section presents the model. Section 3 is devoted to the analysis of the spatial patterns of economic activities and pollution under laissez faire. In Section 4, I look at welfare maximization and derive optimal allocations of production and consumption in geographical space. In Section 5, the choice of environmental-policy instrument choice is discussed. Section 6 summarizes.

2 The Model

Assume a world consisting of two regions, East and West. Both regions are identical as regards preferences and technology. All variables related to the West are indicated by asterisks.

Households

The total population of the two regions is 1, of which β live in the East and $(1-\beta)$ in the West. All households are identical and factor ownership is equally distributed across the households such that each household owns one unit of the factor. Let y and y^* denote the factor incomes of Eastern and Western households, respectively. Moreover, each household inelastically supplies one unit of a numéraire good. Thus, gross income of a representative domestic household is $1+y$. Let x be the consumption of the numéraire good. The other good is a differentiated good and it is available in many different varieties. Product variety is modelled as a continuum. $c(i)$ and $c^*(j)$ denote consumption of domestic varieties in the East and in the West, $m(j)$ and $m^*(i)$ denote the imports of foreign varieties, and θ is the "horses fed with grain"[1] transportation cost mark-up. $p(i)$ and $p^*(j)$

[1] In his seminal work on the "isolated state", Thünen (1842 , p. 16) made the assumption that the horses pulling the carts of grain from the rural region to the city are fed with grain from the carts. Thus, the transportation cost is proportional to the value of the commodity transported. The advantages of this approach are (i) that a transportation sector does not need to be modelled and that (ii) that price elasticities of demand are not affected by the

are the prices of Eastern and Western goods, respectively, and n and $n*$ measure product variety. Thus, the representative households' budget constraints are

$$\int_0^n p(i)c(i)di + \int_0^{n^*} \theta\, p^*(j)m(j)dj + x = 1 + y\,. \tag{1}$$

and

$$\int_0^n \theta\, p(i)m^*(i)di + \int_0^{n^*} p^*(j)c^*(j)dj + x^* = 1 + y^* \tag{1*'}$$

in the East and in the West, respectively .

I assume love-of-variety preferences for the differentiated good like in Dixit/Stiglitz (1977). Utility from consumption is assumed to be quasilinear and it is augmented by subtracting the disutility from environmental pollution.[2] Thus, the utilities of representative residents in the two regions are

$$u = \frac{1}{\gamma}\left(\int_0^n c(i)^\gamma di + \int_0^{n^*} m(j)^\gamma dj\right) + x - \frac{\delta e^{1+z}}{1+z}, \tag{2}$$

$$u^* = \frac{1}{\gamma}\left(\int_0^n m^*(i)^\gamma di + \int_0^{n^*} c^*(j)^\gamma dj\right) + x - \frac{\delta e^{*1+z}}{1+z}. \tag{2*}$$

$\gamma \in (0,1)$ is a measure of substitutability. The elasticity of substitution between different varieties is $\sigma = (1-\gamma)^{-1}$ such that $\gamma=1$ denotes perfect substitutability and $\gamma=0$ an elasticity of one. For $\sigma<1$, demand functions would exhibit price elasticities less than one and this would be incompatible with monopolistic pricing. Quasilinearity implies that all income effects are captured by the numéraire good. Finally, e and e^* denote emissions in the East and in the West, respectively, and we assume that there are no transboundary pollution spillovers. The environmental damage is increasing and convex, i.e. $z>0$. For $z=1$, the damage function is quadratic. δ measures the impact of environmental pollution. The reason for specifying such a damage function is that the some of results to be derived in this paper depend on the curvature of the marginal-damage function. In this model, it is not sufficient to assume that marginal environmental damage is increasing: concavity and convexity of the marginal-damage function matter, too, and the parameter z is used to capture this.

Utility maximization in the East and in the West results in the inverse demand functions

$$p(i) = c(i)^{\gamma-1} = \theta^{-1} m^*(i)^{\gamma-1} \qquad \text{for} \quad i \in (0,n), \tag{3}$$

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introduction of transportation costs. Some 100 years later, this concept was introduced into Heckscher-Ohlin trade theory by Samuelson (1952) and termed "melting-iceberg" transportation cost.

[2] This quasilinear utility function is probably the simplest way of specifying the love-of-variety model. It is even simpler than the model suggested by Pflüger (2003), who also uses a quasilinear specification. The disadvantage of quasilinear utility is that the model is only a partial-equlibrium model in that it neglects interactions between the market for differentiated goods and other goods markets.

$$p^*(j) = \theta^{-1} m(j)^{\gamma-1} = c^*(j)^{\gamma-1} \qquad \text{for} \quad j \in (0, n^*) \tag{3*}$$

Compared to many other economic-geography models, the demand functions are very simple (e.g., see Baldwin et al. 2003; Fujita et al. 1999 and Neary 2001). They do not contain a CES price index. This is a direct result from specifying the utility function (2) as quasi-linear.

Moreover, it is assumed that all varieties are produced with the same technologies and the same factor requirements. Then the prices for these varieties are identical and the arguments *i* can be dropped. Using (1), (1'), (3a), and (3b) in (2) and (2') gives the Eastern and Western indirect utility functions, respectively:

$$\tilde{u} = 1 + y + \frac{1-\gamma}{\gamma}\left(np^{\frac{\gamma}{\gamma-1}} + n^*(\theta p^*)^{\frac{\gamma}{\gamma-1}} \right) - \frac{\delta e^{1+z}}{1+z}. \tag{4}$$

$$\tilde{u}^* = 1 + y^* + \frac{1-\gamma}{\gamma}\left(n^* p^{*\frac{\gamma}{\gamma-1}} + n(\theta p)^{\frac{\gamma}{\gamma-1}} \right) - \frac{\delta e^{*1+z}}{1+z}, \tag{4'}$$

The producers

The supply side of the market for the non-numéraire good is characterized by Dixit-Stiglitz monopolistic competition. There is only one factor of production and its remuneration, which is exogenous to the firm, is *w*. All producers use the same technology characterized by increasing returns to scale. In particular, I assume constant marginal cost *vw* and fixed cost *Fw, F* and *v* being technological unit input requirements. Let *q* denote the output of a representative firm. Its profits are

$$\pi = pq - (F + vq)w \tag{5}$$

Ex ante, profits seem to be variable and can be maximized; *ex post*, they are zero due to free entry and exit of firms. A firm is a monopolist in the market for its specific variety, but its profits are driven to zero by free market entry and exit in the neighbouring markets, where substitutes of the variety are traded. Profit maximization yields

$$\gamma p = vw,$$

i.e. marginal revenue equals marginal cost. To simplify notation, choose units of the input such that $\gamma = v$. Thus,

$$p = w \tag{6}$$

and, by analogy, $p^* = w^*$ for foreign producers. Using (6) and its foreign analogue in the zero-profit condition yields:

$$q = q^* = \frac{F}{1-\gamma}, \tag{7}$$

This is a standard result of the Dixit-Stiglitz model with constant marginal cost. The output of a single variety is determined by the price elasticity and the parameters of the cost function, but it does not depend on any other variables of the model.

