Adding geography to the new economic geography

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Abstract

For reasons of analytical tractability, new economic geography (NEG) models treat geography in a very simple way: attention is either confined to a simple 2-region or to an equidistant multi-region world. As a result, the main predictions regarding the impact of e.g. diminishing trade costs are based on these simple models. When doing empirical or policy work these simplifying assumptions become problematic and it may very well be that the conclusions from the simple models do not carry over to the heterogeneous geographical setting faced by the empirical researcher or policy maker. This paper tries to fill this gap by adding more realistic geography structures to the Puga (1999) model that encompasses several benchmark NEG models. By using extensive simulations we show that many, although not all, conclusions from the simple models do carry over to our multi-region setting with more realistic geography structures. Given these results, we then simulate the impact of increased EU integration on the spatial distribution of regional economic activity for a sample of 194-NUTSII regions and find that further integration will most likely be accompanied by higher levels of agglomeration.

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1. INTRODUCTION

The seminal paper by Krugman (1991) gave rise to what became known as the new economic geography (NEG) literature, where the 'new' refers to the fact that the spatial distribution of population, production and consumption emerges endogenously from full general equilibrium models (Fujita, Krugman and Venables, 1999a; Helpman, 1998; Krugman and Venables, 1995; or Puga, 1999). Any particular spatial distribution of economic agents goes along with spreading (e.g. congestion, housing prices) and agglomeration (e.g. better market access, good access to intermediate suppliers) forces that dis- or encourage agglomeration respectively. The interplay of these two forces determines whether or not agents move to another region, hereby possibly changing the spatial economic landscape. As a result, the theoretical models are able to give predictions about the effect of a change in these spreading or agglomeration forces, for example the effect of lowered trade costs on the distribution of economic activity across space (see also Fujita and Thisse, 2002).

These predictions are, however, typically based on models that treat geography in a very simple way (see also Neary, 2001, p.551). Attention is largely confined to simple 2-region models or multi-region models exhibiting a uni-dimensional spatial structure, with regions lying on a circle, i.e. a racetrack economy (Fujita et al., 1999a ch.6), with the distance between each pair of regions the same, i.e. an equidistant economy (Puga, 1999, Tabuchi et al., 2005) or regions lying on a line, i.e. a line economy (Fujita, et al., 1999b). Some other papers, notably Krugman and Elizondo (1995) and Monfort and Nicolini (2000), introduce 3-region models that allow for differences in the cost of intranational and international trade, but in order to keep these models tractable the authors have to assume the economic mass of the third region to be exogenous. A notable exception is the paper by Behrens, et al. (2005), which presents analytical results in a multi-region trade model with a somewhat more complex characterization of geography, i.e. a transportation network locally described by a tree, showing that in that case changes in transport costs have spatially limited effects.

The reason for making these simplifying assumptions is analytical tractability. Adding a more realistic, asymmetric, geography structure to an NEG model would render the model analytically insolvable (see Behrens et al., 2005, p.16 and Fujita and Mori, 2005, p.396). It is the assumption of a simple geography structure and/or the focus on a 2-region model that allows for the establishment of all the well-known analytical results in the NEG literature (e.g. multiple equilibria, catastrophic (de)agglomeration, etc).

However, when doing empirical or policy work, these simplifying assumptions become problematic since it is unclear whether the conclusions from these simple models carry over to the more heterogeneous asymmetric geographical setting faced by the empirical researcher or policy maker (see also Behrens and Thisse, 2007).. For empirical work, this makes it difficult to relate the underlying theory to empirical estimates of the structural model parameters obtained using multi-region or multi-country data, as e.g. presented in Redding and Venables (2004), Hanson (2005) and Brakman et al. (2006). When doing policy work, it becomes ambiguous to provide policy recommendations for the clearly asymmetric multi-region setting in the 'real world' on the basis of an equidistant (often 2-region) model. To study the effects of increased economic integration in such a 'real-world'-setting, attempts by e.g. Forslid et al. (2002a), Forslid et al. (2002b) and Bröcker (1998) all resort to the simulation of a computable general equilibrium (CGE) model of an asymmetric multi-region or multi sector world. These simulations give some interesting predictions about the effect of the ongoing economic integration in the EU. But the results obtained are difficult to link back to the theoretical model because the properties of the CGE-models that are used for the simulations are generally not known, not even for the simple 2-region or equidistant multi-region case.

This paper takes a more theoretically grounded approach by adding more geographical realism to a well-known NEG-model (Puga, 1999) that encompasses several benchmark NEG-models. A particularly nice feature of that model is that it presents analytical results for both the 2-region and the equidistant multi-region setting, which serve as the theoretical benchmark to which we can compare our findings. In doing so, we follow the recommendations made by Fujita and Krugman (2004), p.158; Behrens and Thisse (2007), section 3; Krugman (1998), p.15 or Fujita and Mori (2005), and it is useful to quote the latter paper at some length:

"While it will continue to be important to pursue building analytically solvable models regarding the basic mechanism of agglomeration and dispersion, it will become even more important to build numerically computable models. After all, there is great need to finally go beyond the basic two-region-two-industry models and go to asymmetric many-region-many-industry models of trade and geography in order to attain practically useful policy implications. Most models with emphasis on the analytical solvability are solvable only in a very limited low dimensional setup, but they are often not computable numerically (at least

not in a reasonable amount of time) once more spatial and industrial structure is incorporated. A most desirable model would be one that has solvability at the low dimensional setup and computability even at the fairly high dimensional setup." (Fujita and Mori, 2005, p.396)

The only other paper that we know of that simulates a NEG model when adding a more realistic depiction of geography is Stelder (2005). Using the Krugman (1991) model, Stelder (2005) tries to replicate the actual spatial distribution of cities across Europe by simulating the Krugman (1991) *cum* geography model. He however does not relate any of his model simulations back to theory, focusing instead on simulating the current spatial distribution of economic agglomerations as closely as possible. Our aim is quite different: we systematically show the impact of introducing several asymmetries (asymmetric 2nd nature geography structure(s), asymmetric initial endowments) to a multi-region NEG model that is analytically solvable when considering its equidistant version.

Our paper is organized as follows. In the next section we introduce the Puga (1999) model. In section 3 we introduce our depiction of geography. To restrict our attention to the introduction of more realistic geography structures, we deliberately assume that all 194 regions are initially of equal size or mass. The introduction of non-equidistant regions does by and large not change the qualitative results from the benchmark 2-region (or equidistant multi-region) model w.r.t. the impact of a change in trade costs on the equilibrium degree of agglomeration. With interregional labor mobility, a continued fall in trade costs will ultimately, and 'catastrophically' lead to complete agglomeration. Without interregional labor mobility, and moving from very high to very low trade costs, spreading will also result to sudden (partial) agglomeration but when trade costs become very low the degree of agglomeration will decrease resulting in a sudden (partial) return to more spreading. A notable difference between the long run equilibria in our non-equidistant, multi-region model and the equidistant Puga (1999) model is that the same long run equilibrium level of agglomeration may go along with a *different* spatial distribution of economic activity across the individual regions. In section 4 we add the role of economic mass to our model by not only allowing for an asymmetric geography structure but by also taking differences in initial size (employment, arable land area) into account. Again, in a qualitative sense the main results from the equidistant model w.r.t. to the impact of changes in trade costs on the long run equilibrium agglomeration carry through. In addition, and by using estimation results of the key model parameters for a sample of 194 European NUTSII regions, we are in a position to answer questions about the impact of increased EU-integration. We find that lowering trade costs will most likely imply more and not less agglomeration for the EU regions. Moreover, both the extent and the spatial pattern of agglomeration depend crucially on the assumption about interregional labor mobility. Section 5 concludes our paper.

2. THE PUGA (1999) MODEL

2.1 Setup of the model

This section provides a brief description of the model introduced by Puga (1999). As mentioned before we use this model as it captures two important benchmark NEG-models, i.e. Krugman (1991) and Venables (1996) as special cases. Also Puga (1999) derives analytical results in the 2-region case as well as in the equidistant multi-region case which allows for a ready comparison to our simulation results. The model set up is as follows[3]. Consider a world consisting of M regions, each populated by L_i workers and endowed with K_i units of arable land. Each region's economy consists of two sectors, agriculture and industry. Labor is used by both sectors and is perfectly mobile between sectors within a region and is either perfectly mobile or immobile between regions. Land on the other hand is used only by the agricultural sector and is immobile between regions.[4]

Production

The agricultural good is produced under perfect competition and free entry and exit using Cobb-Douglas technology[5] and is freely tradable between regions. The industrial sector produces heterogeneous varieties of a single good under monopolistic competition and free entry and exit, incurring so-called 'iceberg' trade costs when shipped between regions ($\tau_{ij} \geq 1$ goods have to be shipped from region i to let one good arrive in region j). Industrial production technology is characterized by increasing returns to scale, i.e. production of a quantity $x(h)$ of any variety h requires fixed costs α and variable costs $\beta x(h)$ that are assumed to be the same in each region. This, together with free entry and exit and profit maximization,

[3] We use the same notation as Puga (1999) for ease of exposition.
[4] Defining the two sectors as being agriculture and industry is arbitrary. The main point is that one sector employs an immobile (both between sectors and regions) factor of production, producing a homogenous good that is freely tradable between regions under perfect competition, and that the other sector employs a mobile (be it between sectors and/or regions) factor of production, producing heterogeneous varieties of the same good that are costly to trade between regions under monopolistic competition.
[5] Puga (1999) defines the agricultural sector somewhat more general. However, when deriving analytical results, he also resorts to the use of a Cobb-Douglas production function in agriculture, see p.318 of his paper.

ensures that in equilibrium each variety is produced by a single firm in a single region. The production input is a Cobb-Douglas composite of labor and intermediates in the form of a composite manufacturing good, with $0 \leq \mu \leq 0$ the Cobb-Douglas share of intermediates. The composite manufacturing good is specified as a CES-aggregate (with $\sigma > 1$ the elasticity of substitution across varieties) of all manufacturing varieties produced. The resulting minimum-cost function associated with the production of a quantity *x(h)* of variety *h* in region *i* can be written as:

$$C(h) = q_i^{\mu} w_i^{M\,1-\mu}(\alpha + \beta x(h)) \tag{1}$$

where q_i is the price index of the composite manufacturing good, and w_i^M the manufacturing wage in region *i*..

