Modelling Agglomeration and Dispersion in RHOMOLO[☆]

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Abstract

The spatial general equilibrium model RHOMOLO with endogenous firm location incorporates multiple sources of agglomeration and dispersion. Agglomeration is driven mainly by increasing returns to scale and localised externalities; dispersion by costly trade and imperfect competition. In RHOMOLO, three mechanisms interact in determining the equilibrium spatial distribution of agents: capital mobility, labour mobility and vertical linkages as captured by costly input-output trade. While households choose their location based on real income differences, firms' spatial equilibrium is determined by the inter-regional equalisation of returns on capital. Illustrative simulation results suggest that in the EU labour mobility has the tendency to magnify the *home market effect* and the *market access effect*. In contrast, the *market crowding effect* seems to dominate the *market access effect* for capital mobility and vertical linkages. These results are in line with the theoretical literature, where the endogenous location mechanism of labour mobility contains two agglomeration forces and one dispersion force, whereas the endogenous location mechanisms of capital mobility and vertical linkages contain one agglomeration force and one dispersion force.

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1. Introduction

Modelling space in a micro-founded general equilibrium framework is a challenging task, particularly if the focus is on the sub-national level. The first versions of the RHOMOLO model (RHOMOLO v.1) (Kancs, 2010; Gardiner and Kancs, 2011) were developed using a neoclassical general equilibrium framework of a competitive economy à la Arrow and Debreu (1954), the essence of which lies on space-less and frictionless exchanges. However, as the model grew to address new issues, such as the distribution of economic activities and regional development, its structure evolved to embrace fundamental new economic geography features.

As for the earlier versions of the model, it may be worth refreshing the memory of the reader on the characteristics and properties of the Arrow-Debreu general equilibrium framework. In this basic framework, the economy is composed of a finite number of agents (firms and households) and commodities (goods and services).[1] A firm is characterised by a production function, describing a possible technological combination between inputs and outputs. A household is identified by a preference relation, an initial endowment, and a portfolio of firms' equities. The general equilibrium is described by an equilibrium system of prices (one price for each input and output), equilibrium production level for each firm, and equilibrium consumption level for each household satisfying the general equilibrium conditions, where all markets clear and each agent chooses the action that maximises her objective function at the equilibrium prices. In particular, (i) each firm maximises its profit subject to the technological constraints; (ii) each household maximises its utility under the budget constraint defined by the value of its initial endowment and its shares in firms' profits; and (iii) the supply and demand on each input and output market are balanced.

In line with such a canonical general equilibrium framework, in the first version of RHOMOLO a commodity was defined only by its physical characteristics. From a spatial perspective, a commodity could be defined also by the location where it is made available. Hence, space could be introduced in the model by considering the same good in different locations as two different economic objects entering agent decisions in a different way. Therefore the same good can be supplied at different prices in different locations.

However, as noted by Eaton and Lipsey (1977), the neoclassical general equilibrium approach of Arrow-Debreu with ubiquitous agents and homogeneous space fails to capture the fundamental spatial features of economies, determining the agglomeration and dispersion of economic activities and production factors. In order to introduce space explicitly into

[1] Assuming that consumers (producers) are homogeneous in each region is equal to modelling a representative consumer (producer) per region.

the modelling framework, RHOMOLO v.1 follows Eaton and Lipsey (1977) and relaxes two assumptions of the canonical general equilibrium model of Arrow-Debreu: the ubiquity of agents and the homogeneity of space.

As for the assumption *ubiquitous agents*, in RHOMOLO v.1 a consumption (respectively, production) pattern describes the quantities of goods consumed (respectively, produced) in a specific location. Relaxing the ubiquity assumption of economic agents has two implications for the spatial equilibrium. First, location choice does not affect the characteristics of agents because, a priori, they have no preferences over the set of locations. Second, the consumption or production choices made by agents vary with their location, as the relative prices change with the supply and demand of each good in each location.

