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The Use of Geographical Grids Models in NEG: Assessing the Effects of EU Integration

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1. Introduction

Since its birth with Krugman (1991, 1993) the growing New Economic Geography (NEG) literature has made substantial progress in theoretical adjustments and refinements. Almost inevitably, concentrating on this means that the implementation of realistic empirical models has been receiving less attention. On of the main gaps to fill is the introduction of a realistic geographical space, a first attempt of which has been Stelder (2005a/b). After the phase of model calibration adjustments in this space can then be introduced as a change of the socio-economic context of the agglomeration process. This allows us to simulate what will happen to regional development and spatial agglomeration when new infrastructure is build and /or countries are joined into more economically integrated groups. This paper gives a rough summary of how this can be done in practice and what are the main obstacles ahead that need to be solved in order to achieve realistic geographic agglomeration models that can be used for forecasting and or policy simulation. In section 2 the use of a geographical grid in an NEG model is briefly summarized. Next, section 3 presents some abstract simulation examples of economic integration. Finally, in section 4 an application for a large model for Europe and Japan is outlined.

2. Geographical Grids in an NEG Model

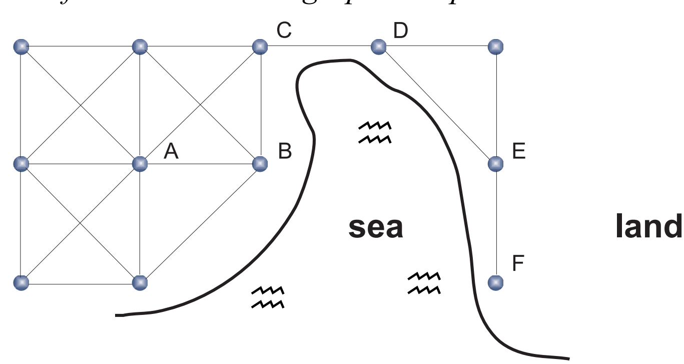
Our starting point is the basic multiregional NEG model presented in Krugman (1993) who uses a discrete system of n locations located on a circle at equal distance from each other[1]. Labour is the only production factor and the economy is divided into two sectors, one geographically fixed sector that does not move to other locations, usually referred to as "agriculture", and a footloose sector called

[1] Later NEG models, such as presented in Venables (1996), Helpman (1998) and Fujita, Krugman and Venables (1999), are not discussed here. Technically, the introduction of a geographical grid in these models would be exactly the same as for the basic model.

"manufacturing" that can choose its optimal location. The starting assumption of zero agglomeration means that each location has a share of $1/n$ of national manufacturing labour (μ) and agricultural labour ($1-\mu$). Under the assumption of monopolistic competition (Dixit and Stiglitz, 1977), consumers like varieties, every product variety is produced by only one firm, and firms and workers tend to migrate to regions where many manufacturing firms are concentrated. Depending on the substitution elasticity σ, workers benefit from a higher real wage in larger cities where more product varieties are produced. The counterforce of this concentration process is transportation costs. Both agricultural and manufacturing workers consume products from other regions under the Samuelson iceberg assumption: when a good travels a distance D, only a fraction of $e^{-\tau D}$ arrives. Long-term equilibrium is achieved when real wage has become the same in all regions and there is no further incentive to migrate[2]. The three basic parameters that determine the outcome are the share of manufacturing labour μ, the transportation cost parameter τ, and the substitution elasticity σ.

In order to transform this model into a geographical one we need three modifications. First, instead of the circle, we use a discrete grid of equidistant locations in the two-dimensional economic plane. With GIS techniques we can put the geographical shape of a country as an overlay on this grid. The result is a "cloud of dots" that represents our economic space just as we would have cut the shape of the country out of a piece of gridline paper. Chart 1 shows the example of a bay cutting out some locations from the grid.

Chart 1: A Grid of Locations in Geographical Space



Source: Stelder (2005a).

Next, assume that each location is connected with all its direct neighbours on the grid, either by a horizontal or vertical road with distance 1 like (A,B) or (B,C), or a

[2] See Stelder (2002), Krugman (1993) or Fujita, Krugman and Venables (1999), chapter 4, for the full description of the basic model.

diagonal road with distance √2 like (A,C). The starting assumption is that there is no sea transport possible so transport from A to F must go over land along the coast. This condition will be relaxed later. Finally, the model needs a shortest path algorithm (SPA) finding its most efficient way through the grid for any pair of two locations *p* and *q*:

$$D1(p,q) = \sqrt{[(pi - qi)2 + (pj - qj)2]} \quad (1)$$

$$\text{if } D1(p,q) > \sqrt{2},\ D1(p,q) = z \quad (2)$$

with *z* being a very large number. The matrix D_1 resulting from (1)–(2) will have entries of 1 for all direct horizontal and vertical neighbours, √2 for all direct diagonal neighbours and *z* for all other combinations of *p* and *q*. From D_1 we derive the final distance matrix D_2 by

$$D2 = SPA\ (D1) \quad (3)$$

using the shortest path algorithm of Floyd (1985). In the simple case of chart 1 transport from A to F will pass C, D and E and total distance will be 2+2√2.