Since all firms produce identical quantities, the number of firms can be inferred from the factor market equilibrium. Let the total factor endowment be 1 and let k and 1-k denote the factor shares located in the East and in the West, respectively. As assumed in (5), domestic factor demand is $n(F+vq)$ and by analogy its foreign equivalent is $n^*(F+vq)$. Using $\gamma=v$ and (7), the equilibrium conditions for the factor markets are

$$n = (1-\gamma)\frac{k}{F}, \tag{8}$$

$$n^* = (1-\gamma)\frac{1-k}{F}. \tag{8'}$$

Using (7) again, we obtain the conditions

$$Q=nq=k \tag{9}$$

and

$$Q^*=n^*q^*=1-k. \tag{9'}$$

Emissions and environmental damage

Emissions are linearly related to production. For simplicity choose units such that the factor of proportionality is unity. Thus, $e=Q$ and $e^*=Q^*$. From (9) and (9'), we have

$$e=k, \tag{10}$$

$$e^*=1\text{-}k. \tag{10'}$$

Thus environmental damages in the East and in the West are $D=\delta k^{1+z}/(1+z)$ and $D^*=\delta(1\text{-}k)^{1+z}/(1+z)$, respectively. In the remainder of the paper, the differential in environmental damage, $D-D^*$, will be of major importance. Its derivative with respect to k is

$$\frac{d(D-D^*)}{dk} = \delta\left(k^z + \left((1-k)^z\right) \quad > \quad 0,$$

which is hump-shaped for $z<1$, u-shaped for $z>1$ and horizontal for $z=1$. It follows that D–D^* is S shaped for $z<1$ and inversely S-shaped for $z>1$. See Figure 1. These curvature properties imply that, starting from a symmetric equilibrium, $k=0.5$, the first unit of factor movement causes the largest (smallest) change in the difference in environmental damage across regions if $z<1$ ($z>1$).

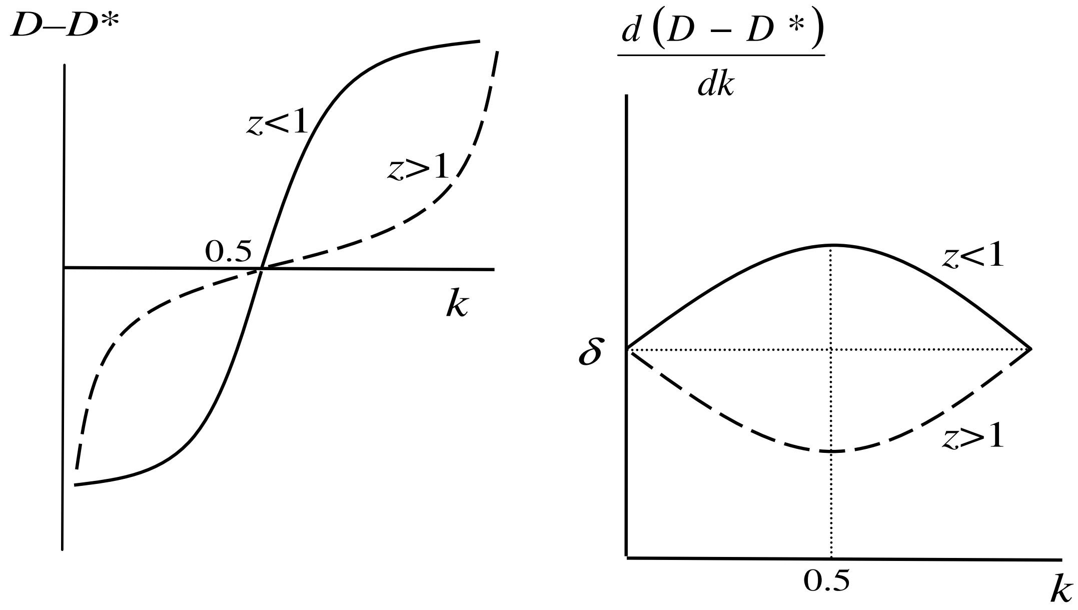

Figure 1: The differential in environmental damages across regions and its change

Goods market equilibrium

In the goods-market equilibrium supply and demand are equal for each variety, i.e.

$$q = \beta c + (1-\beta)\theta m^*,$$

$$q^* = \beta\theta m + (1-\beta)c^*,$$

Inserting the domestic inverse demand functions, (3a) and (3b), and their foreign equivalents and using (7) to substitute for q and q^*, we obtain

$$p = \left[\frac{1-\gamma}{F}(\Theta + \beta(1-\Theta))\right]^{1-\gamma}, \tag{11}$$

$$p^* = \left[\frac{1-\gamma}{F}(1 - \beta(1-\Theta))\right]^{1-\gamma}, \tag{11'}$$

with $\Theta = \theta^{\frac{\gamma}{\gamma-1}} < 1$ as a measure of trade freeness.

Indirect utility

The indirect utilities, equations (4) and (4'), can now be represented as functions of the exogenous parameters of the model and of the patterns of location of factors and factor owners, k and β, respectively. Using (11) and (11') to substitute for p and p^*, (8) and (8') to substitute for n and n^*, and (9) and (9') to substitute for e and e^* in (4) and (4') yields

$$\tilde{u} = 1 + y + \frac{(1-\gamma)^{2-\gamma}}{\gamma F^{1-\gamma}} \left(\frac{k}{(\Theta + \beta(1-\Theta))^{\gamma}} + \frac{\Theta(1-k)}{(1-\beta(1-\Theta))^{\gamma}} \right) - \frac{\delta k^{1+z}}{1+z}, \tag{12}$$

$$\tilde{u}^* = 1 + y^* + \frac{(1-\gamma)^{2-\gamma}}{\gamma F^{1-\gamma}} \left(\frac{\Theta k}{(\Theta + \beta(1-\Theta))^{\gamma}} + \frac{1-k}{(1-\beta(1-\Theta))^{\gamma}} \right) - \frac{\delta (1-k)^{1+z}}{1+z}. \tag{12'}$$

3 Patterns of Location and Agglomeration

As mentioned in the introduction, factors and factor owners are mobile, but they can choose different locations. This implies that the income of the representative household is independent of its region of residence:

$$y = y^* = kp + (1-k)p^*, \tag{13}$$

where (6) and its Western equivalent have been used to substitute for w and w^*.

To analyse the spatial allocation of economic activity, we first look at the locations of the factors and then at the locations of their owners. Factors move if there is a difference in factor remunerations. From (11) and (11'), we have

$$w - w^* = \left(\frac{1-\gamma}{F} \right)^{1-\gamma} \left((\Theta + \beta(1-\Theta))^{1-\gamma} - (1-\beta(1-\Theta))^{1-\gamma} \right) \tag{14}$$

Factors are indifferent where to locate if $\beta=0.5$. In Figure 2, this is represented by the vertical line at $\beta=0.5$. The horizontal parts of the locus are explained by the fact that factor shares cannot be larger than 1 or less than 0. In a next step, let us consider the behaviour of the factor owners. The difference in utility between East and West is

$$\tilde{u} - \tilde{u}^* = \frac{(1-\Theta)(1-\gamma)^{2-\gamma}}{\gamma F^{1-\gamma}} \left(\frac{k}{(\Theta + \beta(1-\Theta))^{\gamma}} - \frac{1-k}{(1-\beta(1-\Theta))^{\gamma}} \right) - \frac{\delta\left(k^{1+z} - (1-k)^{1+z}\right)}{1+z}, \tag{15}$$

where the last term on the right-hand side is the environmental-damage differential depicted in the left-hand part of Figure 1. Assume for a moment that environmental considerations do not matter such that this term vanishes. Then the $\tilde{u} = \tilde{u}^*$ line, along which households are indifferent where to locate, is

$$k = \frac{(\Theta + \beta(1-\Theta))^{\gamma}}{(1-\beta(1-\Theta))^{\gamma} + (\Theta + \beta(1-\Theta))^{\gamma}}. \tag{16}$$