Following the models of comparative advantage, RHOMOLO v.1 introduces the *heterogeneity of space* through differences in technology and endowment with production factors. As in the model of Ricardo (1817), regions have different technologies, and technological advantages vary across sectors. Regions have the tendency to specialise in the production of the good for which the relative opportunity cost is lower. As in the models of Heckscher (1918) and Ohlin (1933), regions have different endowments in production factors and the inter-regional immobility of production factors implies that the relative prices of goods may differ. Inter-regional trade leads each region to partially specialise in the production of goods that use the production factor it is relatively more endowed with.[2]

In summary, RHOMOLO v.1 provided a theoretically consistent micro-founded multi-regional general equilibrium framework for studying the impacts of exogenous macro-economic or policy shocks, but the location of economic agents (workers, firms, etc.) was exogenously given. While the model was able to explain the specialisation patterns resulting from a an exogenously determined economic geography, it could not explain the rise and fall of agglomerations endogenously, which is a key issue for policy makers and local stakeholders. As noted by Krugman (1991), an endogenous modelling of industry location requires: (i) agglomeration and dispersion forces; and (ii) factor mobility to allow these forces to reshape the economic geography. These elements constitute the main innovations of RHOMOLO v.2 and are described in the remainder of the paper.

[2]Among others, Epifani (2005) studies the interplay between factor abundance and agglomeration forces, finding that if endowments are similar enough (i.e., if regions are not too dissimilar in terms of factor ratios), the process of regional integration involves an overshooting of inter-regional specialisation and relative factor prices with respect to the free trade level determined by factor abundance.

2. The RHOMOLO model[3]

In RHOMOLO, the world consists of R regions and S sectors. The domestic economy (which corresponds to the EU) consists of $R-1$ regions $r = 1, \ldots, R-1$, which are included into M countries $m = 1, \ldots, M$. The rest of the world is introduced in the model as a particular region (indexed by R) and a particular sector (indexed by S). Sector S differs from domestic sectors in that it only has one variety which is exclusively produced in region R. Formally, we have $N_{S,r} = 0$ and $N_{s,R} = 0$ for all r and s; and $N_{S,R} = 1$. The foreign variety of final good is used as the numéraire.

Each region is inhabited by H_r households which are mobile between regions. Through migration, they affect the size of the regional market.[4] Each household supplies a specific variety of low, medium and high skilled labour services to firms which are considered as imperfect substitutes to the ones offered by other households. The structure of the labour market is thus also monopolistic competition.[5] The income of households consists of labour revenue (wages), capital revenue and government transfers. It is used to consume final goods, pay taxes and accumulate savings. (see Figure 1).

There are three types of producers in the model: national R&D sector, durable and final goods firms. The final goods sector includes $s = 1, \ldots, S$ different economic sectors in which firms provide final goods to consumers operating under monopolistic competition à la Dixit and Stiglitz (1977) (see Figure 2). Each firm produces a differentiated variety which is considered as an imperfect substitute to other households and firms. Goods are either consumed by households or used by other firms as intermediate inputs or as investment goods. The number of firms in sector s and region r is denoted by $N_{s,r}$. The number of firms in each region is endogenous and to a large extent determines the spatial distribution of economic activity.

Trade between (and within) regions is costly. Goods shipped between (and within) regions incur iceberg transport costs , with $\tau_{s,r,q} > 1$ representing the quantity of sector s's goods

[3]See Brandsma *et al.* (2013) for a formal description of the RHOMOLO model.

[4]Labour mobility is introduced through a labour market module which extends this core version of the model with a more sophisticated specification of the labour market. This is described in Brandsma *et al.* (2014).

[5]Assuming monopolistic competition both on the goods and the labour markets is in line with models such as Blanchard and Kiyotaki (1987). Such specification allows to focus both on price and wage decisions and in particular to introduce nominal rigidities in the model. In addition, as shown by Manning (2010), monopolistic competition is a very simple manner to capture the idea of thick labour markets, namely that the high density of workers raises productivity, thereby making large labour markets more attractive for firms. This enriches the description of the economic geography in the mode.