Preferences

Consumers have Cobb-Douglas preferences over the agricultural good and a CES-composite (also with $\sigma > 1$ the elasticity of substitution across varieties) of manufacturing varieties, with $0 \leq \gamma \leq 0$ the Cobb-Douglas share of the composite manufacturing good. Specifying the composite manufacturing good this way ensures demand from each region for each manufacturing variety, which, together with the fact that each variety is produced by a single firm in a single region, implies that trade takes place between regions.

Equilibrium

Having specified preferences over and the production technologies of the manufacturing and agricultural good, the equilibrium conditions of the model can be calculated. Profit maximization and free entry and exit determine the share of labor employed, L_i^A, the wage level w_i^A in agriculture, which equals the marginal product of labor, and the rent earned per unit of land $r(w_i^A)$. The former two in turn pin down the share of workers in manufacturing, ς_i. Given the assumed Cobb-Douglas production function in agriculture, with labor share θ, we have that:

$$\varsigma_i = \frac{L_i^M}{L_i} = 1 - \frac{L_i^A}{L_i} = 1 - \frac{K_i}{L_i}\left(\frac{\theta}{w_i^A}\right)^{\frac{1}{1-\theta}} \tag{2}$$

where $0 \leq \theta \leq 1$ denotes the Cobb-Douglas share of labor in agriculture, and L_i^M and L_i^A the number of workers in manufacturing and agriculture respectively. Equation (2) shows that, in contrast to Krugman (1991), where agriculture uses only land[6] (θ = 0), or to Venables (1996), where agriculture employs only labor (θ = 1), the share of a region's labor employed in manufacturing is endogenously determined in this model. It increases with a region's labor endowment and agricultural wage level and decreases with a region's land endowment and with the Cobb-Douglas share of labor in agricultural production.

Consumer preferences in turn determine total demand for agricultural products in region *i* as:

$$x_i^A = (1-\gamma)Y_i \tag{3}$$

In the industrial sector, utility maximization on behalf of the consumers, combined with profit maximization and free entry and exit, gives the familiar result that all firms in region *i* set the same price for their produced manufacturing variety as being a constant markup over marginal costs:

$$p_i = \frac{\sigma\beta}{\sigma-1} q_i^{\mu} w_i^{M(1-\mu)} \tag{4}$$

where q_i is the price index of the composite manufacturing good in region *i* defined by:

$$q_i = \left(\int_j \tau_{ij}^{1-\sigma} n_j p_j^{(1-\sigma)} \right)^{\frac{1}{1-\sigma}} \tag{5}$$

where n_i denotes the number of firms in region *i* and

$$w_i^M = \left[(1-\mu) n_i p_i \left(\frac{(\sigma-1)}{\sigma\beta} (\alpha + \beta x_i) \right) \right] (\varsigma_i L_i)^{-1} \tag{6}$$

is the manufacturing wage level in region *i*.

It also gives total demand for each manufacturing variety produced (coming from both the home region *i* as well as foreign regions *j*) which is the same for each variety in the same region due to the way consumer preferences are specified:

$$x_i = \int_j p_i^{-\sigma} e_j q_j^{(\sigma-1)} \tau_{ij}^{1-\sigma} \tag{7}$$

where in (7) demand from each foreign region *j* is multiplied by τ_{ij} because (τ_{ij} –1) of the amount of the product ordered from region *i* melts away in transit (the iceberg assumption), and

$$e_i = \gamma Y_i + \mu n_i p_i \left(\frac{(\sigma-1)}{\sigma\beta} (\alpha + \beta x_i) \right) \tag{8}$$

[6] Krugman (1991) does not call this immobile production factor land, he refers to it as being immobile labor, i.e. farmers.

is total expenditure on manufacturing varieties in region i (the first term representing consumer expenditure and the second term producer expenditure on intermediates), where

$$Y_i = w_i^A(1-\varsigma_i)L_i + w_i^M \varsigma_i L_i + r(w_i^A)K_i + n_i\pi_i \qquad (9)$$

is total consumer income consisting of workers' wage income, landowners' rents and entrepreneurs' profits respectively. Due to free entry and exit these profits are driven to zero ($\pi_i = 0$), thereby uniquely defining a firm's equilibrium output at:

$$x_i = \alpha(\sigma-1)/\beta \qquad (10)$$

Finally, to close the model, the labor markets are assumed to clear:

$$L_i = L_i^M + L_i^A = \underbrace{\left[(1-\mu)n_i p_i\left(\frac{(\sigma-1)}{\sigma\beta}(\alpha+\beta x_i)\right)\right]w_i^{M-1}}_{L_i^M} + \underbrace{K_i\left(\frac{\theta}{w_i^A}\right)^{\frac{1}{1-\theta}}}_{L_i^A} \qquad (11)$$

where the demand for labor in agriculture, L_i^A, follows from the assumption of Cobb-Douglas technology in agriculture and the term between square brackets represents the manufacturing wage bill. Moreover equating labor supply to labor demand in the industrial sector gives an immediate relationship between the number of firms and the number of workers in industry:

$$n_i = \frac{\varsigma_i L_i}{\alpha\sigma(1-\mu)q_i^{\mu} w_i^{M-\mu}} \qquad (12)$$

Long run equilibrium and degree of interregional labor mobility

Next, to solve for the long run equilibrium (LRE), Puga (1999) distinguishes between the case where labor is both interregionally and intersectorally mobile and the case when it is only intersectorally mobile. Without interregional labor mobility, long run equilibrium is reached when the distribution of labor between the agricultural and the industrial sector in each region is such that wages are equal in both sectors. This is ensured by labor being perfectly mobile between sectors driving intersectoral wage differences to zero. When instead labor is also interregionally mobile, not only intersectoral wage differences are driven to zero in all regions in equilibrium. Workers now also respond to real wage (utility) differences between regions by moving to regions with the higher real wages (utility) until real wages are equalized between all regions, hereby defining the long run equilibrium.[7] In effect the model (and its two variants) can be summarized by the following scheme or decision tree[8]:

[7] Note that in case of interregional labor immobility real wages can possibly differ between regions.
[8] Note that the model is actually static which implies that the economy immediately adjusts to the LRE. The model outline in Table 1 merely serves to get the intuition behind the model. Also it is the way we find the LRE when simulating the model.

Table 1 Model outline to find long run equilibrium (LRE)

---

a. Initial distribution of labor over regions and over sectors within each region

b. Labor moves between sectors within each region until sectoral wages are equal.

c. Interregional labor mobility?

C1. NO: long run equilibrium

C2. YES: short run equilibrium → **d.**

d. Interregional real wage equality?

D1. NO: labor moves between regions in response to differences in real wages, with workers moving to those regions with higher real wages, hereby changing the distribution of labor over the regions → process restarts at **a.** with this new distribution of labor over regions and sectors.

D2. YES: long run equilibrium

Interregional labor immobility

The long run equilibrium in case of interregional labor immobility can now be shown to be a solution $\{w_i, q_i\}$ of three equations that have to hold in each region. In our case (when using wage-worker space) these are, using the fact that in equilibrium $w_i^M = w_i^A = w_i$:

$$q_i = \frac{\sigma\beta}{\sigma-1}\left(\frac{1}{\alpha\sigma(1-\mu)}\sum_j\left(\varsigma_j L_j q_j^{-\mu\sigma} w_j^{1-\sigma(1-\mu)}\tau_{ij}^{1-\sigma}\right)\right)^{1/(1-\sigma)} \tag{13}$$

$$w_i = \left(\frac{\sigma\beta}{\sigma-1}\right)^{\mu-1} q_i^{\mu/(\mu-1)}\left(\frac{\beta}{\alpha(\sigma-1)}\sum_j e_j q_j^{\sigma-1}\tau_{ij}^{1-\sigma}\right)^{1/(\sigma(1-\mu))} \tag{14}$$

$$e_i = \gamma(w_i L_i + K_i r(w_i)) + \mu/(1-\mu) w_i \varsigma_i L_i \tag{15}$$

, where (13) is obtained by substituting (4) and (12) into (5), (14) by substituting (4) and (10) into (7), and (15) by substituting (4), (10) and (12) into (8).

Interregional labor mobility

In case of interregional labor mobility, a solution to (13)-(15) merely constitutes a short run equilibrium (SRE). With interregional labor mobility, workers will move between regions in response to real wage differences until the interregional real wage differences, that are possible to persist when workers are unable (or unwilling) to move between regions, are no longer present. More formally, the LRE solution *{w_i,q_i}* for each region *i* has to adhere to the additional condition that real wages, ω_i, are equal across all regions:

$$\omega_i = q_i^{-\gamma} w_i = \omega \qquad \forall i \tag{16}$$

Having specified the equilibrium equations, the next point of interest is to determine the equilibrium distribution of firms and people over the *M* regions in the model and how this distribution depends on the level of economic integration modelled here by the level of trade costs, τ_{ij}.

2.2 Economic Integration

Puga (1999) makes the following simplifying assumption in order to derive analytical results with respect to ongoing economic integration: trade costs between each pair of regions are the same and there are no costs of transporting goods within one's own region, i.e.:

$$\tau_{ij} = \tau, \text{ if } i \neq j \qquad \text{and} \qquad \tau_{ij} = 1, \text{ if } i = j \tag{17}$$

The difference between interregional labor mobility and immobility on agglomeration with respect to economic integration is best summarized by Figures 1a and 1b respectively[9].