Its slope is

$$\left.\frac{dk}{d\beta}\right|_{\tilde{u}=\tilde{u}^*} = \gamma(1-\Theta) \frac{(\Theta + \beta(1-\Theta))^{\gamma-1}(1-\beta(1-\Theta))^{\gamma} + (\Theta + \beta(1-\Theta))^{\gamma}(1-\beta(1-\Theta))^{\gamma-1}}{\left[(\Theta + \beta(1-\Theta))^{\gamma} + (1-\beta(1-\Theta))^{\gamma}\right]^2} > 0.$$

From (16), we have that k=0.5 for $ß$=0.5 and that k>0 for $ß$=0 and k<1 for $ß$=1. Moreover, taking the second derivative, one can establish that the slope is minimized in the symmetric equilibrium ($ß$=k=0.5) and that it increases towards the boundaries of the (0,1) interval. The resulting $\tilde{u}=\tilde{u}*$ line is depicted in Figure 2 together with the w=w* line. There are three equilibria: full agglomeration in one of the two regions or an equal distribution of population and factors across the regions. Let us introduce simple adjustment dynamics, such that factors move to the region offering higher wages and people move to the region offering a larger indirect utility

$$\dot{k}=\lambda_k\left(w-w*\right),$$

$$\dot{ß}=\lambda_ß\left(\tilde{u}-\tilde{u}*\right).$$

λ_k and $\lambda_ß$ are positive adjustment-speed parameters. The Jacobian of the linearized dynamic system is

$$J=\begin{pmatrix} 0 & \lambda_k \dfrac{\partial\left(w-w*\right)}{\partial\beta} \\ \lambda_ß \dfrac{\partial\left(\tilde{u}-\tilde{u}*\right)}{\partial k} & \lambda_ß \dfrac{\partial\left(\tilde{u}-\tilde{u}*\right)}{\partial\beta} \end{pmatrix} \sim \begin{pmatrix} 0 & + \\ + & - \end{pmatrix}, \tag{17}$$

where the signs of the elements of J are displayed in (17) as well. The adjustment dynamics are indicated by horizontal and vertical arrows in Figure 2. There are two centripetal forces and one centrifugal force in this model. Factor movements always foster agglomeration. Factors move to where the majority of the consumers live because the region with larger demand generates higher facor remuneration. In the case of housholds, there are two forces, one centripetal, the other centrifugal. Consumers are attracted by producers offering a large degree of product variety without incurring transportation costs. In this respect, they like agglomeration, too. This is what Fujita et al. (1999, p. 346) call "thick markets". On the other hand, they do not like to live where many other households live because the high demand raises local prices. This overcrowding effect is the centrifugal force of the model. The two centripetal forces, however, dominate and the two agglomeration equilibria are stable whereas the symmetric dispersion equilibrium is unstable – unless a trajectory starts on the saddle path leading to this point. Mathematically, this follows from the fact that the Jacobian, J, has a negative determinant and both off-diagonal elements are positive. However, as initial conditions are historically given, the probability of starting exactly on this saddle is infinitesimally small. Thus, the corresponding equilibrium is irrelevant and laissez faire implies full agglomeration, i.e. the industry and the households locate in the same region.[3]

[3] Note that unlike in other geography models, dispersion is not a stable equilibrium. This means that a variant of the black-hole condition discussed in Fujita et al. (1999, Ch. 4) is violated here due to the quasilinearity of the utility function.

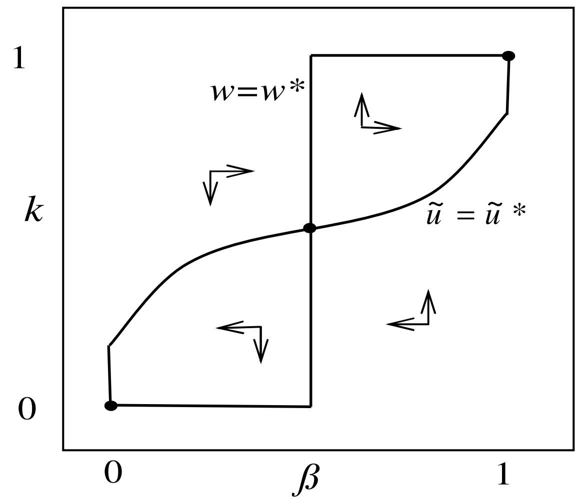

Figure 2: Patterns of location in the absence of environmental concerns

Having determined agglomeration patterns in the absence of environmental problems, let us now consider environmental pollution. In this case, the second-row, first-column element of the Jacobian in (18) may change its sign. The slope of $\tilde{u} = \tilde{u}^*$ line can be determined via total differentiation of (15):

$$\frac{d\beta}{dk} = \frac{\dfrac{1}{\gamma(\Theta+\beta(1-\Theta))^{\gamma}} + \dfrac{1}{\gamma(1-\beta(1-\Theta))^{\gamma}} - \dfrac{F^{1-\gamma}\delta\left(k^{z}+(1-k)^{z}\right)}{(1-\Theta)(1-\gamma)^{2-\gamma}}}{(1-\Theta)\left(\dfrac{k}{(\Theta+\beta(1-\Theta))^{1+\gamma}} + \dfrac{1-k}{(1-\beta(1-\Theta))^{1+\gamma}}\right)} \qquad (18)$$

The sign of the slope $\tilde{u} = \tilde{u}^*$ line is ambiguous since the first two terms in the numerator on the right-hand side are positive, whereas the second term is negative. Note that the numerator of the third term contains the marginal environmental-damage differential depicted in Figure 1. Four cases can be distinguished.

- In the first case, the marginal damage is very small such that the change in location of the $\tilde{u} = \tilde{u}^*$ line is so small that the qualitative behaviour of the system is the same is in Figure 1. The $\tilde{u} = \tilde{u}^*$, however, line is steeper than the one depicted in Figure 2.
- In the second case the marginal damage is so large that the second term in the numerator on the left-hand side always dominates the first term. This implies that the $\tilde{u} = \tilde{u}^*$ line changes its slope.

- The third case is characterized by highly convex marginal environmental damage, i.e. z substantially larger than 1. In this case, the sum of marginal damages is small for k close to 0.5, but large for k close to 0 or 1. The $\tilde{u} = \tilde{u}^*$ line is inversely S-shaped
- The fourth case is characterized by highly concave marginal environmental damage, i.e. z close to 0. In this case, the sum of marginal damages is large for k close to 0.5, but small for k close to 0 or 1. The $\tilde{u} = \tilde{u}^*$ line is S shaped.

In what follows, I will investigate the latter three of the four cases graphically. The first case shows patterns that are qualitatively the same as those depicted in Figure 1 already.

Case 1

Since the $\tilde{u} = \tilde{u}^*$ line is steeper than the one depicted in Figure 2, equilibria with incomplete agglomeration of households are possible. The underlying reason is that living in an agglomeration is not that beneficial anymore if producers generate environmental pollution. Besides that, the congestion externality, i.e. higher prices for local goods in the more densely populated region, matters and people prefer to locate in the peripheral region a certain fraction larger than 50 but less than 100 percent of the people live in the agglomeration.