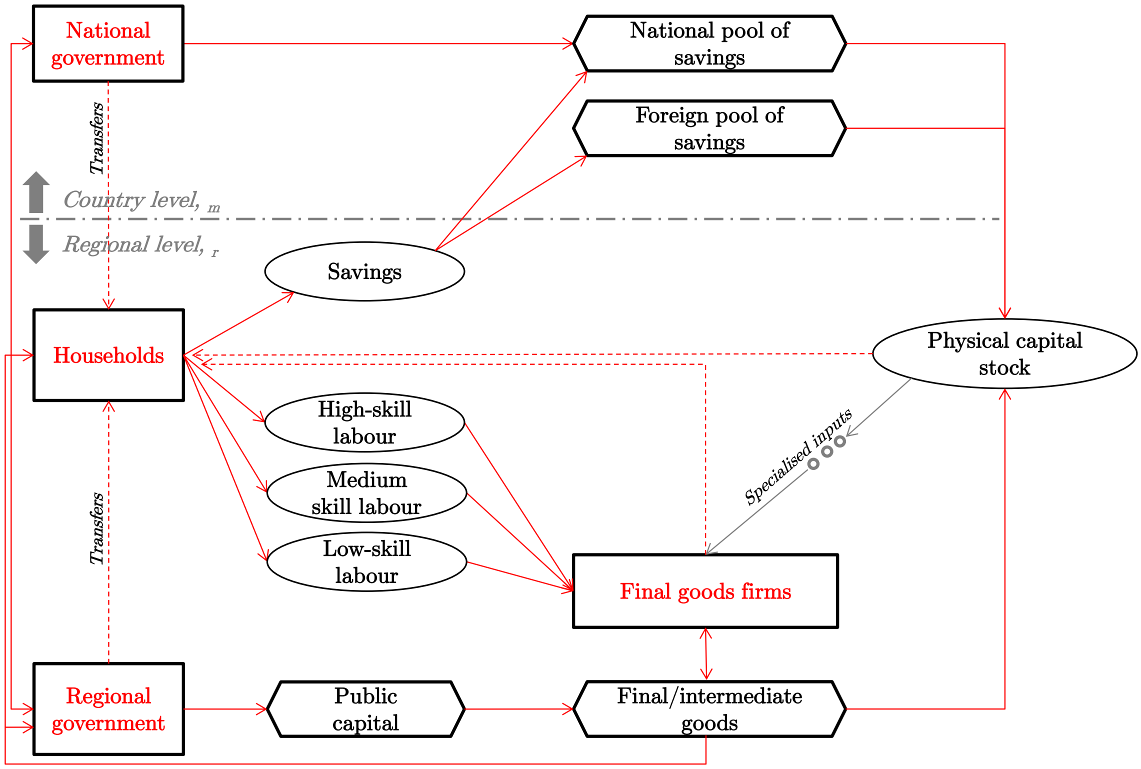

Figure 1: Households in the RHOMOLO model: labour supply, consumption and savings.

which needs to be sent from region r in order to have one unit arriving in region q (see Krugman, 1991, for instance). Transport costs are assumed to be identical across varieties within region-sectors, but specific to sectors and trading partners (region pairs). They are borrowed from the model TRANSTOOLS and are related to the distance separating regions r and q but, in addition, also depend on other factors, such as transport infrastructure or national borders.[6] They are asymmetric (i.e. $\tau_{s,r,q}$ may differ from $\tau_{s,q,r}$), and are also assumed to be positive within a given region (i.e. $\tau_{s,r,r} \neq 1$) which captures, among others, the distance between customers and firms within the region.

The description of technological change directly follows Romer (1990) and Jones (1995). In their production process, final goods firms use durable goods. Each variety of durable goods is produced by a specific (durable goods) firm and traded on a regional market whose structure is monopolistic competition. In order to start operating, each durable goods firm

[6]Information and documentation on the TRANSTOOLS model can be found on http://energy.jrc.ec.europa.eu/transtools.

must acquire a design from the national research sector which uses human capital and the existing knowledge to produce new designs. Firms in the durable goods sector can only obtain designs from its national R&D sector by buying a licence which must be renewed each period, which entails fixed costs.

Public research augments the stock of knowledge, which in turn increases the productivity and hence output of the national R&D firms. For calibration purposes, the size of public research is determined by the level of public expenditure in R&D. The production of ideas in both the public and private domain is approximated by patents filing. The stock of knowledge depends on the production of new designs, which also replace previous designs becoming obsolete. The absorption of ideas from other regions is discounted by a measure of spatial weight matrix.