Figure 1 Trade costs and the long run equilibrium in 2 region model

Figure 1a

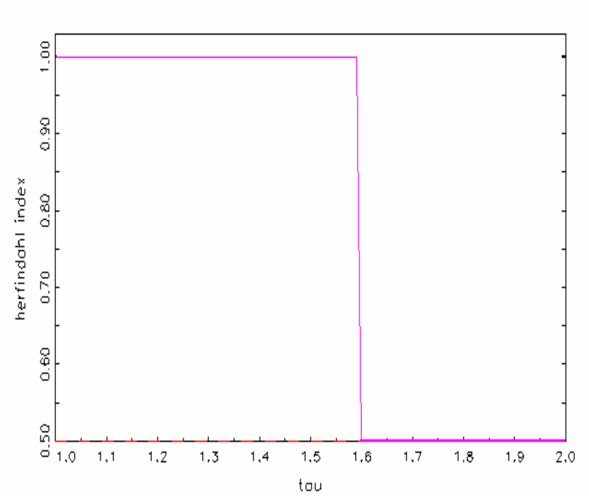
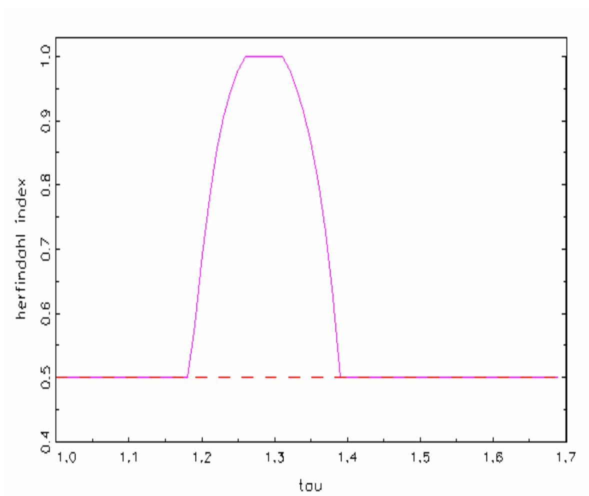


Figure 1b



Notes: Simulation parameters as in Puga (1999), p.333. In Figure 1a, μ = 0.2, γ = 0.1, θ = 0.55, σ = 4 and in Figure 1b: μ = 0.3, γ = 0.4, θ = 0.94, σ = 4. The breakpoints, see appendix A, are in Figure 1a, $\tau_S = 1.6002$. Figure 1b, $\tau_{S,1} = 1.1839$ and $\tau_{S,2} = 1.3887$. Note, that in the case of only two regions the Herfindahl index on the y-axis is similar to depicting one region's share. See section 3.1 for more details on the use of the Herfindahl index.

[9] See Appendix A for the analytics behind these Figures.

Figures 1a and 1b are obtained from a simulation of the symmetric 2-region model. These two figures replicate Figure 2 and 6 in Puga (1999) and are also known as the tomahawk and the bell shaped curve, respectively.

Figures 1a and 1b show that the assumption about interregional labor mobility crucially affects the sensitivity of the spatial distribution of economic activity to increased levels of economic integration. Starting from a relatively high level of trade costs (e.g. 1.7), increased integration (moving from right to left along the x-axis) will in the case of interregional labor mobility result in a sudden (catastrophic) change in the (economic) landscape characterized by a shift from perfect spreading to complete agglomeration. In case of interregional labor immobility, increased integration will also first result (but less catastrophically) in agglomeration, but as integration continues, the economy ultimately moves back to spreading. This return to symmetry in case of interregional labor immobility is caused by the fact the spreading force imposed by the increased difficulty with which firms have to attract their workers from the agricultural sector is not weakened (as in case of an interregional labor mobility) by the possibility to attract workers from the other region. As with ongoing economic integration trade or transport costs become relatively small, this means that wage differences become more important as a cost factor in production. Eventually the spreading forces (i.e. the lower wage level in the periphery) 'take over' and industrial firms spread out over both regions again. This does not happen with interregional labor mobility as the higher real wage levels in agglomerations keep attracting workers from the periphery (see also e.g. Helpman (1998), as to how not only 'non-traded production inputs' (here the interregionally immobile labor force), but also non-traded consumption goods can give rise to such a return to symmetry at low levels of trade costs).

3. BEYOND AN EQUIDISTANT SETUP

The results regarding the impact of increased levels of integration on the long run equilibrium, as summarized by Figures 1a and 1b, crucially depend on the assumption of an equidistant regional structure, i.e. equation (17). It is difficult to envisage such a regional structure with more than three regions on a flat plain; more important it is at odds with the real world. There, regions are related to each other by a more complicated geography structure:

$$\tau_{ij} \neq \tau \qquad (18)$$

All empirical work within the new economic geography literature, be it multi-country (e.g. Redding and Venables, 2004) or multi-region (e.g. Hanson, 2005; Brakman et al., 2006;

Crozet, 2004 and Knaap, 2006) studies, imposes such a *multi-dimensional* geography structure on the data. The geography structure depends usually on bilateral distances between regions and sometimes also incorporates the idea that ex- or importing to a region in a different country involves extra trade costs (tariffs, language barriers, etc). The practice of relating the estimated structural parameters back to the analytical results obtained from the theoretical models (mostly the simplest 2-region version of the underlying model) to answer questions like "where on the bell (tomahawk) are we?" can thus be considered largely tentative or even misleading (see also Behrens and Thisse, 2007). The most elegant solution to this problem would of course be to develop an analytically solvable version of an NEG-model with a multi-dimensional geography structure. However, given the mathematical difficulties that are far from straightforward (probably even impossible) to overcome[10], we propose a different strategy in this paper: simulation. Instead of trying to explicitly solve for equilibrium using equations (14)-(16), and also (17) in case of interregional labor mobility, making some necessary simplifying assumptions in the process, one can also use these equations to simulate model outcomes. A major advantage of this is that it does not require any simplifying assumptions about the geographical dependencies between regions. A drawback, however, of performing merely simulations is that one is never 100% certain whether or not the results found are due to the particular parameter setting used in the simulation and whether or not the equilibrium solution found is unique or not[11]. However by extensive simulation (starting at different initial distributions of labor over the regions and/or sectors, and using many different, though cleverly chosen on the basis of the analytical results in the uni-dimensional case, model parameters) one can get a good grasp of the model's behavior in a multi-region, multi-dimensional geography case. Even more so from an empiricist's point of view, where the number of parameters to use is restricted to merely one set of parameters, i.e. those estimated (see also section 4), hereby substantially limiting the number of simulations needed when performing robustness checks.

3.1 The simulation setup

[10] The model not only becomes analytically intractable, also the concept of agglomeration breaking becomes more problematic when considering more than two regions (what is agglomeration and when is it breaking is not as clear-cut as in the 2-region case).

[11] Given the fact that the symmetric 2-region version of the model with interregional labor mobility is characterized by multiple equilibria (see Robert-Nicoud (2004) for a formal proof) it is not unthinkable to also be a characteristic of a multi-region model with a multi-dimensional geography structure.

The version of the model that we simulate consists of 194 regions, the number of NUTSII[12] regions that make up the 15 countries of the European Union before its eastward expansion in 2004. Our simulation model solves for the long run equilibrium (LRE) in case of an interregionally immobile labor force using a sequentially iterative search algorithm that follows the schematic outline of the model as presented in Table 1, where the algorithm stops whenever the nominal wages in each region change less than 0.00000001% between iterations. In case of interregional labor mobility, we also have to specify the way workers move in response to real wage differences between regions (and subsequently solve for the equilibrium distribution of labor between manufacturing and agriculture in order to have identical wages within a region). Following Fujita et al. (1999), we assume that workers move according to the following simple dynamics, which can be reconciled with for example evolutionary game theory (see Weibull, 1995, see also the discussion in Baldwin et al., 2003):

$$d\lambda_i / \lambda_i = \psi(\omega_i - \bar{\omega}), \qquad with\ \bar{\omega} = \sum_j \lambda_j \omega_j \tag{19}$$

where $\lambda_i = L_i / \sum_j L_j$, $\bar{\omega}$ the average real wage per capita and ψ is a parameter governing the speed at which people react to real wage differences. Again we define equilibrium to be reached whenever the number of people in each region changes with less than 0.00000001% between iterations. We explicitly mention the stopping criterion used in our algorithm as we found the equilibrium solution quite sensitive (especially in case of interregional labor mobility) to its specification. With a less stringent stopping criterion (e.g. 0.000001%) than the one we use in our baseline simulations, the search algorithm may stop 'too early', presenting a short run equilibrium characterized by partial agglomeration as the long run equilibrium (see also footnote 17). In general we stress that the type of search algorithm used to find the LRE, i.e. the way 'dynamics' are artificially but necessarily introduced in an essentially static model, is of paramount importance and can potentially give misleading results regarding the agglomeration pattern in the LRE (see e.g. Fowler, 2007 and Brakman et al. 2001; for more discussion on this see also section 3.2).

Next, we have to choose the parameter values for which to show the simulation outcomes. Figures 1a and 1b already showed that our simulation model replicates the findings in Puga

[12] Nomenclature of Territorial Units for Statistics, a division of the EU15 in regions for which statistical information is collected by Eurostat. Excluding Luxembourg and the overseas territories of Portugal, Spain and France, the following 14 countries (nr. regions) are included in the sample: Belgium (11), Denmark (3), Germany (30), Greece (13), Spain (16), France (22), Ireland (2), Italy (20), The Netherlands (12), Austria (9), Portugal (5), Finland (6), Sweden (8) and The United Kingdom (37).

(1999) using the same parameter values as in that paper. For our multi-region simulations, however, we use different parameter values, namely $\mu = 0.6$, $\gamma = 0.2$, $\theta = 0.55$, $\sigma = 5$. This choice is made for the following important reason. Using this set of model parameters, we can isolate the impact of the assumption made about the interregional mobility of the labor force on the conclusions drawn regarding the effect of increased integration on the spatial distribution of economic activity. It precludes a situation where the choice of parameters is such that it results in (uninteresting) LRE characterised by complete agglomeration or symmetry for all levels of trade costs in either of the two interregional mobility scenarios (note: the latter is the case when using the same parameter values as in Puga, 1999[13]).