Case 2

Case 2 is depicted in Figure 3. Compared to Figure 2, $\tilde{u} = \tilde{u}^*$ line is rotated in a counter-clockwise fashion. If the resulting indifference line is rather flat like the one depicted in Figure 3, there will be vertical segments for β=0 and β=1. The point of intersection with the w=w^* line is either a stable node or a stable spiral. This follows from the Jacobian, equation (18), which now has a positive determinant. However, as the Jacobian is a linear approximation of the true dynamics which is reasonably accurate only close to the equilibrium, unstable paths farther from the equilibrium cannot be exluded. Figure 3 shows an example starting from agglomeration. Assume that all firms and housholds are located in the East, i.e. β=k=1. Households suffer from pollution and start moving to the West. At β=0.5, firms start to relocate, too, since factor incomes are higher in regions where demand is larger. At some point, all households have moved, but firms are still relocating to the West. If the number of firms is getting too large, people flee environmental pollution and start relocating to the East again. When β>0.5, firms start to follow until at some time housholds relocate to the West. There are two effects generating this cycle. On the one hand consumers like to live in a clean environment, i.e. they want to locate far awy from the producers. The producers,on the other hand, like big markets and want to locate close to the consumers. Thus, the producers chase the consumers and the consumers try to flee. Since there are only two regions in the model, the result is a cycle. In the real world, there are, of course, more than two regions, but analogous patterns are observable in the process of de-urbanization. People move from the city to the country side, but shopping centres, petrol stations etc follow and tend to disturb the idyll. As a reaction peolple move even further.

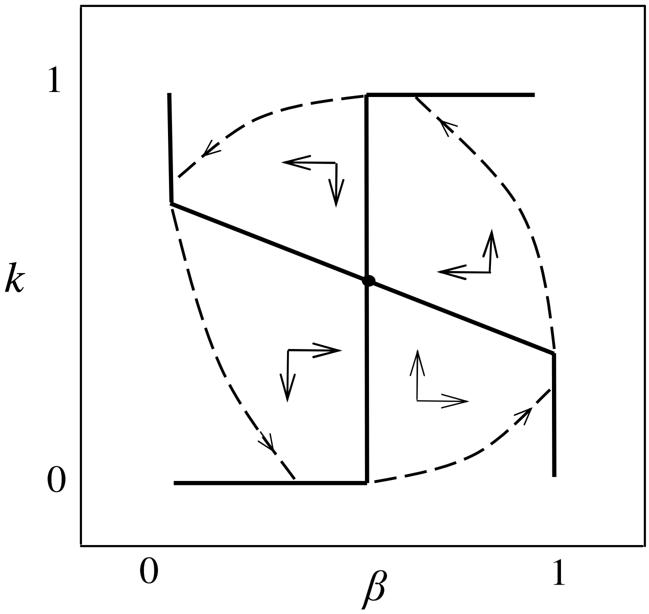

Figure 3: Patterns of location for large values of δ: The chase case

Two additonal remarks need to be made. As already mentioned, the dispersion equilibrium, β=k=0.5 is locally asymptotically stable. Thus, instead of the chase-and-flee circle, the long-run laissez-faire solution of the model might be one in which firms and housholds are equally distibuted across the two regions. However, as the adjustment path may be spiralling, the chase-and-flee property can prevail here, too. The second remark is related to the question as to which parameters induce the change from Scenario 1 (depicted in Figure 2) to Scenario 2 (depicted in Figure 3). Inspection of equation (18) shows that one of the decisive parameters is the marginal environmental damage. The larger δ, the more likely is scenario 2. This is intuitive and does not deserve further explanation. The other decisive parameter is the fixed cost, F, which occurs in the second term in the numerator on the right-hand-side of equation (18). The larger F, the smaller is the consumer surplus. See equatios (12) and (12'). A large value of F results in a low degree of product variety and this is bad for consumers. Thus, the compensation consumers get in terms of consumer surplus when they locate close to dirty producers is small and environmental concerns tend to dominate material wants.

Case 3

If z is large, the differential in environmental damage between the East and the West is increased more than proportionally in relation to the number of firms if firms relocate. Close to the dispersion equilibrium, the system has the same properties as that known from case 1. It is a saddle and, thus, unstable. When *dß/dk*=0 in equation (18), the $\tilde{u} = \tilde{u}^*$ line bends backwards and additional equilibria with fully dispersed households and incomplete industrial agglomeration are feasible. See Figure 4. Both equilibria are stable nodes or spirals and the initial conditions determine which equilibrium is approached. A chase-and-flee cycle like depicted in Figure 3 cannot be excluded, however. For a high degree of industrial agglomeration, the marginal and absolute damages in the industrialized region are very large such that households living have large incentives to relocate and like in Case 2 factors tend to follow.

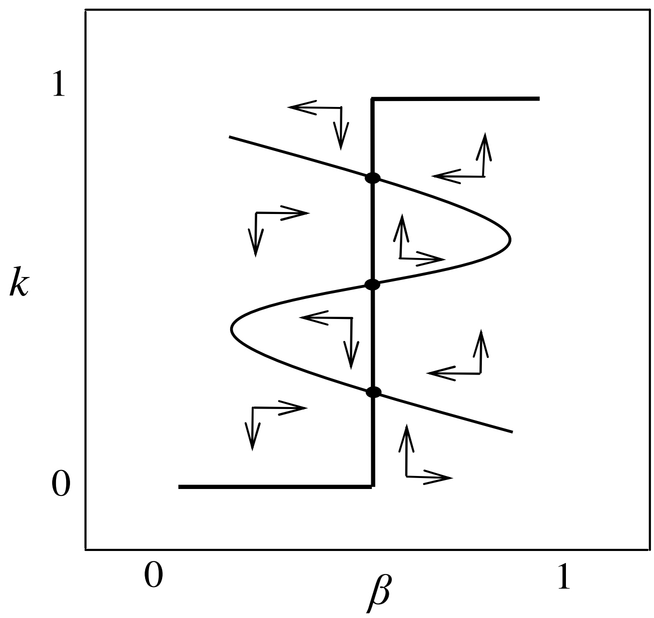

Figure 4: Patterns of location for large values of z

Case 4

If z is small, the curve may be S-shaped like the one depicted in Figure 5. Close to the dispersion equilibrium, the system exhibits the same qualitative behaviour as the one discussed in Case 2. The dispersion equilibrium is locally stable. Far from this equilibrium, agglomeration forces dominate and the properties of the system resemble those of the one discussed in Case 1. There are two equilibria with dispersed households and partially agglomerated factors and they are unstable. Finally, there are two stable agglomeration equilibria with full agglomeration of the industry in one region and a majority (which may be 100%) of the households residing in the same region. Thus, depending on historical conditions, factor movements and household migration may either result in agglomeration or in dispersion.