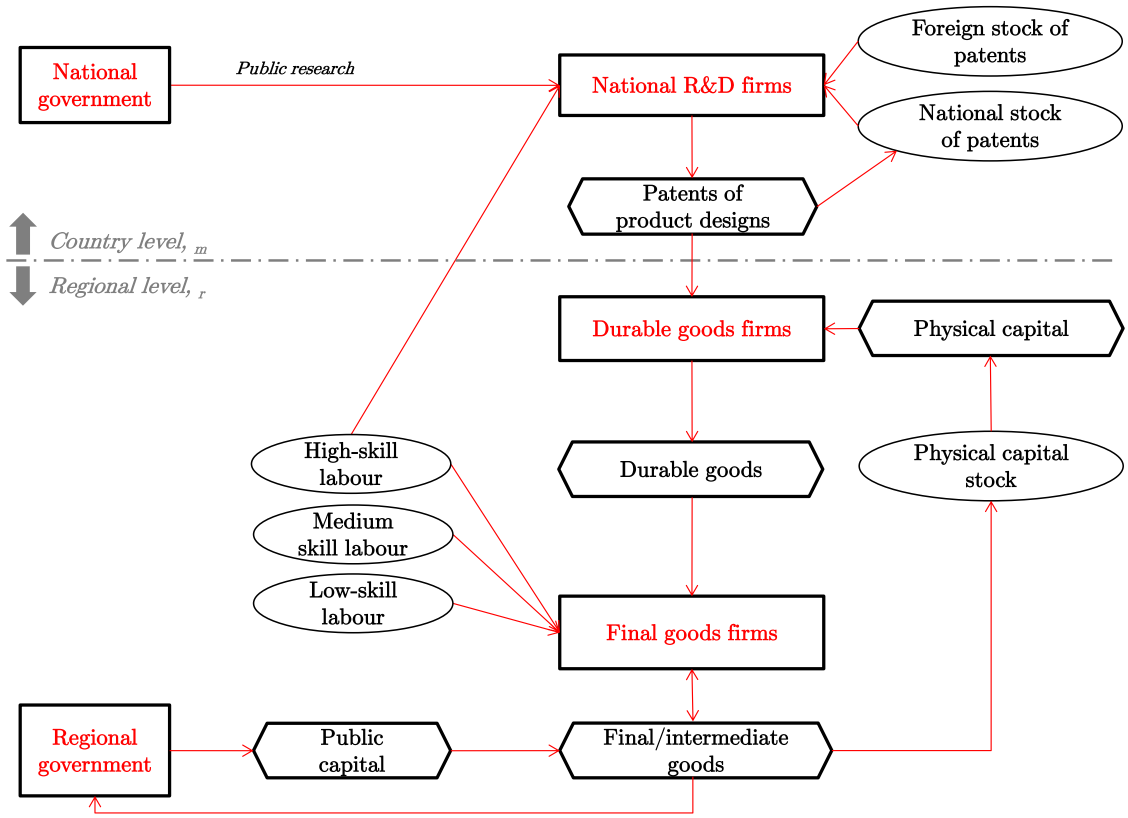

Figure 2: Firms and production structure in the RHOMOLO model: final goods firms, national R&D firms and durable goods firms.

The public sector consists of a two level of government: national and regional. It levies taxes on consumption and on the income of regional households. It provides public goods in the form of public capital, which is necessary for the operation of firms. It also subsidises the private sector, including the production of R&D and innovation, and influences the capacity of the education system to accumulate human capital.

The detailed regional and sectoral dimensions of RHOMOLO imply that the number of (non-linear) equations to be solved simultaneously is extremely high (ca. 1.5 million). Therefore, in order to keep the model manageable from a computational point of view, its dynamics is kept relatively simple. Agents are assumed to save a constant fraction of their income in each period and form their expectations based only on the current and past states of the economy. The dynamics of the model is then described as in a standard Solow model, with a sequence of short-run equilibria related to each other through the build-up of physical and human capital stocks, in addition to knowledge and assets.

RHOMOLO contains several endogenous agglomeration and dispersion forces affecting location choices of firms (see Brandsma *et al.*, 2013, for a formal derivation of spatial equilibrium in RHOMOLO). Three effects drive the mechanics of endogenous agglomeration and dispersion of economic agents in RHOMOLO: the *market access effect*, the *price index effect* and the *market crowding effect*. The *market access effect* captures the fact that firms in large/central regions enjoy easier access to consumers (in the sense of lower iceberg transport costs) than firms in small/peripheral regions, and hence the tendency of firms to locate their production in large/central regions and export to small/peripheral regions. The *price index effect* captures the impact of firms' location and trade costs on the cost of living of workers, and cost of intermediate inputs for producers of final demand goods. The *market crowding effect* captures the fact that because of higher competition on input and output markets, firms may prefer to locate in small/peripheral regions with fewer competitors.

Table 1: Mechanisms and forces of agglomeration and dispersion in RHOMOLO

	Mobility of capital	Mobility of labour	Vertical linkages
Market access effect	(+)	(+)	(+)
Price index effect		(+)	(+)
Market crowding effect	(−)	(−)	(−)

Notes: (+) denotes agglomeration, (−) denotes dispersion.