The model can now be run using distance matrix D_2. In order to get a first impression of its behaviour let us take a look at chart 2a–d. It shows the results of four experiments with an 8x11 rectangle and a peninsula added on the southeast side of size 2x5. We could think of this economic space with a total of 98 possible locations as a simple model for the U.S.A., where the peninsula represents Florida.

The assumed initial distribution is zero agglomeration or what can be mentioned as the "no history assumption": the model starts with each location having an equal share of national agricultural and manufacturing labour. Another way of putting it is "in the beginning there were only little villages". The prime purpose of this type of simulation is to get a pure assessment of the influence of the geographical space on the economic agglomeration tendencies in the country without any historical distribution to start with. We will return to this issue later.

Chart 2a is the result of a first run with a strong concentration bias (low τ value). Two large cities emerge, but not symmetrical because the eastern city is draw down by the "Florida market". All manufacturing labour has concentrated in these two cities. The remaining grid points have become true "villages" in the sense that only their immovable agricultural sector has remained. If we assume a less extreme concentration bias by changing σ into 6 and τ into 0.3, the result is two three-city belts in the north and the south (chart 2b). Because of the Florida market, the southern city in the East is larger than its northern counterpart while the two western cities are of equal size. In addition, as would be expected, something like the city of Miami emerges in the south of the peninsula as a smaller seventh city that, despite its smaller size and scale economies, remains competitive with the other larger cities due to its remote position. Next, if transportation costs are again raised one point from 0.3 to 0.4 the pattern starts to shift and becomes less symmetrical (see chart 2c). Another city emerges in the mid-west and the two largest centre cities move away from each other creating some like a Chicago/Detroit and a Dallas/Houston agglomeration. In Florida a second smaller city is formed in the northwest, but not at the cost of Miami, which remains of the same size.

Chart 2a: μ=0.3, σ=5, τ=0.2

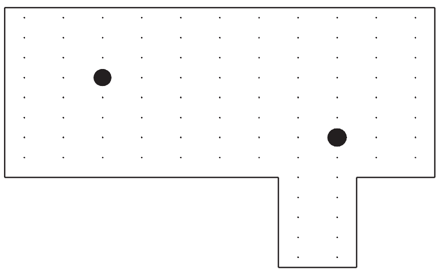


Chart 2b: μ=0.3, σ=6, τ=0.3

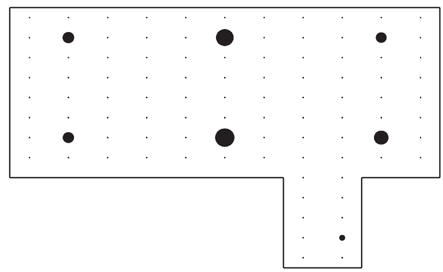


Chart 2c: μ=0.3, σ=6, τ=0.4

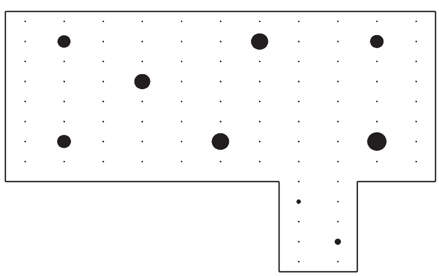
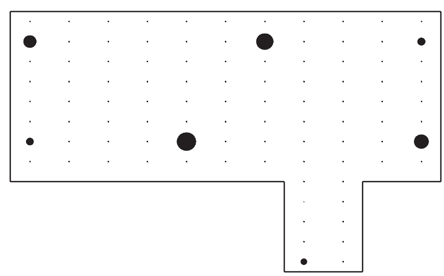


Chart 2d: μ=0.3, σ=6, τ=0.3, foreign trade

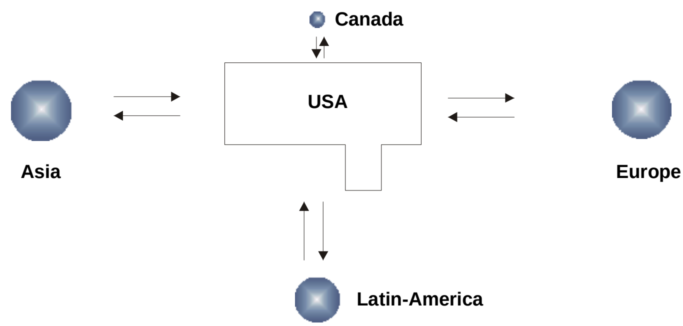


Source: Stelder (2005a).

The reason why there are no large cities along the east- and west coast is because we do not assume any locational advantages of coast locations as possible harbours and because there is no foreign trade. Chart 2d shows how the city distribution changes compared to chart 2b when trade with the outside world comes into effect leading to agglomerations along the borders. We have chosen the easiest way to do this by simply giving all locations along the east coast and the west coast, and the two most southern locations of Florida a twice as high value in the initial distribution. This gives them an initial advantage in economies of scale over all other locations. The result shows that harbour cities now enter the equilibrium, including the Miami city, which in turn causes the two agglomerations in the middle again to move in opposite direction away from each other.