To provide a benchmark for the simulation results in the rest of the paper, Figures 2a and 2b show the effect of increased integration, using the above mentioned parameter values, in case of the simplest, equidistant 194-region version of the model. Because we are dealing with more than two regions, the vertical axis depicts the Herfindahl index, $HI = \sum_i \lambda_i^2$, as our agglomeration measure (where in case of interregional labor (im)mobility λ_i denotes the share of a region's (manufacturing) workers in the total number of (manufacturing) workers in the economy). The advantage of using the HI-index is that it allows us to distinguish between different levels of agglomeration in a multi-region setting.[14]

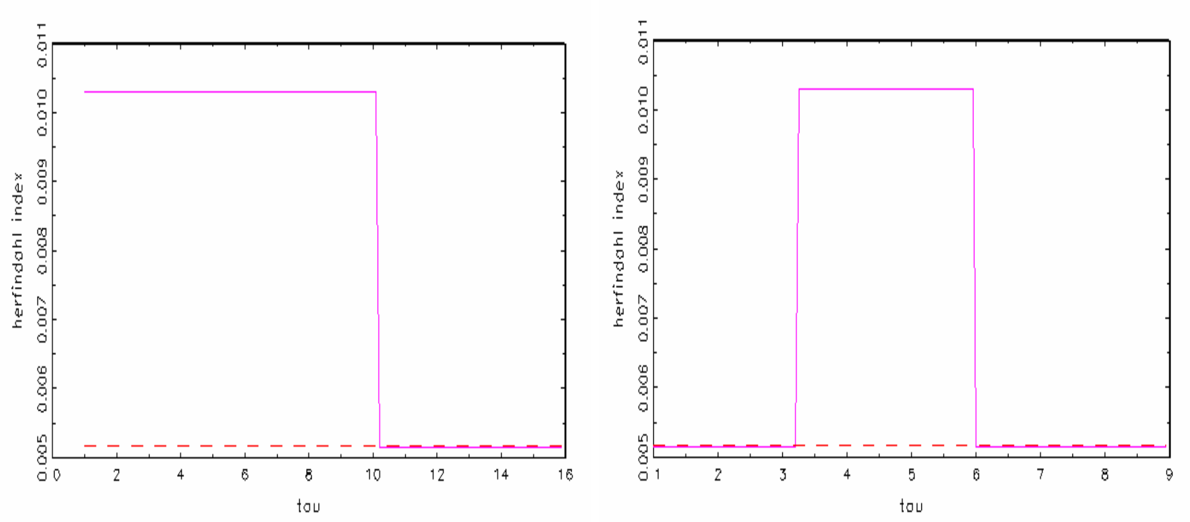
Figure 2 shows that the effect of integration on the spatial distribution of industrial activity is qualitatively similar to the effect shown in Figure 1 and depends crucially on the assumption of whether or not labor is mobile between regions. In Figure 2a labor is mobile between regions and, as in Figure 1a, ongoing integration results in a sudden move from symmetry to agglomeration. Figure 2b shows the same move from symmetry to agglomeration and back to symmetry, as in Figure 1b, although here we find that the shift from symmetry to agglomeration is not gradual as in Figure 1b (see Puga (1999), footnote 18 for a discussion of this result).

[13] We found that being able to obtain the effect of increased integration in case of an interregionally immobile labor force similar to Figure 1b, is quite sensitive to two of the structural parameters., namely θ and μ. Either θ or μ needs to be set 'large enough'. Instead of, as in Puga (1999), picking a high value of θ, we decided for the latter option, where our choice is mainly driven by the fact that such a high share of labor in agriculture seems to be more at odds with reality than assuming a high share of intermediates in final production (see e.g. Hummels et al., 2001, who document a large increase in trade in intermediates over the last decades).

[14] Although there are other arguably preferable measures of agglomeration (see e.g. Bickenbach and Bode, 2006), we deem the HI suitable when looking at the change of agglomeration level in response to changes in trade costs. Using other, more sophisticated measures does not change our results qualitatively.

Figure 2 Trade costs and the long run equilibrium for 194 equidistant regions

Figure 2a   Figure 2b



Notes: Simulation parameters: $\mu = 0.6$, $\gamma = 0.2$, $\theta = 0.55$, $\sigma = 5$. In Figure 2a, $\tau_S = 10.107$. Figure 2b, $\tau_{S,1} = 3.2024$ and $\tau_{S,2} = 5.9710$. M = 194. Stability is checked by equally shocking half of the regions in terms of number of workers in Figure 2a or in terms of number of workers in manufacturing in Figure 2b. Given that we equally shock half the regions, agglomeration means an equal division of labor/firms over these 97 regions, i.e. HI =0.0103. If we instead shock a different number of regions equally, these shocked regions will attract all footloose activity equally. For example, when shocking only a single region, this region will attract all activity (HI = 1). The dashed line shows the value of the HI associated with a perfect spreading equilibrium, HI = 1/194.

3.2. Introducing more realistic geography structures.

Using Figure 2 as a benchmark, we now turn to introducing an asymmetric geography structure to the model. Instead of assuming all regions equidistant to each other we define the level of trade costs between region *i* and *j* as being pair specific, i.e.

$$\tau_{ij} = \tau_{ji} = \tau D_{ij}^{\delta}(1 + bB_{ij}),\ if\ i \neq j \quad and \quad \tau_{ij} = 1,\ if\ i = j \tag{20}$$

where D_{ij} is the great-circle distance between region *i*'s and region *j*'s capital city, τ the transport cost parameter, B_{ij} an indicator function taking the value zero if two regions belong to the same country and one if not, δ is the so-called distance decay parameter determining and $b \geq 0$ a parameter measuring the strength of the border impediments. Specifying trade costs this way is common in empirical studies (see e.g. Anderson and van Wincoop (2004) and Redding and Venables (2004)). It captures the notion that trade costs increase with distance and it also allow international trade to differ from intranational trade (either tangible in the form of e.g. tariffs, or intangible in the form of differences in language, culture, etc). Note, that each simulation starts with an *equal* distribution of labor and land over the regions (and in case of labor also over the sectors within a region) in the sample. In this way we are able to isolate the effect of non-equidistant regions from the influence of economic mass.

In the next section, we also allow regions to differ in their initial economic mass, measured by interregional differences in initial employment and arable land area, as in reality the resulting economic geography is very much the result of the interplay between relative (distance) and absolute (economic mass or size).

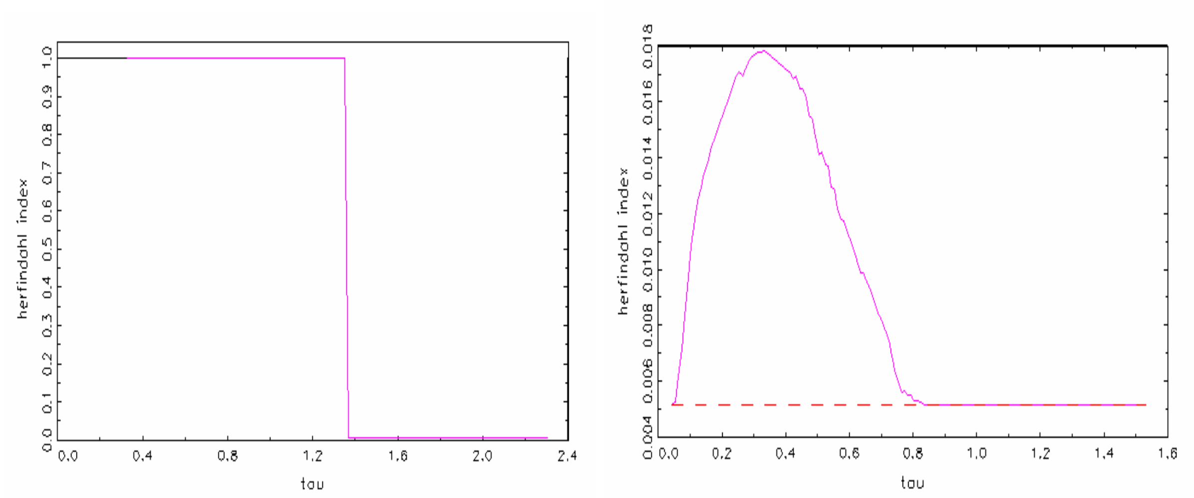
We simulate the effect of ongoing integration on the spatial distribution for the following two cases (for a combination of these two, see Appendix B):

a. Assuming no border effect, $b = 0$, and looking at the effect of lowering the transport cost parameter, τ given a fixed distance decay parameter δ. → *see Figure 3*[15].

b. Assuming no transport costs, i.e. $\tau = 1$ *and* $\delta = 0$, and looking at the effect of lowering the border effect, b. → *see Figure 4.*

Figure 3 Transport costs and the LRE for 194 non-equidistant regions

Figure 3a Figure 3b



Notes: $\mu = 0.6$, $\gamma = 0.2$, $\theta = 0.55$, $\sigma = 5$ and $b = 0$, $\delta = 0.38$ see estimation results in Brakman et al. (2006). The dashed line shows the value of the HI associated with a perfect spreading equilibrium, HI = 1/194.

The ‘a’ panels of Figures 3 and 4 show the results of increased integration[16] for interregionally mobile labor and the ‘b’ panels for labor immobility. Comparing Figures 3 and

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[15] One could also use the distance decay parameter δ to simulate the effect of decreasing transport costs. Results are very similar to those presented and are available upon request.

[16] Note that when modeling increased integration as a lowering of transport costs τ, eventually one reaches a point at which trade costs between two regions are exactly equal to one, i.e. $\tau_{ij} = \tau_{ji} = 1$. From this point on a further decrease of τ would result in these trade costs becoming smaller than one, which would violate the rationale behind the iceberg-assumption (this would imply that in order to deliver one unit, less than one unit would have to be shipped). We restrict the minimum transportation costs to $\tau_{ij} = 1$: if a further reduction of τ results in a value of trade costs between two regions less than 1, we fix it at 1. As a result the minimum value that τ takes is such that trade costs between any pair of regions equal 1.

4 to the benchmark equidistant case presented in Figure 2, we observe that the effect of ongoing integration still crucially depends on the assumption whether or not the labor force is interregionally mobile.

Figure 4 The border effect and the LRE for 194 non-equidistant regions

Figure 4a

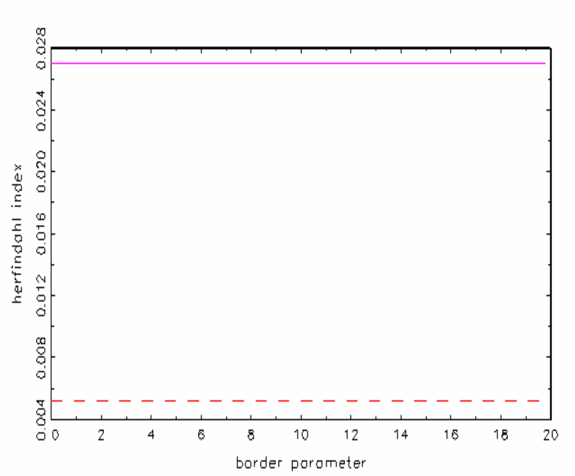
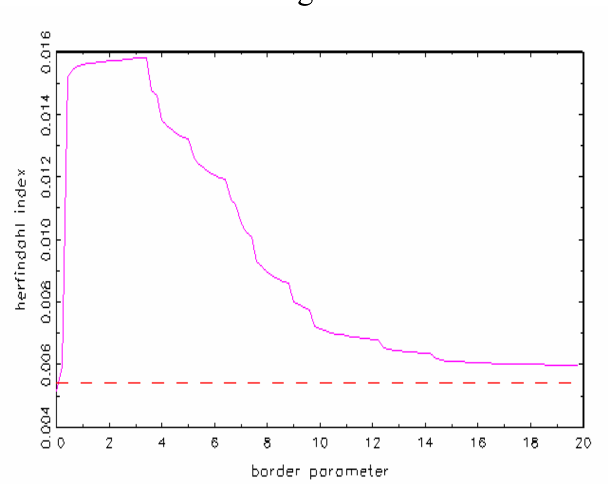


Figure 4b



Notes: $\mu = 0.6$, $\gamma = 0.2$, $\theta = 0.55$, $\sigma = 5$ and $\delta = 0$, $\tau = 1$. The dashed line shows the value of the HI associated with a perfect spreading equilibrium, HI = 1/194.