RHOMOLO contains three endogenous location mechanisms that bring the agglomeration and dispersion of firms and workers about: the mobility of capital, the mobility of labour, and vertical linkages (see Table 1). Following the mobile capital framework of Martin and Rogers (1995), we assume that (i) capital is mobile between regions; and (ii) the mobile capital repatriates all of its earnings to the households in its region of origin. Following the mobile labour framework of Krugman (1991), we assume that workers are spatially mobile (though the mobility is not perfect); mobile workers not only produce in the region where they settle (as the mobile capital does), but they also spend their income there (which is not the case with capital owners); workers' migration is governed by differences in the expected income, and differences in the costs of living between regions (the mobility of capital is driven solely by differences in the nominal rates of return).[7] Following the vertical linkage framework of Venables (1996), we assume that, in addition to the primary factors, firms use intermediate inputs in the production process; similarly to final goods consumers, firms value the variety of intermediate inputs; trade of intermediate inputs is costly.

3. Data and empirical implementation

3.1. Dimensions of RHOMOLO

RHOMOLO covers 267 NUTS2 regions in EU27, which are disaggregated into 6 NACE Rev. 1.1 sectors (see Table 2 and Figure 3, respectively). The detailed regional and sectoral disaggregation imposes significant data requirements. In particular, the empirical implementation of the RHOMOLO model requires data for all exogenous and endogenous variables at regional (and sectoral) level for the base year (2010), and numerical values for behavioural parameters.

Table 2: Sectoral disaggregation of the RHOMOLO model

Code	Sector description
AB	Agriculture, hunting and forestry
CDE	Mining and quarrying, manufacturing, electricity and gas
F	Construction
GHI	Wholesale and retail trade, repair of motor vehicles, motorcycles, personal and household goods, hotels and restaurants, transport and communications
JK	Financial intermediation, real estate and business services
LMNOP	Non-market services

Source: Authors' aggregation based on the EUROSTAT (2003) NACE Rev. 1.1 classification.

The base year (2010) data are compiled in form of an inter-regional Social Accounting Matrix (SAM) (see Potters *et al.*, 2013; Thissen *et al.*, 2014, for details). For the construction

[7] In the model also the regional unemployment rates enter the migration problem of workers.

of all EU27 countries' SAMs, data of the World Input Output Database (WIOD) and the Global Trade Analysis Project (GTAP) have been used. The WIOD database provides International Input-Output tables, International and National Supply and Use tables, National Input-Output tables, and Socio-Economic and Environmental Accounts covering all EU27 countries and 13 other major regions in the world for the period from 1995 to 2009. An important advantage of the WIOD data is that re-exports are subtracted from the direct exports to calculate the final value of exports. Generally, the WIOD data are available for 59 NACE Rev. 1.1 sectors, which for the purpose of the present study are aggregated into six macro-sectors (see Table 2). First, the SAMs are constructed at the national level, and then regionalised by taking into account all available regional and sectoral data constraints, such as, regional data on value added, employment and other regional and sectoral information from EUROSTAT (see Potters *et al.*, 2013; Thissen *et al.*, 2014, for details).