Of course this solution is not very satisfactory because giving locations along the coast a higher initial value is telling the model what you want it to tell you[3]. A better alternative would be to add the main foreign trade partners as extra locations proportional to their economic size at the correct distance (see chart 3). In this grid model all locations along the border can be given a straight connection to the foreign trade partners. For all other inland locations the shortest path algorithm can then decide through which border location (port) their foreign trade flows will go.

Chart 3: Integration Example 1: Adding Foreign Trade



Source: Stelder (2005a).

The model in chart 3 now would have 102 locations: the 98 locations on the U.S.A.-grid and four extra locations representing the foreign trade partners. The constraint on the model should be that only the internal city distribution of the U.S.A. is endogenous while keeping the relative size of the U.S.A. as a whole and the foreign trade countries constant. In other words: all eight import- and export flows are kept constant of which each U.S.A. city takes its endogenous share.

The approach in chart 3 can now be seen as a first simple option of how economic integration can be handled in a NEG model. It shows how the opening up of international borders of a country can effect domestic regional development and spatial agglomeration trends.

3. Real Geographical Grids: A Model for Europe

Having set out the basic structure of a geographical agglomeration model, the next step towards a real empirical model is pretty straightforward. The actual geographical shape of a country can now be approximated by the same type of base grid of equidistant locations combined with a geographical map.

[3] In the same way we could instruct the model to come up with larger agglomerations in the North-East because that is where the historical inflow of immigrants started.

Because of its differentiated geographical shape, Western Europe seems a promising and interesting case to test the explanatory power of the model. Just as the number of pixels in a digital picture, the accuracy of modelling an economic space of a particular shape is determined by the resolution of the grid. Our current computational limits allow us a maximum number of around 2700 locations. Chart 4 shows the grid of the basic model with 2637 locations created from an overlay of a high resolution square grid and a geographical map[4]. The borders are chosen along the former Iron Curtain, but with unified Germany included. Ireland and Great Britain are included but Scandinavia and the Balkan are left out. These choices are purely pragmatic. Dividing the present computational maximum over Scandinavia and the Balkan as well would make the grid resolution too low.

First, the colours in chart 4a–b shows that geographical altitude is included, so natural barriers like mountains can be reflected in D_1. With GIS each location p_{ij} is modified to p_{ijk} with the third height dimension k indicating the local altitude. Equation (1) – (3) is thus replaced by:

$$D_1(p,q) = \sqrt{[(p_i - q_i)^2 + (p_j - q_j)^2 + (p_k - q_k)^2]} \quad (4)$$

$$\text{if } \sqrt{[(pi - qi)2 + (pj - qj)2]} > \sqrt{2}, \text{ D1(p,q) = z} \quad (5)$$

$$\text{D2 = SPA (D1)} \quad (6)$$

It should be noted that in a low-resolution model some height barriers might not enter the grid because a mountain top may fall right between two low grid locations. In such a case the distance and consequently the transportation costs between the two locations are underestimated[5]. In chart 4b the grid resolution is detailed enough to capture the main height barriers of the Alps and the Pyrenees.

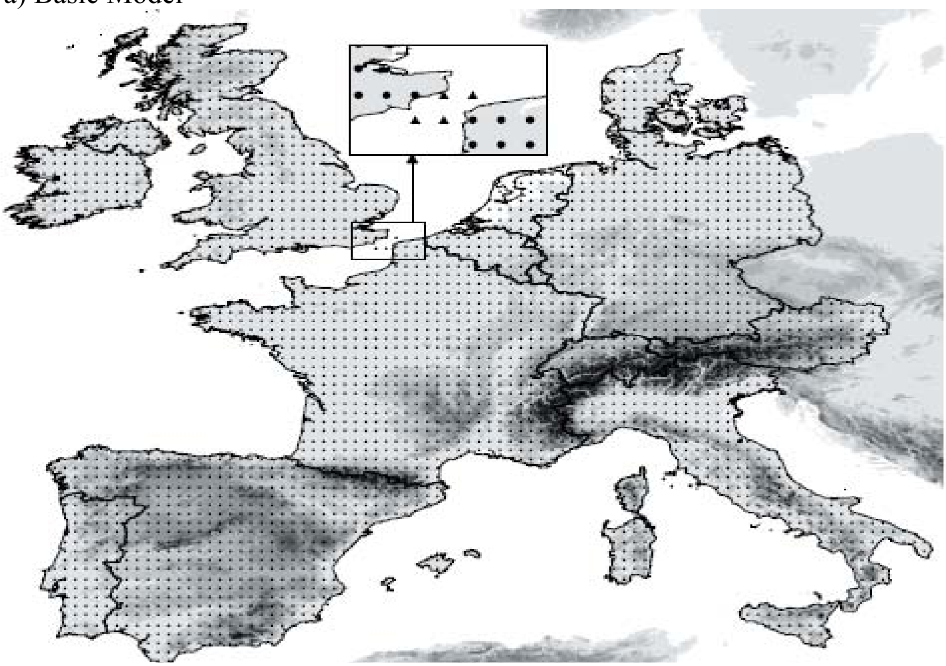
Next, sea transport is enabled at specific points as extra grid locations along which the shortest path function SPA can find its way, but which are excluded as possible locations in the equilibrium. The inlay in chart 4a shows these “transport only locations” between Great Britain and France. In the basic model version connections are added in the same way between Northern Ireland and the Glasgow region, between the two main islands in Denmark, and between Sicily and the Italian mainland. Note that Mallorca, Corsica, Sardinia and other smaller islands are isolated groups of locations in the model and therefore cannot trade with other locations.