Without interregional labor mobility (see Figures 3b and 4b), ongoing integration will, as in the equidistant case, first result in an increased agglomeration followed by a return to symmetry with further integration. The shift from symmetry to agglomeration and back to symmetry is however not as sudden as in the equidistant case (resembling much more the bell-shaped curve as found for Puga's parameter settings, recall Figure 1b). Moreover, complete agglomeration is never reached; manufacturing activity is still present in several regions. With interregional labor mobility, ongoing integration in the form of decreasing trade costs, as depicted in Figure 3a, also has a similar effect as in the equidistant case. It results in a sudden (catastrophic) change in the economic landscape from symmetry to complete agglomeration. With a positive border effect, as in Figure 4a, full agglomeration is always the long run equilibrium outcome for *any* level of the border effect shown here (see the next section for more details on this finding)[17].

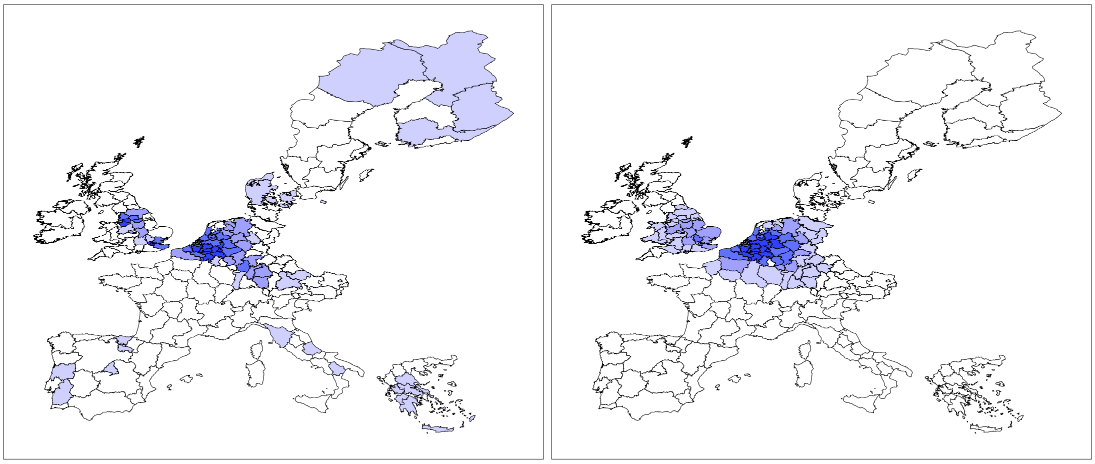
[17] The above results in case of interregional labor mobility are different from the findings in Stelder (2005) and Brakman et al. (2006) (the latter is also based on Stelder's model but starting the simulations from the actual distribution instead of an equal distribution). In these two papers, multi-region simulations of the Krugman (1991) model (where labor is also mobile between regions) with an asymmetric geography structure give rise to LRE characterized by incomplete agglomeration, with the level of agglomeration increasing and the number of agglomerated regions decreasing the lower trade costs. Here we find that agglomeration forces are so strong in a model with interregional labor mobility, that when the spreading equilibrium becomes unstable each introduced asymmetry (be it initial endowment, or (as here) geographical location) in the limit results in the one region that

3.3 *Same overall degree of agglomeration – but different spatial distribution*

A major difference with the equidistant case (even more so with the simple 2-region version of the model) is that the same level of agglomeration as measured by the Herfindahl index does not necessarily mean the same spatial distribution. This is especially so when there is interregional labor *im*mobility as illustrated by Figure 5, but also in case of interregional labor mobility, the same level of agglomeration does not necessarily mean the same spatial distribution (see Appendix B).

In Figure 5, the left and the right panel show the spatial distribution of the manufacturing sector obtained using the same parameters as in Figure 3 but for two different values of τ, chosen such that the distribution in both panels gives rise to the *same* value of the Herfindahl index. That is, the left (right) panel shows the distribution 'on the right (left) side of the bell' in Figure 3b, corresponding to a lower (higher) level of economic integration respectively.

Figure 5 Similar agglomeration but different regional distribution



Notes: Simulation parameters as in Figure 3b. Left panel: $\tau = 0.5$. Right panel: $\tau = 0.16$. HI = 0.0146.

In the simple equidistant models these two distributions would be exactly the same. As can be seen from Figure 5, this no longer holds when allowing for a more realistic geography structure: the left panel shows a distribution with a group of centrally located core regions (in

is the most favorable in terms of net asymmetries attracting all industrial activity. That the above-mentioned papers instead find partial agglomeration when labor is interregionally mobile could possibly be explained by the particular geography structure used in those papers. For example the exponential distance decay function, resulting in highly localized areas of relatively cheap trade, or the particular distance grid used in these papers (in Brakman et al. (2006) also the initial labor distribution, see also section 4). We have to note that the only way we are able to find partial agglomeration patterns similar to those presented in the above-mentioned papers (even when using similar model parameters and the same distance decay function) is when using a higher stop criterion in our search algorithm (see p.14/15 for a discussion of the sensitivity of the simulated LRE to the stop criterion).

Belgium, The Netherlands and the western part of Germany) but still some industrial activity in the peripheral regions (Sweden, Greece, Portugal). The right panel shows a larger group of centrally located core regions (now also extending into the southern UK and northern France) and no more industrial activity in the peripheral regions.

More generally we find, on the basis of more extensive simulations (not shown here), that starting from a symmetric distribution of industrial activity, increased economic integration has the following effect on the spatial distribution of economic activity[18]. At a certain level of integration, agglomeration starts, with a number of core regions attracting activity from nearby regions, still leaving some level of industrial activity in the peripheral regions. As integration proceeds, this process continues until the peripheral regions are completely specialized in agriculture, and industrial activity only takes place in the centrally located core regions. A further falling of trade costs eventually reverses this process, with industrial activity gradually spreading from the core, at first to nearby regions (not to the peripheral ones!) and eventually reaching the peripheral regions again.

3.4 The importance of the geography structure imposed

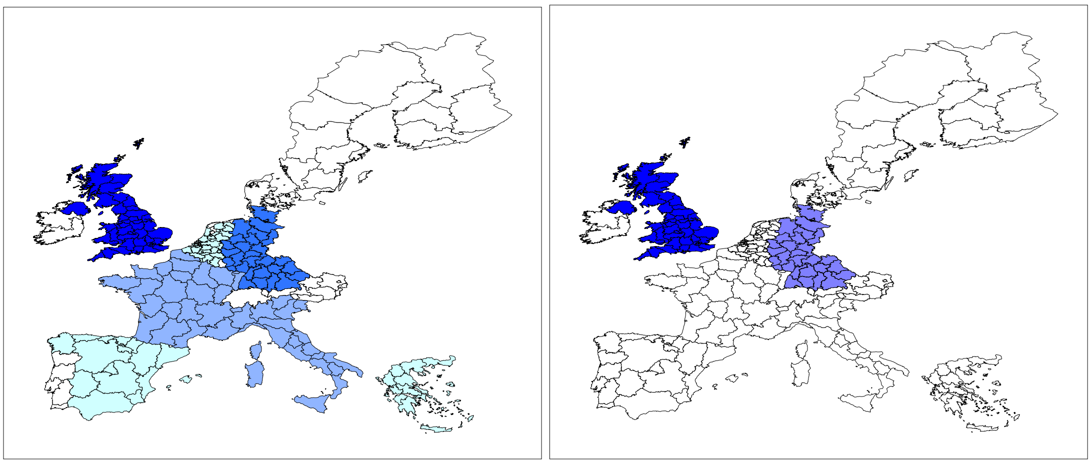
Essentially, the way regional interactions in the regional economy are modeled, i.e. the imposed geographical structure connecting the regions, crucially and predictably influences the way integration affects the distribution of economic activity (see also Behrens and Thisse, 2007). That is, in our case, the distance matrix, D_{ij}, and the border-dummymatrix, B_{ij}, together determine the equilibrium outcomes whereas the parameters (δ, τ and b) in the transport cost function determine the strength of the D_{ij} and B_{ij} effects.[19] When only D_{ij} is allowed to have an effect by setting the border parameter b equal to zero, agglomeration will always be in or around the most centrally located regions in case of interregional labor immobility (see Figure 5) and *in* the most centrally located region in case of interregional labor mobility (i.e. Brabant-Wallon in our case).

When instead only B_{ij} is allowed to have an effect by setting δ and τ equal to zero and one respectively, Figure 6 shows what happens when border impediments are decreasing in the case of an interregionally immobile labor force. Now agglomeration, if it occurs, will be in

[18] Modeling a decrease in transport costs by using the distance decay parameter δ gives exactly the same pattern.
[19] If more asymmetries are introduced (as e.g. in the next section an asymmetric initial distribution of labor) these will also play a crucial role.

countries with many regions relative to other countries, with the regions within these countries all having the same share of footloose industrial activity. As can be seen when comparing the left and right panel of Figure 6, when the border effect becomes less important, ever fewer countries retain footloose activity.

Figure 6 Changing the border impediments B_{ij} (Fig. 4b in more detail)



Notes: Simulation parameters as in Figure 4. Left panel: b = 8. Right panel: b = 3.

In case of interregional labor mobility (not shown here), the largest country in terms of number of regions, i.e. the UK in our case will eventually attract all industrial activity (again equally spread over the regions within the UK)[20]. Appendix B shows the results when both B_{ij} and D_{ij} are both "switched on".