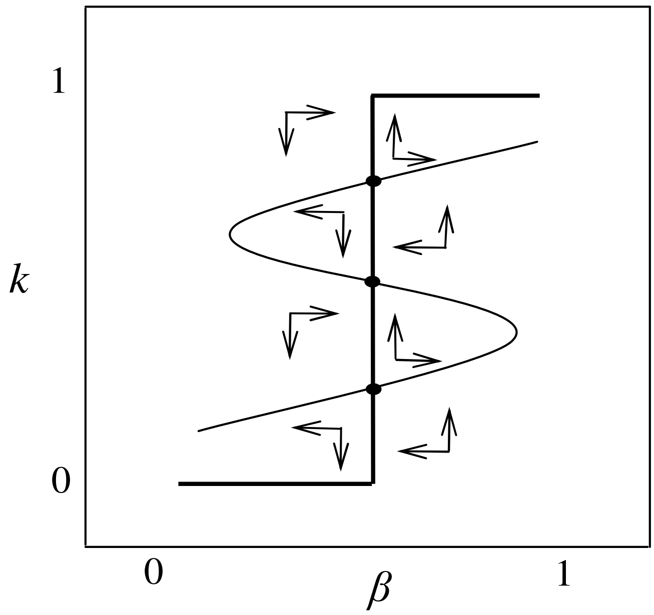

Figure 5: Patterns of location for small values of z

4. Optimal Environmental Policy

Let W denote welfare. Welfare is the population-weighted sum of utilities in the East and in the West, $\beta\tilde{u}+(1-\beta)\tilde{u}^*$. Using (12a) and (12b), we have

$$W=1+\frac{(1-\gamma)^{1-\gamma}}{\gamma F^{1-\gamma}}\left(\frac{k}{(\Theta+\beta(1-\Theta))^{\gamma-1}}+\frac{1-k}{(1-\beta(1-\Theta))^{\gamma-1}}\right)-\frac{\beta\delta}{1+z}k^{1+z}-\frac{(1-\beta)\delta}{1+z}(1-k)^{1+z}. \quad (19)$$

This is to be maximized with respect to respect to β and k. The derivatives with respect to k and β are:

$$\frac{\partial W}{\partial k}=\frac{w-w^*}{\gamma}-\delta\beta k^z+\delta(1-\beta)(1-k)^z, \quad (20a)$$

$$\frac{\partial W}{\partial \beta}=\tilde{u}-\tilde{u}^*, \quad (20b)$$

where the wage differential and the indirect-utility differential are determined by eqs. (14) and (15) repectively. Two special cases can be considered easily: (i) absence of environmental damages and (ii) dominance of environmental damages.

- In the absence of environmental damages, i.e. if δ=0, full agglomeration,is optimal. Equations (20a) and (20b) imply that welfare is increasing (decreasing) in β and k if the corrsponding wage or utility differential is positive (negative). This implies that the gradient pointing to the maximum corresponds to the arrows depicting the adjustment dynamics in Figure 2. The agglomeration equilibria are maxima and the symmetric dispersion equilibrium is a saddle.

- The other extreme case of dominating environmental damages can be considered by either letting δ go to infinity in eq. (19) or by setting the openness parameter $\Theta=1$. In that case the non-environmental part of welfare is independent of locations chosen by households and factors. The large term in brackets on the right-hand side of eq. (19) simply becomes unity. Welfare depends only on the environmental-harm term at the end of the right-hand side of (19). This term is always non-positive. It can be maximized by setting $\beta=0$ and $k=1$ or vice versa, i.e. by perfectly separating households and factors from each other.

Thus, two extreme cases of welfare optima have been identified: concentration of households and production in the same region and perfect separation of households and production. Matters are more difficult if environmental damages are neither dominating everything else nor negligible. Solutions cannot be determined explicitly anymore. Thus, the following approach was employed:

1. Select parameters of the Dixit-Stiglitz model. Here I assume that $F = \Theta = \gamma = 0.5$. Then, determine welfare maxima numerically for different values of z and δ. A difficulty here is that welfare maxima may be interior or boundary maxima depending on the parameters. Thus, I did not only look at first-order conditions, but also at the gradients of the welfare function.

2. Depict the movements of the maxima for changes in the environmental-impact parameters in a (β,k) space for different values of z.

The procedure is described in more detail in the appendix.

Figures 5a, 5b, and 5c show results for convex, linear, and concave marginal environmental damage corresponding to parameter values of $z=4$, $z=1$, and $z=0.2$, respectively. The parameter δ is increased from zero to infinity (in practice to a very large finite value) and the arrows depict the movement of the optimum as δ increases. Solid lines represent continuous movements of the welfare-maximizing spatial pattern and dotted lines indicate jumps from one maximum to another one. The figures are stylized insofar as they depict the qualitative results. In particular, the solid lines may be bended rather than linear as shown in the diagrams.

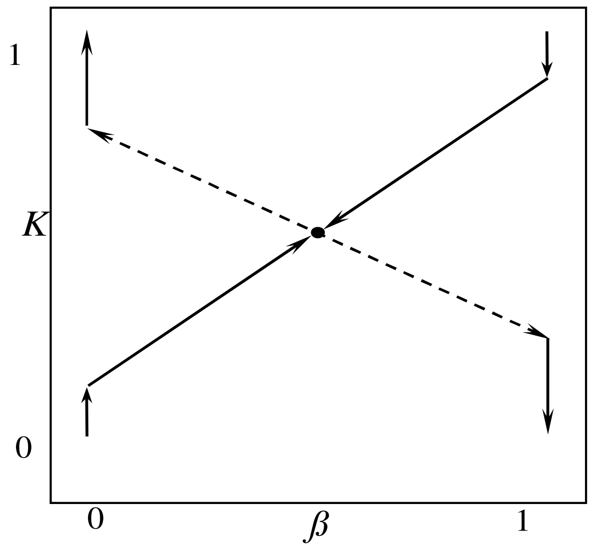

Figure 5a: Effects of increasing δ for *z*=4

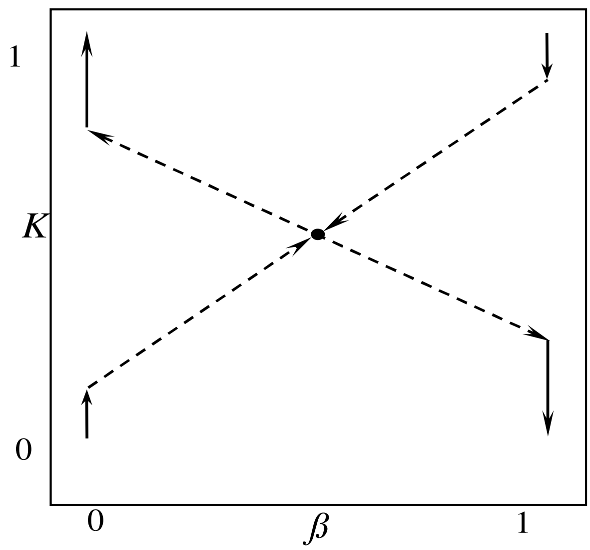

Figure 5b: Effects of increasing δ for *z*=1

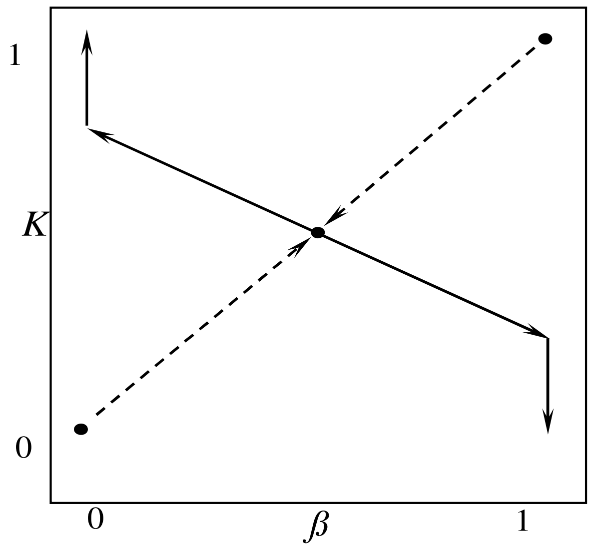

Figure 5c: Effects of increasing δ for *z*=0.2

All three figures show that the optimum is full agglomeration if δ=0 and perfect separation if δ is very large. For some intermediate levels of δ, the welfare maximum is attained by dispersion, i.e. by *ß*=*k*=0.5. Other possible welfare maxima include the possibilities of imperfect agglomeration and imperfect separation. In particular, we have the following results:

- *z*=4. For small values of δ, there is full agglomeration. As δ is increased, the optimum moves to partial agglomeration and then to total dispersion, i,e. 50% of factors and factor owners living in the East and the remaining 50% in the West. As δ is further increased beyond a particular critical value, the equilibrium jumps to partial separation: all households should be located in one region and the majority of the production in the other region. If δ becomes very large, perfect separation becomes optimal.
- *z*=1. Again, the optimum is full agglomeration for small values of δ. As δ is increased, some firms should move to the peripheral region. At a critical value of δ, the optimum jumps to dispersion and then again jumps to If δ becomes very large, perfect separation becomes optimal.
- *z*=0.2. Full agglomeration is optimal for small values of δ. As δ is increased, some firms should move to the peripheral region. At a critical value of δ, again a jump occurs and dispersion is the optimum. However, unlike in the other two cases the movement of the optimum from dispersion to perfect separation is smooth.

Of course the arrows, in Figures 5a-c do not represent dynamics, but comparative statics. The important result is that besides full agglomeration and perfect separation all other geographical patterns can be optimal: partial agglomeration, partial separation, and dispersion.

5. Instruments of Environmental Policy

How can the optimum be achieved? For small environmental damages, the policy is laissez faire. If environmental damage matters, however, full agglomeration is no longer optimal: incomplete agglomeration of firms is warranted and for extreme environmental damages even perfect separation of firms and residents is desirable. The standard instrument in environmental economics to implement the welfare-maximizing allocation is an environmental tax on the emission of pollutants. In this model, the emissions are proportional (and with the normalizations used in Section 2 even identical) to the use of factors. Thus, one could employ factor taxation instead. However, such taxes do not do the job. The impact of a tax on factor utilization in the East is shown in Figure 6. This figure shows the laissez-faire solution known from Figure 2. Additionally, the dotted line depicts the change in the indifference locus after the introduction of the tax in the East. It is seen that the (unstable) dispersion equilibrium is shifted to the West, whereas the stable equilibria remain where they were before. The tax has an impact only on the unstable equilibrium, which is irrelevant, but not on the stable equilibria, which are relevant. The underlying reason is that the location behaviour of firms is driven by centripetal forces only. Either they agglomerate in one region or in the other region. Economic incentives may have an impact on where agglomeration occurs, but not on the degree of agglomeration.

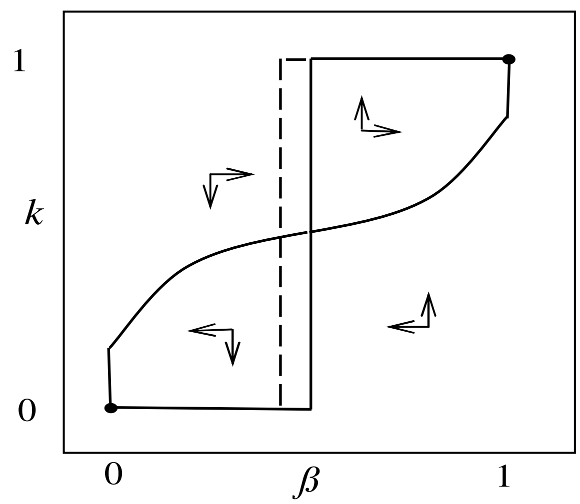

Figure 6: The impact of factor taxation in the East

As there is no tax instrument enforcing factors not to agglomerate in one region, the policy must be command and control. The optimal allocation of factors across regions must be enforced by law – not by economic incentives. Once the optimum allocation of production has been determined, consumers choose their locations optimally without further government interventions. This follows from the first-order condtion (20b).

6 Summary and Conclusions

This paper has looked at a world in which factors of production and their owners are mobile but in which factor owners do not have to live where their factors are employed. With trade costs and Dixit-Stiglitz preferences, there are centripetal and centrifugal forces and agglomerations may emerge. If environmental harm is large, a chase-and-flee pattern is possible. People want to live in a clean environment, i.e. they avoid industrial agglomerations. However, their role as factor owners induces an investment pattern that contradicts their self-interest as consumers of environmental quality. They tend to locate their factors where the demand is, i.e. close to the consumers. Since each investor's contribution to the environmental harm she experiences individually is marginal, the environmental concern is not taken into account and the industry chases the consumers.

Optimal spatial patterns in the presence of environmental concerns range from complete separation over dispersion to complete agglomeration. Command and control is to be used to implement the optimal allocation of factors across regions.

An interesting feature of this model is that results depend on the curvature of the *marginal* environmental damage curve. In standard environmental economics models, it is assumed that marginal environmental damage is increasing, but its second derivative does not matter. Here it does matter. The underlying reason is that locational decisions involve a comparison of environmental damages in the two regions. In other words, locational decisions are based not on the absolute level of environmental damage but on its East-West differential. This implies that third derivatives of the damage function play a role in situations where only second derivatives would occur in standard models.

Several extensions of the model come into mind. Firstly, all pollution was treated as a purely local public bad in this paper. Transboundary pollution spillovers were neglected. They can be introduced easily and the results would be quite straightforward. The pollution differential between regions would be mitigated and the chase-and-flee scenario as well as the optimality of separation would be more unlikely. A second extension would pertain to the adjustment dynamics in the laissez-faire case. Like Krugman (1991, Appendix B) and Baldwin (2001), one could consider forward-looking expectations instead of the static-expectations used in this paper to model adjustment processes. The conjecture is that history-vs.-expectations outcomes will be possible if environmental damage is small. Whether the introduction of forward-looking expectations could induce a stable dispersion equilibrium in situations in which this paper derived the chase-and-flee cycle, remains to be investigated A third extension would be the introduction of abatement activities. In the model discussed here, abatement is not possible and the only policy reducing environmental harm is to separate production from consumption. This does not reduce emissions but the relevant immissions (deposition). The cost of this "immission abatement" is borne by the consumers in terms of increased transportation cost. True abatement, i.e. reduction of emissions, would result in higher production cost. In a more general model this cost would have to be compared to the transportation cost effect of "immission abatement" when the optimal environmental policy is sought. This is another promising area of future research

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Appendix: Derivation of Optimal Solutions

A.1 The Methodology

In this model, welfare is not necessarily concave and, thus, the first-order conditions, (20a) and (20b), do not necessarily determine the welfare maximum. Even though the model is simple compared to other NEG models, the welfare maximum cannot be determined analytically. The procedure to find maxima used here is the following one. The starting point is the δ=0 scenario. In this case, the first-order conditions are depicted by the indifference lines of Figure 2. the (β,k) diagram, the first-order conditions

$$\frac{\partial(\tilde{u}-\tilde{u}^*)}{\partial k}=\frac{(1-\Theta)(1-\gamma)^{2-\gamma}}{\gamma F^{1-\gamma}}\left(\frac{1}{(\Theta+\beta(1-\Theta))^{\gamma}}+\frac{1}{(1-\beta(1-\Theta))^{\gamma}}\right)-\delta k^{z}-\delta(1-k)^{z}. \quad \text{(A3)}$$