[4] The grids in chart 4 are projected as a flat surface. This is an abstraction because in reality it is impossible to draw an equidistant grid on a round globe surface.

[5] Transportation across mountains can be given an extra weight indicating higher costs. See Stelder (2005a) for more details.

Chart 4: A Geographical Grid for Europe

a) Basic Model



b) Extended Model

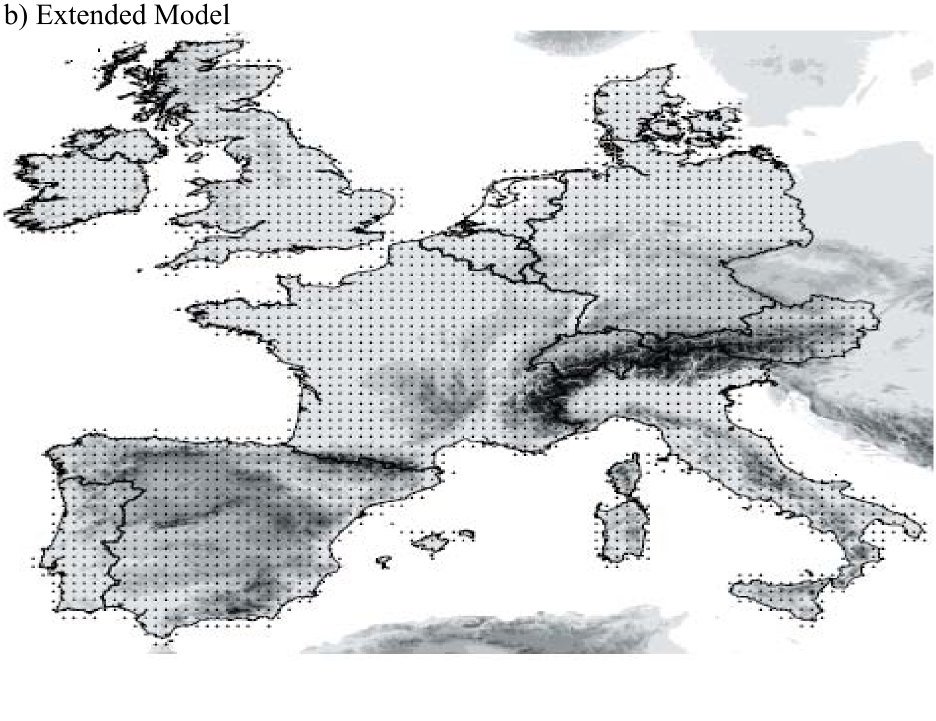


Chart 4b shows an extended model version allowing sea transport along the coasts and from/to all islands. Again, a pragmatic choice had to be made. The grid cannot be extended over sea too much because we do not want the network to become too large[6]. A differentiation between the two transportation modes can be achieved through replacing D_2 in (6.6) by

$$D3(p,q) = \alpha \, D1\,(p,q) \qquad (7)$$

and

$$D4 = SPA\,(D3) \qquad (8)$$

with

$\alpha = 1$ if p and q are both land locations
$\alpha = \beta_1$ if p is a land and q is a sea location or vice versa
$\alpha = \beta_2$ if p and q are both sea locations

Parameter $\beta_1>1$ is a "transhipment mark-up" representing extra costs of (un)shipping in a harbour. Parameter β_2 indicates whether sea transport is relatively more or less efficient than transport across land. In the basic model (chart 4a) β_1 and β_2 are both set to 1 assuming toll-less bridge connections from and to all sea locations. In the extended model (chart 4b) β_2 can be set lower to 1 in order to take account of the historical influence of earlier centuries when water transport was the most efficient mode. Specific connection costs like toll-levies for the Channel were not used but may be entered ad hoc in D_1. It is clear that in this way the agglomeration effects of a wide range of infrastructure investments can be simulated[7].

The choice between model a) and b) and the setting of matrix D is yet another option for economic integration analysis. When land transport becomes more efficient, which is typical for the transition period around 1850–1900 with the introduction of railroads, the comparative economic efficiency between regions and cities start to change. In addition, EU integration in more recent times can be handled by reducing transport costs in matrix D at those locations where international borders are crossed. For illustration purposes, however, let us first look at the model behaviour as a simple comparison between model a) and b) and a first evaluation of how relevant the geographical structure of the model is for the predicted agglomeration forces.

6 The calculation of the matrix of all shortest paths is the main limitation.

7 The effects of a high speed train connection in the Netherlands was modelled in this way by Knaap and Oosterhaven (2000). A comparable study is being undertaken in the EU-funded IASON project, aimed at simulating the regional economic effects of a new transeuropean infrastructure network. See Bröcker et al. (2002) for more details.