To sum up, many of the qualitative conclusions obtained from the simple symmetric NEG models carry over when introducing a more realistic asymmetric geography structure like the one depicted by our equation (20). Catastrophic agglomeration as a result of increased integration remains a characteristic of the model with interregional labor mobility. Also in case of interregional labor immobility, the impact of increased integration shows a similar pattern in terms of the long run equilibrium agglomeration levels (first increasing and finally decreasing) as in the simple symmetric models. However, as shown in this section, a big difference with the symmetric versions of the model is that the same level of agglomeration (in terms of some agglomeration index) does not necessarily mean the same spatial distribution of economic activity once a more realistic geography structure is added to the

[20] Note that this shows the importance of the definition of a region. Using a different subdivision of countries into regions will have an impact on the simulation results when considering the importance of border effects.

model. Finally, the simulated effects of increased integration depend crucially (and predictably) on the type(s) of asymmetric geography structure imposed.

Now that we have established what the effects are of introducing non-equidistant regions in the Puga (1999) model, we next turn to the question whether and how the long run equilibria are affected by the introduction of regional differences in economic size alongside the asymmetries introduced in the present section.

4 EUROPEAN INTEGRATION WHEN (RELATIVE) GEOGRAPHY MATTERS

The asymmetric geography structure between regions is certainly not the only "real world" asymmetry faced by the empirical researcher or policy maker. Instead, the current (unequal) distribution of economic activity is probably what is most important, either in being used as input in the estimations or as the basis of implementing (new) policies. This section takes note of this and tries to offer some guidance in how to use estimated parameters from a structural NEG model to be able to provide policy makers with predictions regarding the effect of ongoing European integration on the current distribution of economic activity. Instead of relating these estimated parameters back to the simple symmetric version of the NEG model (see e.g. Crozet, 2004), we argue that suggestions regarding the impact of ongoing integration should instead (ideally) be obtained by simulating the same NEG model as estimated, i.e. with the same asymmetries present and using the estimated model parameters (see Brakman et al. (2006) for a first pass at this).

4.1 Estimating the structural parameters

To illustrate the usefulness of this strategy, we need to obtain estimates of the structural model parameters in the Puga (1999) model. Using data from Cambridge Econometrics on compensation per employee and gross value added (GVA) for our sample of 194 EU15 NUTS-II regions as in the previous section over the period 1992-2000[21], we obtain the estimates of σ, δ and b by estimating, using NLS panel data techniques, the wage equation (in logs) as shown in wage equation (14) while substituting (20) for τ_{ij}.[22] Parameter values of μ and γ are calculated using data from OECD's Input-Output Tables (edition 2002) and θ is

[21] Due to wage data availability we use data at the NUTS I-level for Germany and London, which leaves us with 183 regions.

[22] For more detail, see Brakman et al. (2006). Like in Brakman et al. (2006) we set $\mu = 0$ in the estimation of the wage equation. First-nature geography variables are omitted as explanatory variables, we do include country dummies.

calculated by using Eurostat data on the compensation of employees and gross value added in the agricultural sector in the EU-15 for the year 1995. Table 2 shows the resulting parameter estimates, together with the breakpoint(s) that would apply at these parameter settings for our 194-region model if we would stick to an equidistant geography structure (shown in case of both interregional labor mobility and immobility, respectively).

Table 2 Structural parameter estimates

σ	7.122
δ	0.102
b	*285.65 [set to 0 in simulation exercises]*
γ	0.335
μ	0.284
θ	0.234
Labor interregionally mobile	
τ_s	3.199
Labor interregionally immobile	
$\tau_{s,1}$ and $\tau_{s,2}$	symmetry always stable

Notes: In the estimation of the wage equation σ and δ are significant (p-value: 0.000). b is insignificant (p-value: 1.000).

Next, we use these parameters in a simulation exercise with $b = 0$[23]. Also, instead of introducing only the geography structure by means of a non-equidistant relative geography structure between regions based on (20) as in section 3, we now also introduce, in staying as close as possible to the Puga (1999) model, the true initial distribution of labor (total employment share) and land (arable land share), as shown in Figures 7a and 7b respectively, as additional asymmetries to the simulation exercises.

4.2 Simulating the impact of ongoing EU integration

Having specified the simulation settings in the previous section, we now turn to simulating the the effect of ongoing integration. As in the previous section, we do this in two different ways:

1. *a decrease in interregional transport costs* τ, e.g. the EU supports the construction and upgrading of transportation links (roads, railways, etc).

[23] One can choose any parameter value for the border effect as one can be 99% sure that it lies within the range [-1.16 x 10^{14}, 1.16 x 10^{14}]. A possible reason for the insignificance of this parameter may be that the extent of the border effect differs substantially among different pairs of EU15 countries (see Breinlich (2006), who provides evidence on this)

2. *a decrease in border impediments b*, e.g. the EU stimulates the formation of an internal market by removing trade barriers (streamlining national regulations, removing border controls, etc).

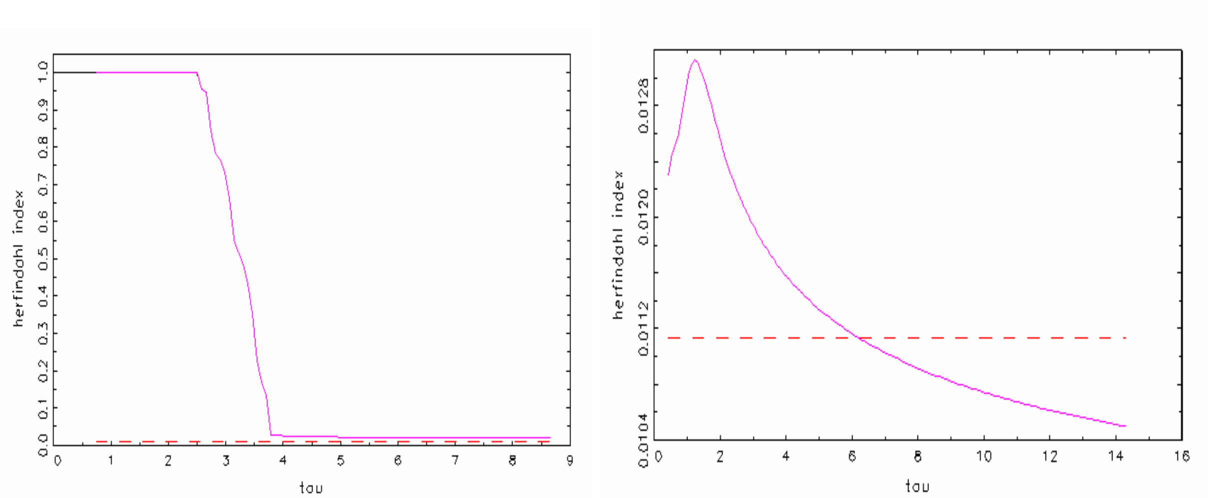
4.2.1 Decrease in transport costs.

Here we look at the effects of lowering the transport cost parameter τ on the spatial distribution of economic activity[24]. Figure 8 below shows the resulting long run equilibrium when labor is either a) interregionally mobile (left panel) or b) interregionally immobile (right panel) for each value of transport cost.

In both Figure 8a and Figure 8b, the dashed line shows the value of the Herfindahl index associated with the actual, initial spatial distribution of economic activity across the 194 regions.

Figure 8. Transport costs and the long run equilibrium when geography matters

Figure 8a Figure 8b



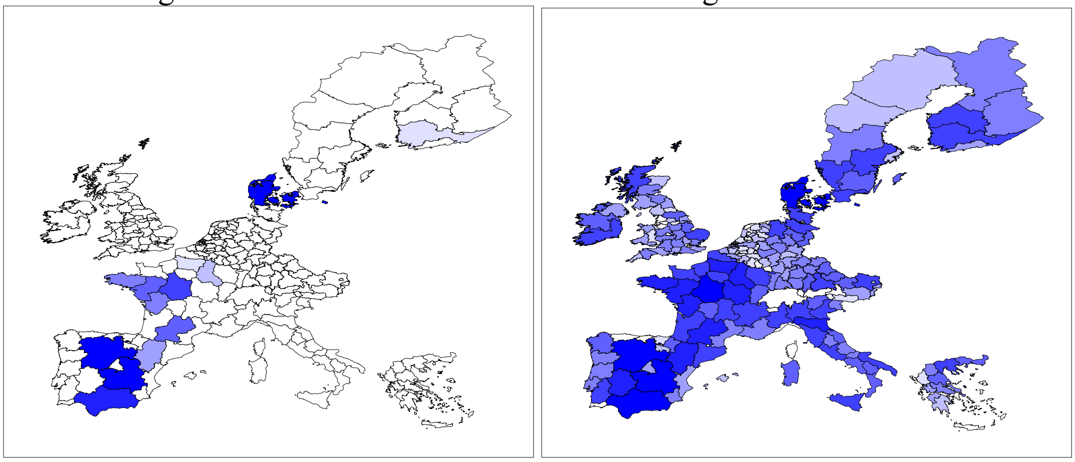
Notes: Simulation parameters as in Table 2 and the simulations are started using the actual distributions of arable land and total employment (see Figure 8). Left panel: interregional labor mobility. Right panel: interregional labor immobility.

With interregional labor mobility (see left panel Figure 8), agglomeration increases with decreasing transport costs. Note, however, that the process is gradual rather than catastrophic. This is in contrast to the findings in section 3. A closer look at the map of Europe with the equilibrium distribution for different levels of transport costs provides the reason for this finding (see Figure 9 below).

[24] Again, the results using the distance decay parameter δ instead are similar and available upon request.

Figure 9. **Interregional labor mobility and arable land as spreading force**

Figure 9a: $\tau = 3.15$ Figure 9b: $\tau = 10$



Notes: The simulation parameters as set as in Table 2 and starting the simulation using the actual distribution of arable land and total employment.

At very low levels of transport costs we find (as before) complete agglomeration in the region Île-de-France with Paris as the main city (not shown in Figure 9). When transport costs increase, spreading forces take over and the economy moves towards a more equal distribution across the 194 regions. As Figure 9 shows, the most important spreading force turns out to be the (unchanging) distribution of arable land! Once agglomeration forces become less important due to the increasing transport costs, labor starts moving towards the regions that by virtue of their large supply of arable land offer higher wages (see Figure 9a). With very high transport costs this finally results in the distribution of manufacturing activity being (almost) the same as the distribution of arable land (compare Figure 9b to Figure 7b, the corresponding correlation coefficient is 0.962).