The right-hand side is negative (positive) if the environmental damage parameter δ is large (small). The second-row, second-column element of the Hessian is

$$\frac{\partial(\tilde{u}-\tilde{u}^*)}{\partial \beta}=-\frac{(1-\Theta)^2(1-\gamma)^{2-\gamma}}{F^{1-\gamma}}\left(k(\Theta+\beta(1-\Theta))^{1-\gamma}+(1-k)(1-\beta(1-\Theta))^{1-\gamma}\right), \quad \text{(A4)}$$

To discuss the properties of the system (A1), we determine the isoclines. Given the choice of the adjustment dynamics, the isoclines also determine the loci along which the first-order conditions, (20a) and (20b), are satisfied. Their slopes are

$$\left.\frac{dk}{d\beta}\right|_{\frac{\partial W}{\partial k}=0}=\frac{\frac{\partial(\tilde{u}-\tilde{u})}{\partial k}}{\beta D''(k)+(1-\beta)D''(1-k)} \quad \text{(A5)}$$

$$\left.\frac{dk}{d\beta}\right|_{\frac{\partial W}{\partial k}=0}=-\frac{\frac{\partial(\tilde{u}-\tilde{u})}{\partial \beta}}{\frac{\partial(\tilde{u}-\tilde{u})}{\partial k}} \quad \text{(A6)}$$

From the fact that the Hessian matrix has negative diagonal elements and that the off-diagonal elements are equal, we can infer that the slopes of the $\partial W/\partial k=0$ line and the $\partial W/\partial \beta=0$ line have the same signs for given values of k and β. In other words: in the intersection points they are either both increasing or both decreasing.

To calibrate the model, we use the following numerical values of the parameters of the geography module:

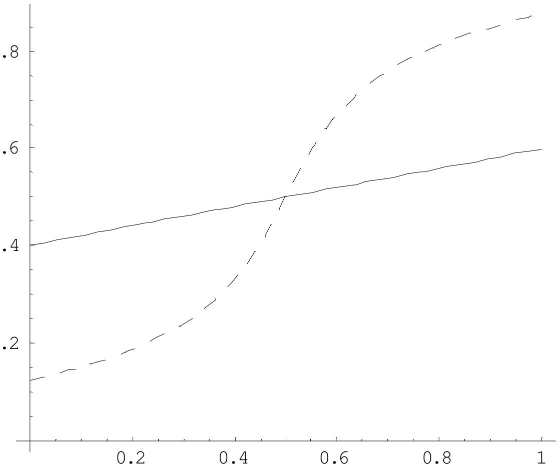
$$F = \gamma = \Theta = 0.5 .$$

For the environmental-damage function, we use the values z=0.2, z=1, and z=4 to indicate concave, linear, and convex environmental marginal damage respectively. As regards the δ

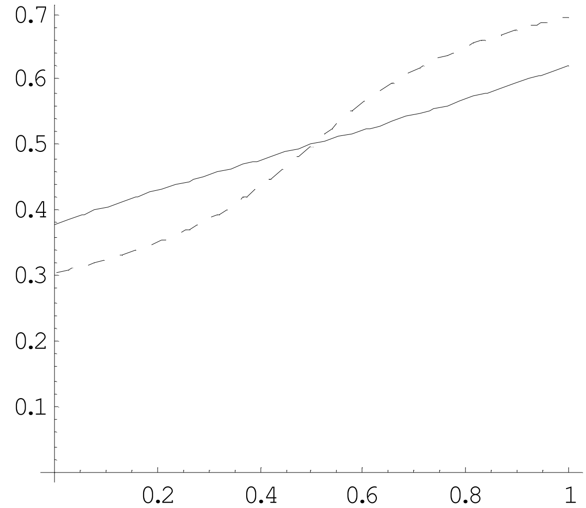
parameter of the model we start with δ=0 and increase this parameter to very large values. Figures A1 to A3 depict the isoclines for z=0.2, z=1, and z=4, respectively, and selected values of δ. Figures have been drawn using MATHEMATICA®. $\partial W/\partial \beta$=0 is depicted as a solid line, $\partial W/\partial k$=0 as a dotted line. For δ=0, the phase diagram is the same as in Figure 2: the dispersion equilibrium is a saddle and the agglomeration equilibria are the welfare optima. With increasing values of δ, the isoclines rotate and change their shapes. It is seen that the $\partial W/\partial \beta$=0 line is rotated in a counter-clockwise fashion whereas the $\partial W/\partial k$=0 line is rotated clockwise. If the $\partial W/\partial \beta$=0 line is cut by the $\partial W/\partial k$=0 line from below, the intersection point is a saddle and represents a local welfare minimum; if it is cut from above, the intersection point is stable and represents a local maximum.