Chart 5: (S1) Basic Model (n=130), τ=0.45, μ=0.55, σ=5

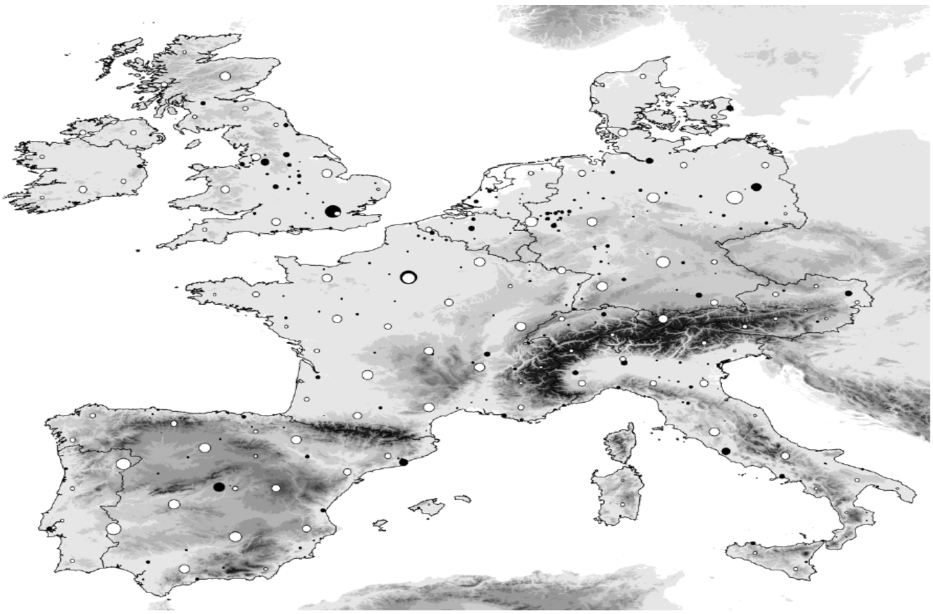
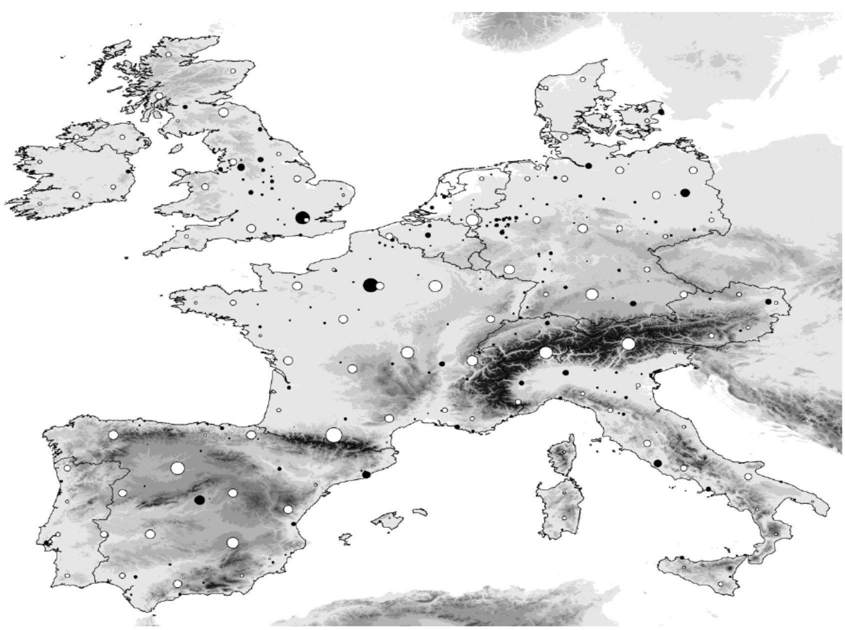


Chart 6: (S2) Basic Model (n=115), no Altitude, τ=0.45, μ=0.55, σ=5



Experiments with different parameter configurations for abstract grids have shown that equilibria which are not extremely dispersed or concentrated are usually found with values in the range of 0.35-0.45 for τ, 0.45–0.55 for μ and 4.5–5.5 for σ. Both the basic and the extended model were calibrated for different parameter configurations in order to find the maximum possible fit with reality, which will be discussed in the next section.

Chart 5 (simulation S1) shows an equilibrium of 130 cities with τ=0.45, μ=0.55 and σ=5. The white dots are the model results plotted proportionally to manufacturing labour and the black dots are the 250 largest cities plotted proportionally to population in 2000[8]. As expected with the no history assumption, the model produces a long-term equilibrium that is more evenly spread than in reality. Because population density is historically higher in the north than in the south, the model predicts too many large cities in Spain and too few cities in the UK, the Netherlands, Belgium and the Ruhr area.

All large countries have 4–6 main cities. In the UK and Ireland there are white dots close to Belfast, Glasgow, Dundee and Newcastle. The Midlands agglomeration, however, is only approximated by a white dot close to Liverpool. In the south, Norwich and the Plymouth/Southampton area are pretty close and there is a correct simulation of London, although far too small. In France the largest white dot is indeed on the spot (Paris). The other simulated cities are too large because in reality Paris is 6 times as large as France's second largest city Lyon. Both Lyon and Marseille, however, have a white dot nearby and Clermond-Ferrand is on the spot.