The catastrophic agglomeration patterns found in section 3 in the case of interregional labor mobility are thus (partly) due to the fact that in the simulations presented there, land is equally distributed over the regions, imposing no additional assymetries between regions. We are more likely to find catastrophic agglomeration when initial differences in economic size or mass are not taken into account[25].

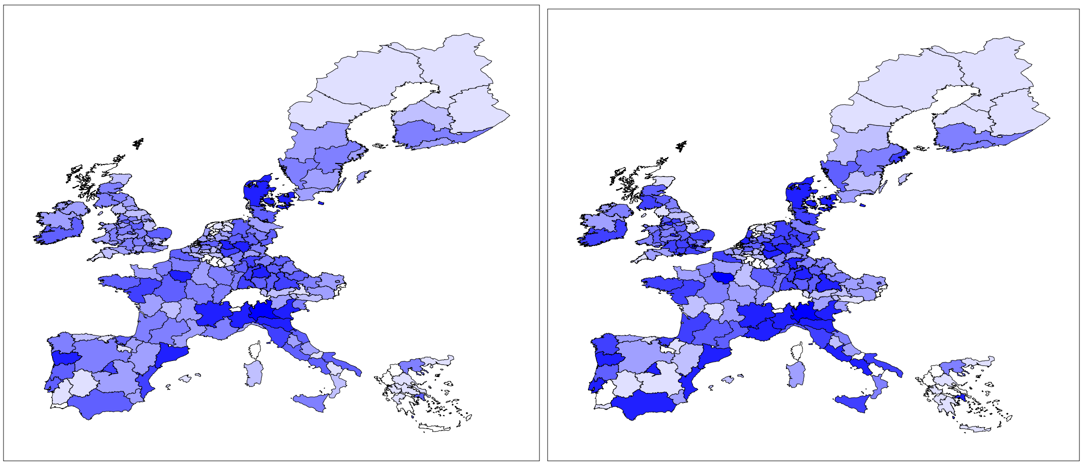
Without interregional labor mobility (see Figure 8b), we again find a 'bell-shaped' agglomeration pattern. What is particularly interesting about the long run equilibrium depicted by Figure 8b, however, is that for $\tau = 6.183$, *the Herfindahl index of the simulated*

[25] When we endow each region with the same amount of land while using the actual distribution of employment, we again find catastrophic agglomeration with decreasing transport costs. Results available upon request.

LRE distribution is identical to the Herfindahl index for the actual distribution of manufacturing employment. Even more striking (as the same Herfindahl index does not necessarily mean the same distribution across regions), when we compare this long run equilibrium distribution for this level of transport costs (Figure 10b) with the actual distribution of manufacturing labor for our 194 regions (Figure 10a), they are remarkably similar (the correlation coefficient is 0.809).This suggests that the model is able to reproduce the actual spatial distribution of economic activity in the EU quite accurately.

Figure 10. Interregional labor immobility: actual and simulated long run equilibrium

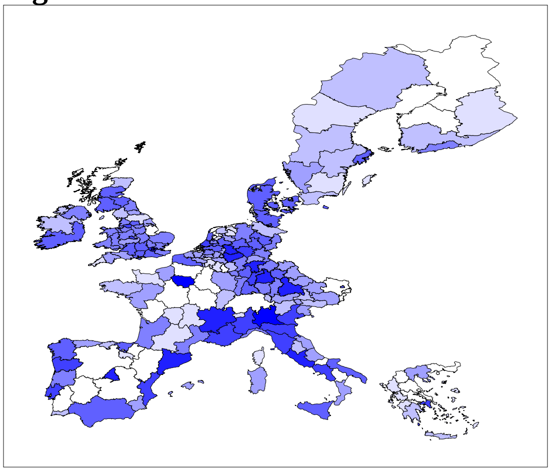
Figure 10a: Actual manufacturing labor   Figure 10b: LRE at $\tau = 6.181$



Notes: In the right panel the simulation parameters as set as in Table 2 and $\tau = 6.181$ and starting the simulation using the actual distributions of arable land and total employment.

This finding immediately suggests a way to provide an answer to the (up to now unsatisfactory answered) question "*where on the bell are we?*". Taking τ =6.181 seriously, we are now able to provide a more satisfactory answer to this question in our sample of 194 EU regions, interregional labor immobility. Given the fact that we have pinpointed the actual location on the bell curve, our simulation example suggests, see Figure 8b, that increased integration is most likely to result in more agglomeration in the future, with only a return to a more equal distribution once transport costs have become very low (note however that the this return will not mean going back to a completely symmetric distribution of footloose activity). Finally, Figure 11 shows the distribution at the 'top of the bell' (top of curve depicted by Figure 8b). Remarkably, this does resemble the so-called Blue Banana (the name given to the pattern of industrial agglomeration in Europe ranging from the southern UK to the Netherlands, through Germany to the north of Italy) quite well. This finding suggests that increased European integration will lead to a more pronounced 'Banana' pattern in the EU.

Figure 11 A simulated blue banana



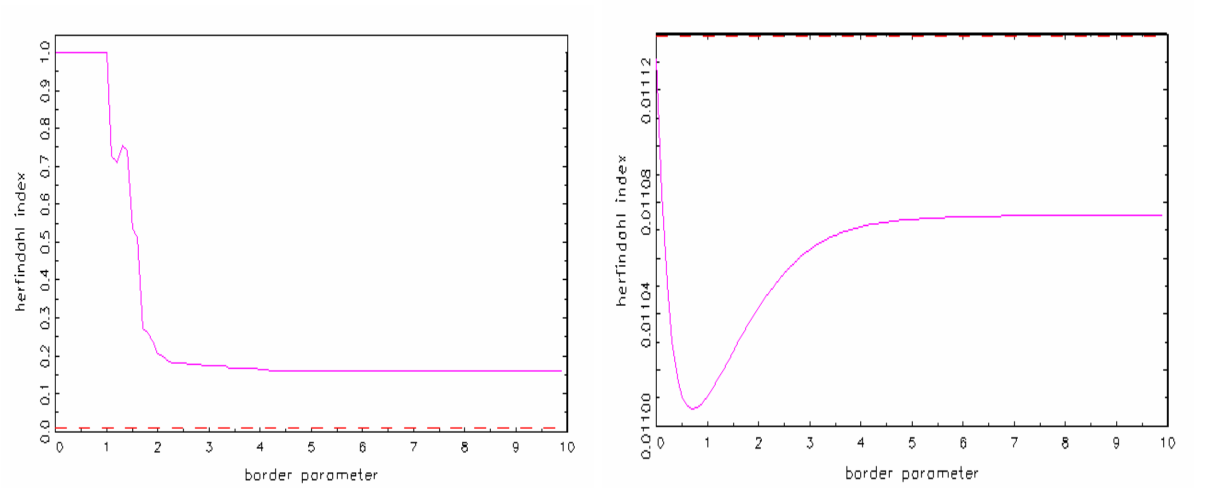
Notes: The simulation parameters are as in Table 2 with τ = 1.3 and the simulation is based on the actual distributions of arable land and total employment.

4.2.2 Decrease in border impediments.

Again as in section 3, we model a decrease in border impediments by a decrease of the border parameter *b*. Figure 12 shows the resulting long run equilibria in case of a) an interregionally mobile and b) an interregionally immobile labor force (see Figures 12a and 12b respectively).

Figure 12. A decrease of border impediments and the long run equilibrium

Figure 12a Figure 12b

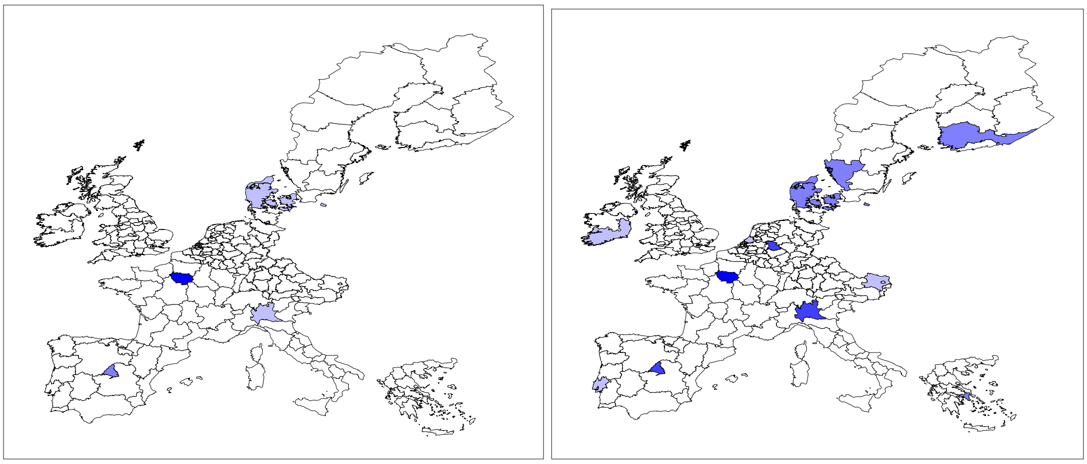


Notes: Simulation parameters as in Table 2 and the simulations are started using the actual distributions of arable land and total employment (see Figure 9). Left panel: interregional labor mobility, τ = 1. Right panel: interregional labor immobility, τ = 6.183. The dashed line shows the value of the HI associated with the initial distribution.

With interregional labor mobility, the effect of less border impediments is qualitatively similar to that of a decrease of transport costs τ: it is characterized by a move from a more equal distribution over the regions towards full agglomeration (again in Île-de-France) once the border effect disappears. This process is not catastrophic, but the agglomeration level increases gradually towards full agglomeration as the border impediments become weaker. The difference, however, is that when border impediments become extremely high, the distribution of manufacturing activity does not (as with very high transport costs) become the same as the distribution of arable land over the regions. Instead, the distribution at these very high levels of border impediments is characterized by one region in each country attracting all of its country's manufacturing activity (compare Figures 13a and 13b, where border impediments are respectively low and very high).

Figure 13.The effect of increasing the border impediments

Figure 13a: border effect = 1.6 | Figure 13b: border effect = 10



Notes: The simulation parameters as set as in Table 2 with τ = 1 and starting the simulation using the actual distributions of arable land and total employment.

As the border impediments decrease (*b* falls), the number of countries with a region containing some industrial activity decreases (with the countries containing regions with a relatively high supply of arable land, the ones retaining some manufacturing activity the longest) until eventually all industrial activity takes place in Île-de-France.