A2 Results for z=4 and Changes in δ

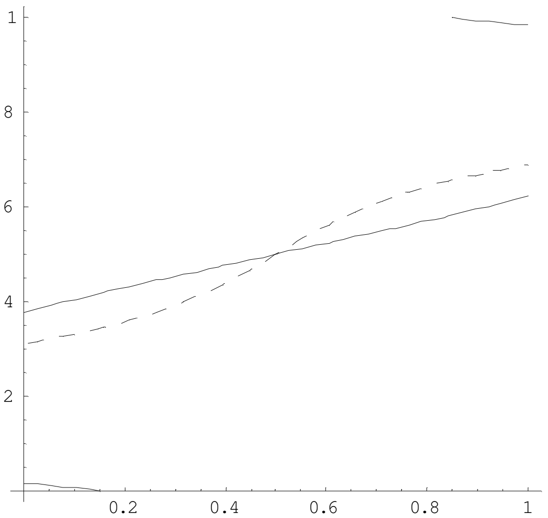
z=4, δ=1



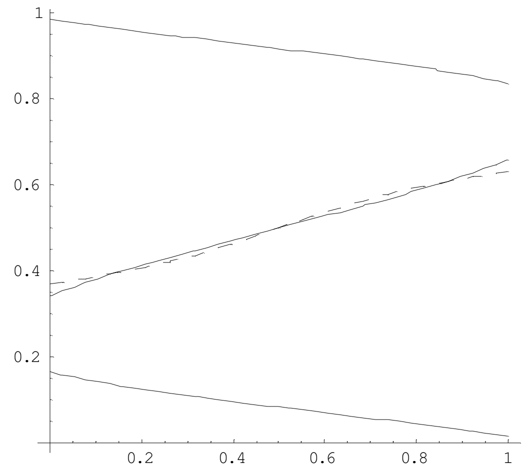
z=4, δ=2.5



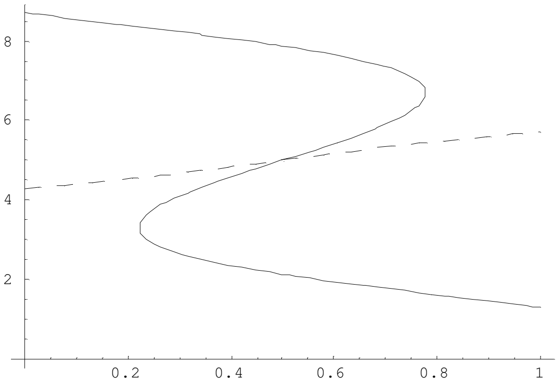
z=4, δ=2.6



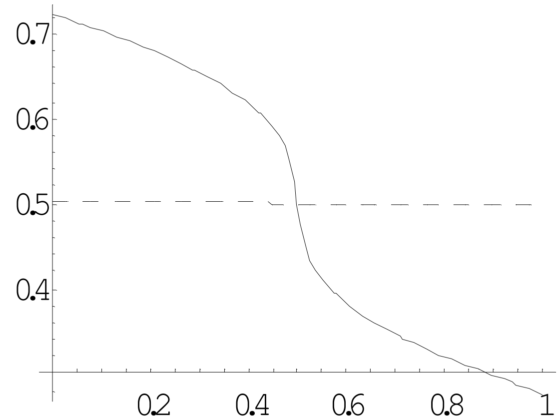
z=4, δ=3,7



z=4, δ=5.5

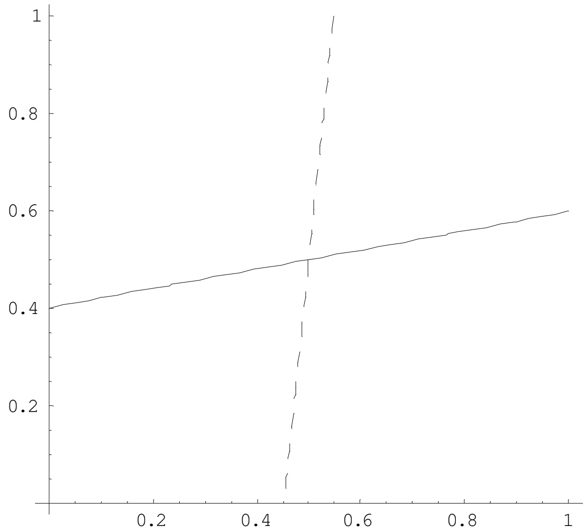


z=4, δ=9.5

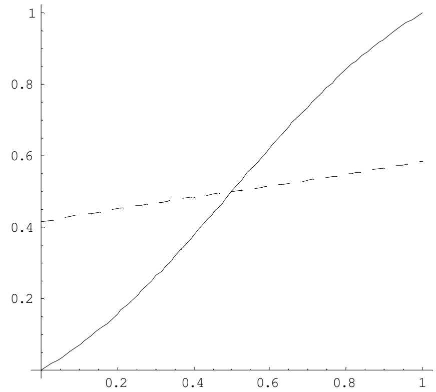


A3 Results for *z*=1 and Changes in δ

z=1, δ=0.6

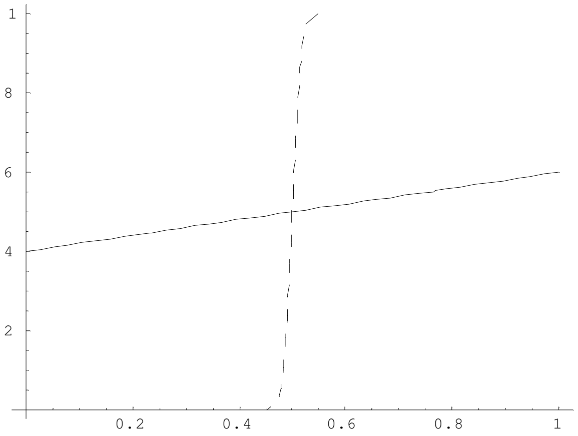


z=1, δ=1

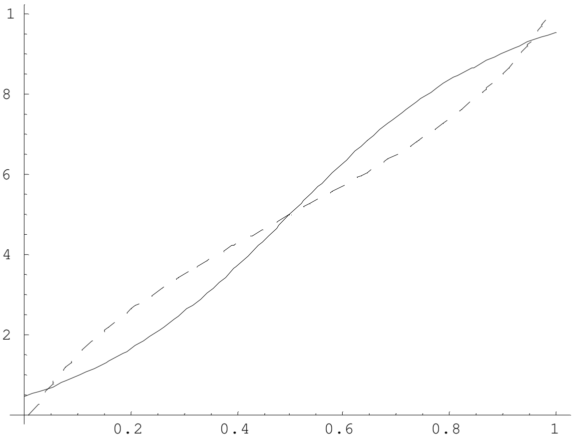


A4 Results for *z*=0.2 and Changes in δ

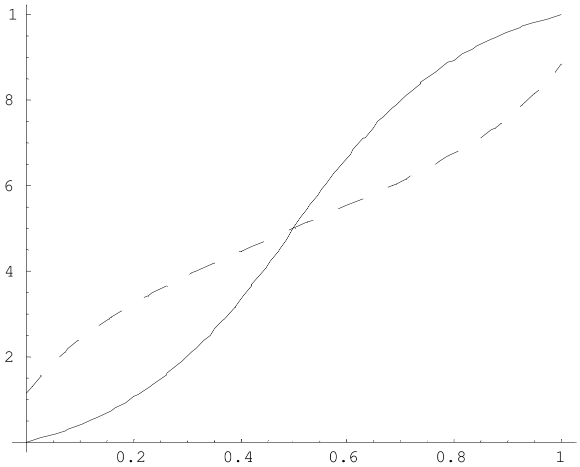
z=0.2, δ=0.1



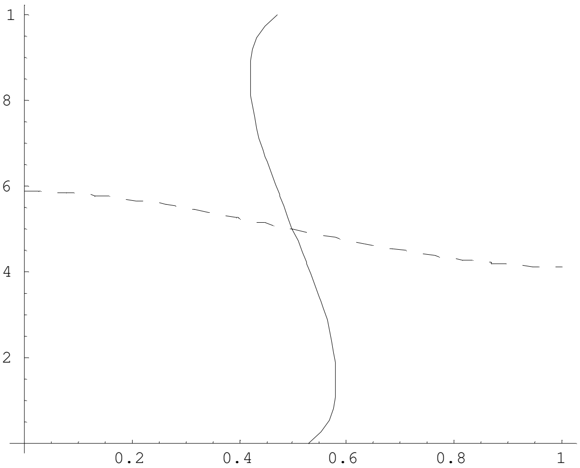
z=0.2, δ=0.58



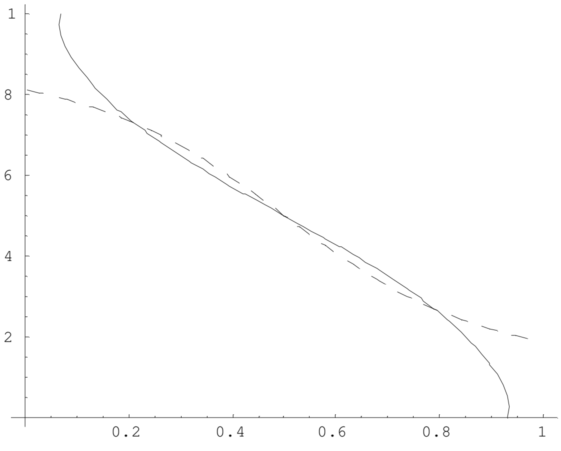
z=0.2, δ=0.6



z=0.2, δ=0.7



z=0.2, δ=0.82



z=0.2, δ=0.9