The model seems to fit a little better for Germany, which has a less centralized tradition. The largest white dot is close to Berlin and there are white dots close to the Rurhgebiet, Hannover/Braunscheig, Strasbourg, Nurnberg and Munich. For Italy there are remarkably good simulations for Turin, Milan, Bologna, Rome and Napels. On Sicily, the three largest cities Palermo, Catania and – to a lesser extent – Messina are pretty close. On the Iberian Peninsula the model does not work at all: there is a circle of cities around instead of one on the spot of Madrid, and the simulated total population of Spain is just as large as that of France. Only Barcelona has a correct simulation in its vicinity.

Simulation S2 (chart 6) is identical to S1, but without the geographical altitude taken into account. As expected, without regions being isolated by mountains the total number of cities decreases from 130 to 115. In addition, treating Europe as a flat area means that the Pyrenees and the Alps become central areas with large agglomerations. The largest French city is now almost on the Spanish border taking up some agglomerations of Northern Spain, including the correct simulation of Barcelona in S1. The good simulations for Turin and Milan in S1 are gone

[8] The actual database consists of 522 cities with a population over 50.000 inhabitants. In chart 6.5–6.8 only the 250 largest cities are plotted.

indicating that these agglomerations are better predicted in the "protection shadow" of the Alps.

Chart 7: (S3) Basic Model (n=208), τ=0.45, μ=0.5, σ=5.5

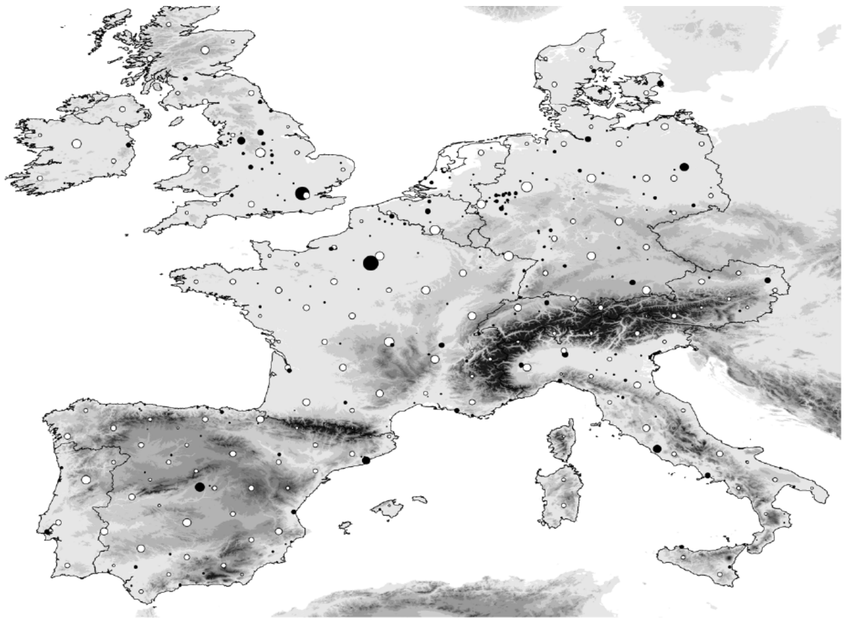


Chart 8: (S4) Extended Model (n=193), τ=0.45, μ=0.5, σ=5.5, β_2=0.25

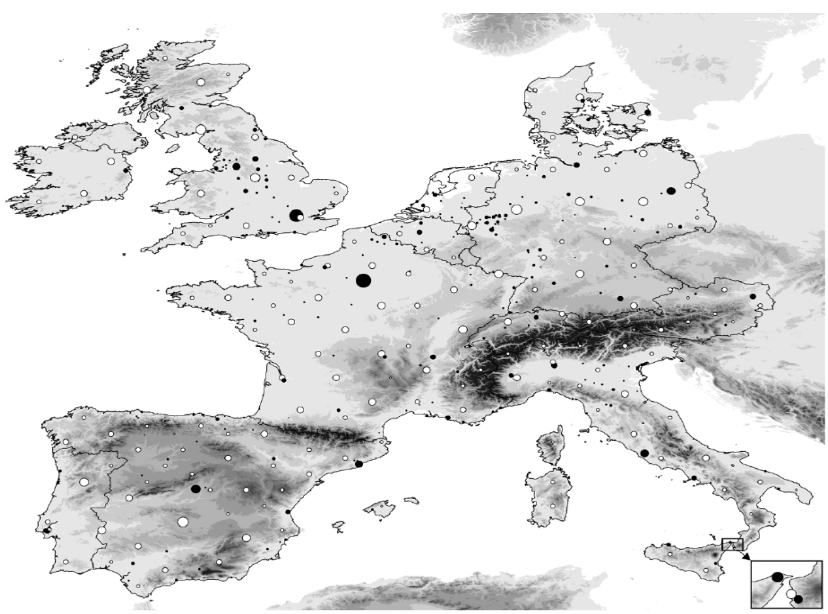


Chart 7 shows simulation S3 with much more cities (208), caused by lowering the share of the manufacturing sector from 55% to 50% (μ=0.5) and decreasing the economies of scale by raising σ from 5 to 5.5. In the UK, there now is a correct large agglomeration predicted in the heart of the Midlands and London has become larger. The white dot close to Dundee has disappeared but another one has merged close to Aberdeen. In France, Paris is still there, but smaller, accompanied by some close approximations of Bordeaux and Clermond-Ferrand (both on the spot), Toulouse, Lyon, Nantes and Rouen. In Spain and Portugal, the simulation has not improved in the centre (no large Madrid), but there are now close white dots for – again – Barcelona, Zaragosa, Pamplona (on the spot), Bilbao, Vigo and Lisbon. In Northern Italy, now both Turin and Milan are almost on the spot and of the right size, accompanied by good approximations of Verona, Parma and a close but small dot for Geneva. There is still a close white dot for Bologna, although slightly shifted to the south, and another one close for Florence.