In case of interregional labor *im*mobility, we model the impact of a decrease of border impediments using τ = 6.181, the value that resulted in a very similar simulated distribution as the actual distribution of manufacturing labor (recall Figure 8b and Figure 10). Although a first look at Figure 12b shows the interesting pattern of an 'inverted bell curve', a closer look at the scale of the y-axis shows that the difference in terms of agglomeration level is extremely small (also when mapping the distribution), so that one can say that, in case of an immobile labor force, an increase of the border impediments has almost no apparent effect on the spatial distribution of footloose activity (the correlation coefficient between the distribution at $b = 0$ and at $b = 10$ is 0.987!). Note that the insensitivity of the simulated long run equilibrium distribution to changes in the border parameter is very much consistent with the results found in the estimation of the wage equation where the estimated border parameter was highly insignificant.

5. CONCLUSIONS

Most new economic geography models treat geography in a very simple way: attention is either confined to a simple 2-region or to an equidistant multi-region world. As a result, the main predictions regarding the impact of e.g. diminishing trade costs are based on these simple models. In empirical work these simplifying assumptions become problematic as conclusions from these simple models may not carry over to the heterogeneous geographical setting faced by the empirical researcher or policy maker. This paper partly fills this gap by establishing, through careful simulation, the effect of adding more realistic geography structures to the NEG model of Puga (1999), one of the main NEG models that also encompasses several other core NEG models.

We first show that many, although not all, conclusions from the simple models do carry over to our multi-region setting with more realistic geography structures. The effect of increased levels of integration on the level of agglomeration is very similar to that found in the simple equidistant (2-region) models. With interregional labor mobility, agglomeration levels increase with the level of integration, where as in the 2-region models, this increase is mostly catastrophic. Without interregional labor mobility, increased integration is accompanied by a steady (not catastrophic) increase in the level of agglomeration. And when integration proceeds even further this process is reversed, resulting in a return to an equal distribution of economic activity over all the regions, hereby confirming the bell shaped pattern in the 2-region models. Although the qualitative results are similar to the simple equidistant (2-region) models, a major difference is that the same level of agglomeration – as measured by, e.g. the HI-index –corresponds to very different spatial distributions, especially when labor is interregionally immobile.

Having established the effect of introducing more realistic geography structures to a multi-region NEG-model, we next introduce more asymmetries to the simulations, i.e. the actual distributions of employment and arable land. Moreover, using estimates of the structural model parameters, we simulate the impact of increased EU integration on the spatial distribution of regional economic activity for a sample of 194 NUTSII regions. Again the results depend crucially on the assumption about the mobility of the labor force between regions. When labor is interregionally mobile, the model's predictions about the level of agglomeration are probably too extreme (only few (or even one) regions will attract all footloose activity). When labor is interregionally mobile the model's prediction becomes less extreme. More importantly, we are in that case able to answer questions like 'where on the bell are we?'. In our example of the former EU15, we find that more integration will most likely lead to more agglomeration. For EU policy makers an important challenge, as they will have to deal with increased spatial inequality.

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APPENDIX A BREAKPOINTS OF THE PUGA (1999) MODEL

Focusing on the 2-region version of the model only (in Puga (1999) Appendix A1 and A2 show the results for the M-region equidistant version of the model), we briefly summarize the analytics behind Figures 1a and b.

In case of an interregionally mobile labor force, see Figure 1a, there exists a minimum level of transport costs at which a symmetric distribution of firms and workers is a stable equilibrium, i.e. symmetry is stable for levels of transport costs[26]:

$$\tau_{ij} = \tau \geq \tau_S = \left(1 + \frac{2(2\sigma - 1)[\gamma + \mu(1-\gamma)]}{(1-\mu)\{(1-\gamma)[\sigma(1-\gamma)(1-\mu)-1] - \gamma^2\eta\}} \right)^{1/(\sigma-1)} \tag{A1}$$

where η is the wage elasticity of labor supply from a region's agricultural to its manufacturing sector[27]. Also a maximum level of transport costs at which agglomeration (i.e. with industrial production and the labor force located in only one region) is a stable equilibrium can be derived, i.e. agglomeration is stable for levels of transport costs smaller or equal to τ_B, being a solution to

$$\tau^{[\sigma(1-\mu)(1-\gamma)-1]} \left(\tau^{2(1-\sigma)} + \frac{(1-\mu)(1-\gamma)}{1 + \tau^{\theta\gamma/(1-\theta)}(\tau^{2(1-\sigma)} - 1)} \right) = 1 \tag{A2}$$

In case of an interregionally immobile labor force, see Figure 1b, the results are quite different. In that case Puga (1999) shows that a symmetric distribution of industrial production is an unstable equilibrium for the following range of transport costs: $0 < \tau_{S,1} < \tau < \tau_{S,2} < \infty$, with $\tau_{S,1}$ and $\tau_{S,2}$ the solutions of the following quadratic expression[28]:

$$\begin{aligned} &[\sigma(1-\mu)-1][(1+\mu)(1+\eta)+(1-\mu)\gamma][\tau^{1-\sigma}]^2 \\ &\quad -2\{[\sigma(1+\mu^2)-1](1+\eta)-\sigma(1-\mu)[2(\sigma-1)-\gamma\mu]\}\tau^{1-\sigma} \\ &\quad +(1-\mu)[\sigma(1-\mu)-1](\eta+1-\gamma)=0 \end{aligned} \tag{A3}$$

and stable for levels of transport costs smaller than $\tau_{S,1}$ and larger than $\tau_{S,2}$.

---

[26] This is the case provided that the denominator is larger than zero. If this does not hold, agglomeration is the only stable equilibrium for all possible levels of transport costs.

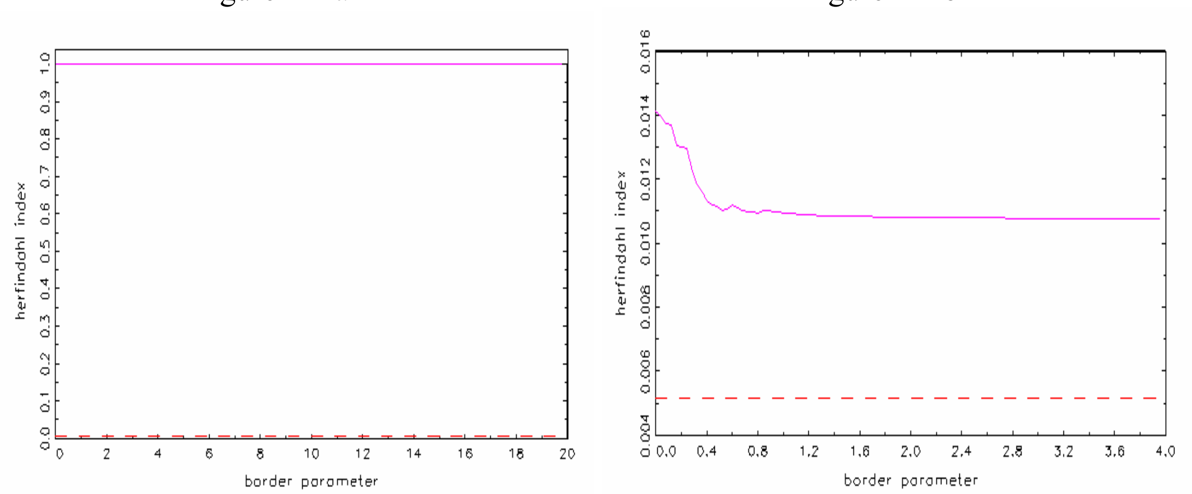
[27] Here $\eta = \theta(1-\gamma)/\gamma(1-\theta)$ given the assumed Cobb-Douglas production function in agriculture.

[28] Note that in order for equation (21) to have 2 solutions in the required range, the model parameters have to adhere to some additional requirements (see Puga (1999) , Appendix A2 for the details).

APPENDIX B DISTANCE AND BORDER EFFECT

To illustrate what happens when both geography structures (distance and border effects) are allowed to play a role consider the different effect of increased transport costs on the one hand and increased border impediments on the other hand when starting from the same initial distribution. We choose this initial distribution as the one where $\delta = 0.38$, $\tau = 0.5$ and $b = 0$, which in case of interregional labor mobility amounts to full agglomeration in the region Brabant-Wallon and with labor interregionally immobile in the situation shown in Figure 6a. Starting from this distribution, increasing the level of transport costs would in this case eventually result in an equal spreading of industrial activity over all 194 regions (see Figure 3b) whether or not labor is interregionally immobile. This is not the case when increasing the magnitude of the border effect.

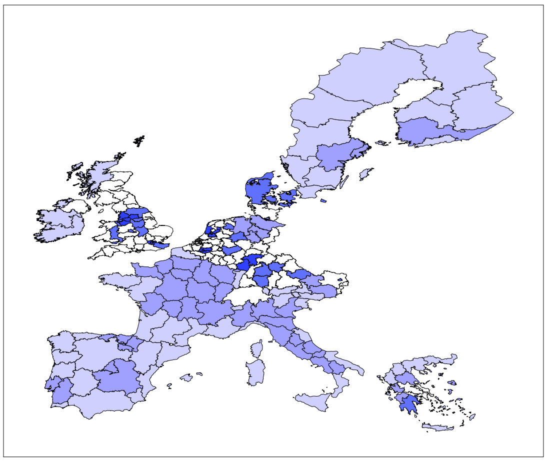
Figure A1-a Figure A1-b



Notes: Simulation parameters: $\mu = 0.6$, $\gamma = 0.2$, $\theta = 0.55$, $\sigma = 5$ and $\tau = 0.5$, $\delta = 0.38$.

In that case, see Figure A1-a, agglomeration remains the only equilibrium outcome as the border effect increases in strength when labor is mobile across regions and we observe no return to spreading. However the region in which all activity agglomerates switches, as a result of the increased cost of international trade (i.e. B_{ij} gaining in importance in determining the equilibrium outcome), from the most centrally located region, i.e. Brabant-Wallon, to the most centrally located region in a large country with many regions, i.e. Rheinhessen-Pfalz. With labor immobile between regions, see Figure A1-b, symmetry is also not reached with an increase in the border effect; instead the economy settles at the situation depicted in Figure A2 once international trade becomes more than 5 times as costly as intranational trade.

Figure A2 Figure A1-b in more detail



Notes: Simulation parameters as in Figure A1-b, b = 4.

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