Going from France to Germany there seems to be a good simulation of seven white dots along the line Paris-Brussels-Ruhrgebiet-Hannover-Braunscheig-Magdeburg-Berlin, although the second dot (Brussels) should be more to the north and Berlin itself is now simulated too small. In the south of Germany, the approximation of Munich is improved and there is now also a white dot in the Frankfurt area. Denmark has a remarkably good approximation of its three main cities Copenhagen, Aarhus and Odense, but the other large cities predicted in Jutland do not exist in reality. Finally, in Austria the three white dots close to Linz, Vienna and Graz do not change compared to simulation S1.

Finally, simulation 4 (chart 8) is a rerun of S3 with the extended sea-tranport model of chart 4b. The parameter $\beta 2$ is set to 0.25 meaning that transport costs over sea are assumed to be 25% of transport costs across land. As expected, this assumption has the largest effects in the northern UK and Denmark, were islands and peninsulas now all become interconnected. Ireland is now better connected with the UK leading to a better simulation of Dublin, but there is no approximation of Glasgow and Dundee anymore. In the rest of the UK there is only a better approximation of the coastal agglomeration of Newcastle. The situation is better in the Netherlands that now has a correct simulation of the Rotterdam harbour. In Denmark, the predicted size of Aarhus is now much better, but Copenhagen has shifted and has become smaller, probably due to competition from Rostock at the northern coast of Germany, which in its turn is now much better predicted. It should be expected, however, that inclusion of the rest of Scandinavia into the model should lead to a better estimate of Copenhagen again because of its strategic trading position with Sweden. In the rest of Europe, the sea transport assumption does not change very much. In France, the three largest cities close to Paris move slightly up in the north-west direction, and the harbour city Bordeaux has become larger. Likewise, in Portugal the estimate for Lisbon has become both closer and larger. Finally, the zoomed inlay shows that the harbour city of Reggio di Calabria is correctly predicted on the mainland side of the Street of Messina.

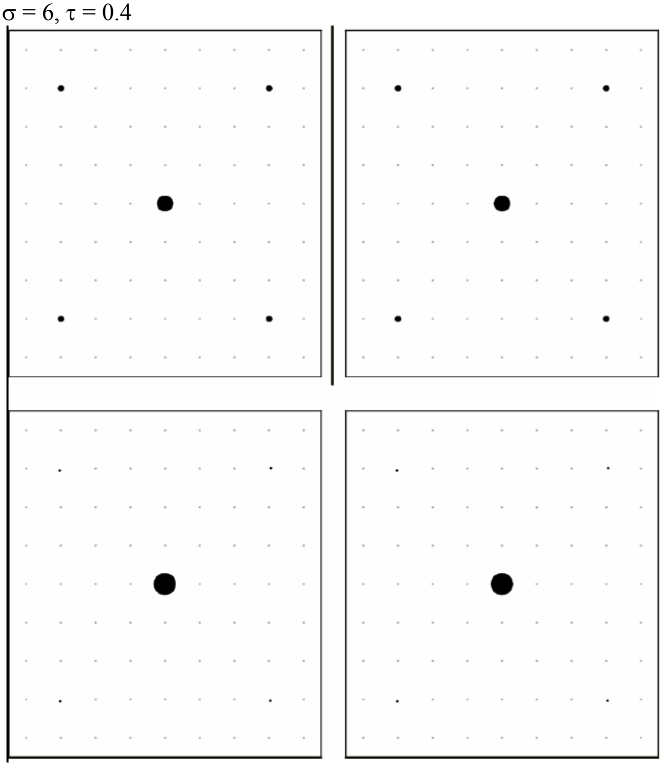
The question to what extent these models can actually assess the influence of geography on economic agglomeration over time is discussed in detail in Stelder (2005a/b) but falls beyond the scope of this paper. For the purpose of this paper we need a more elaborate discussion about the possible implementations for economic integration analysis.

4. Towards Economic Integration

Let us assume that we now have two countries with a historical agglomeration result but which do not trade with each other. The most simple simulation for this situation is given in chart 9. Two identical square grids are adjacent but isolated from one another. This is comparable with the former situation in Europe where Easty and West were isolated by the Iron Curtain.

Chart 9: Introducing Integration

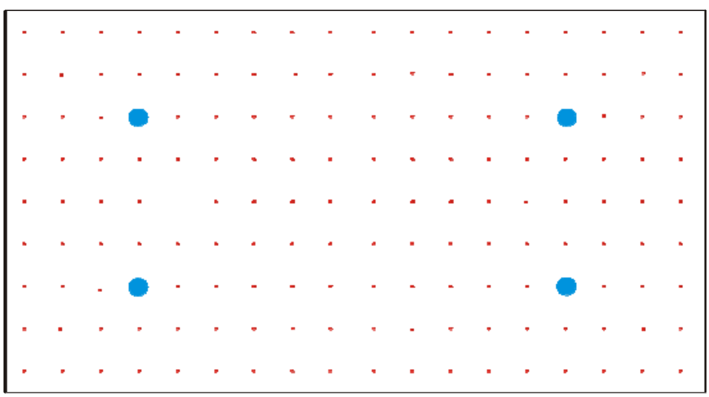
9x9 grid; $\pi = 0.4$, $\sigma = 6$, $\tau = 0.4$



In the original situation, each country has the central largest agglomeration in the centre accompanied by 4 second order cities in each quadrant. These separate equilibria where obtained as a long term result of the parameter configuration mentioned. After removing the separation between the two countries the two country grids become connected as if they now together form a new integrated 18x9 location grid. The agglomeration effect of this integration is that the satellite cities loose some agglomeration advantage to the two larger centres because the latter now can have access to each others market areas. As a comparison, chart 10 shows that indeed the historical growth of the two centres in the middle has occurred on a place that would not have been natural when under the same parameter assumption the 19*8 grid would have been an integrated economy from the start. In that situation, there would have been four middle sized cities in each quadrant.

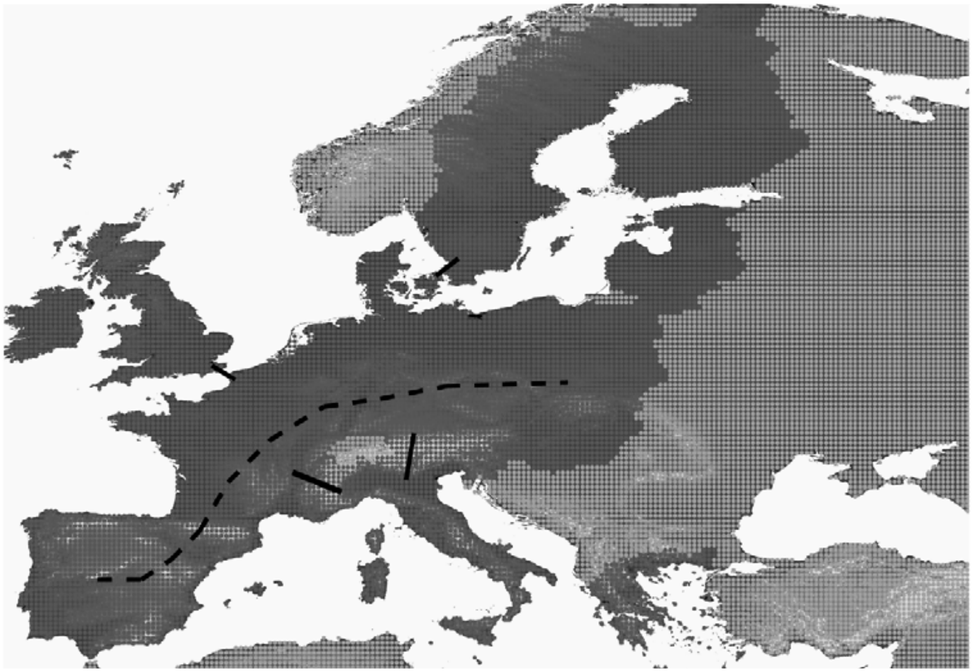
Chart 10: Full Integration from the Start

18x9 grid; $\pi = 0.4$, $\sigma = 6$, $\tau = 0.4$



It is not very useful to further elaborate on different simulations with abstract models of the type described above because our main interest is how these processes work in more realistic models. In this example there is indeed increasing agglomeration c.q. increasing concentration inside both countries as a result of their integration. This is typical for recent economic growth in the former eastern European countries that has a strong bias towards the main agglomerations. Integration in this view can be detrimental to the periphery leading to increasing regional inequality.

Chart 11: Reach of the Larger European Grid Model



The implementation of the kind described in charts 9–10 in currently under construction for a larger model of Europe that covers all EU-25 countries (see chart 11). Although there are no results yet some remarks can be made here about its implementation issues. First, the original grid of charts 5–8 will not be simply extended, but it will be combined with a realistic matrix of distance and transport costs that reflects the increasing integration phase of countries like Poland etc. while keeping the Ukraine, Belarussia and Russia at a relatively higher "economic distance" from the EU. Second, extending the model further to the east than the EU itself enables the model to keep track of trade and economic connections of the former eastern European countries to their Russian neighbours as well. This is a more sophisticated modification of the external trade option discussed in chart 3. Third, as shown in chart 11, several infrastructure projects can be inserted into the model like a transeuropean network (illustrated by the dashed line) or tunnels and bridges across water or mountains. Finally, contrary to the "no-history assumption" in chart 9–10, the model in chart 11 will start with the actual city distribution of today. Once calibrated to today's agglomeration structure, a change in infrastructure and/or economic integration policy can be evaluated as to what effects this will have on the European agglomeration structure in the future.

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