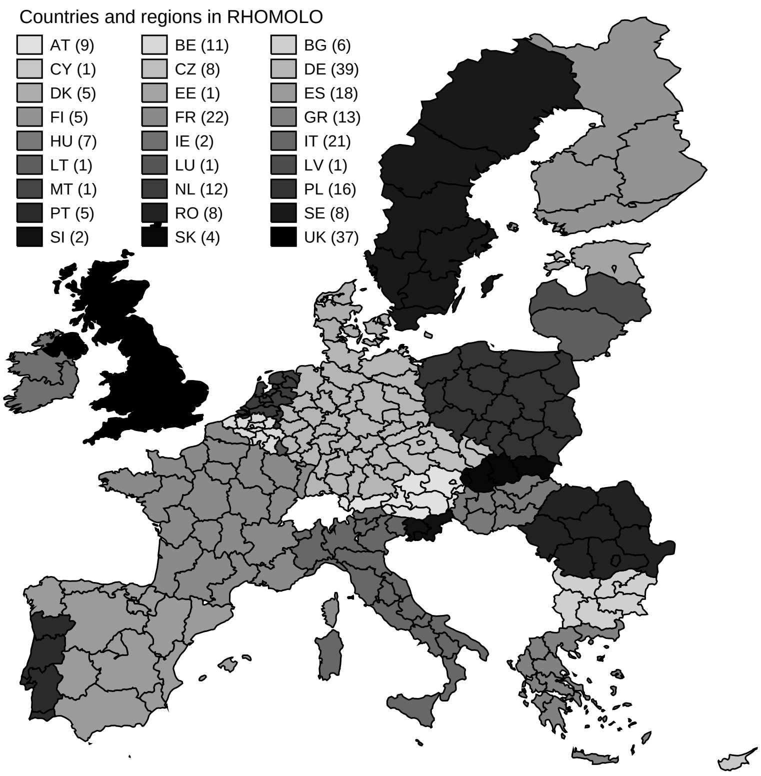

Figure 3: Spatial disaggregation of the RHOMOLO model. Notes: The number of NUTS2 regions in each country are in parentheses.

3.2. Data for inter-regional variables

Inter-regional labour migration is captured as net changes in the regional labour force (see Brandsma *et al.*, 2014, for details). The net aggregate relocation of workers between any two regions is a function of the expected income and distance, which requires data for labour migration, regional GDP and unemployment and migration elasticities. EUROSTAT's Regional Migration Statistics dataset provides data on within country migration. The key statistics on migration in OECD countries provides data on international migration. The Household Income and Active Population data is also extracted from EUROSTAT. Finally, data on region- and sector-specific unemployment and wages is micro-estimated based on the EUROSTAT's Labour Force Survey (LFS).

Inter-regional trade flows are estimated using inter-regional traffic counts data from Thissen *et al.* (2013). This data is harmonised with the available macro-constraints from RHOMOLO's SAMs: the distribution of production and consumption over the EU regions to ensure consistency with the country level trade flows data from the COMEXT international trade statistics, and the rest of RHOMOLO's data. Inter-regional trade costs come from the TRANSTOOLS database.

3.3. Data for inter-temporal variables

Knowledge accumulation is accounted for in RHOMOLO through region-specific R&D intensities (innovation expenditures), which are available at the regional level from the EUROSTAT's Science and Technology Indicators database. Whereas R&D data by sector are available at the national level, comparable data are not available at the regional level for most of the countries. In order to regionalise the national R&D data by sector, we use the EUROSTAT's database, which distinguishes four sectors of performance – namely governments, higher education institutions, business sector and private non-profit organisations. Most of RHOMOLO sectors fall under the broader business sector. In a second step, we correct for the sectoral disaggregation by using the regional gross fixed capital formation by NACE sector. In this way we are able to construct the best available proxy for NACE sector R&D spending at the regional level – given the current availability of data.[8]

The regional stock of human capital is proxied by 3 levels of education: low skill (isced0_2), medium-skill (isced3_4), and high skill (isced5_6). Wages are differentiated on the basis of education levels, in order to allow for internalisation of investment decisions of households

[8]Currently undergoing extension of the innovation module in RHOMOLO with additional features beyond R&D includes two elements. First, European Commission-based regional patent statistics and citations offer valuable information on technological proximity across regions in Europe. Second, the inclusion of the micro-estimated data from the Community Innovation Survey is used to identify a broader set of regional innovation features – closely related to the policy domains identified in the current taxonomy of cohesion policy investments.

on the amount of education to be invested in each period. Data for this come from the LFS and the EU KLEMS database.

The regional stock of physical capital is constructed according to the Perpetual Inventory Method (PIM), because comparable data for all EU27 countries on capital stock at the regional/sectoral level of disaggregation are not available from any statistical data source. This approach takes the initial stock by country and industry (regionalised by GVA share) in the year 1995 and calculates the final capital stock by region and industry in 2010 by adding the yearly capital investments and depreciating the existing stock every year. We used the following data: gross fixed capital formation on NUTS 2 level and by sector in current prices for the years 1995-2010; price deflators for converting into constant prices; initial stocks for calculating the net capital stocks for each year applying the PIM from the EU KLEMS database. These data are available at the national level, but regionalised by the GVA share; depreciation rates (calculated by weighing the average service life of each of the six types of assets, using the EAS95 classification).

3.4. Model parameters

In order to parameterise the RHOMOLO model, all key structural parameters are estimated econometrically. For example, all parameters related to the wage curve and inter-regional labour migration are estimated in a panel data setting for each country (Brandsma *et al.*, 2014; Persyn *et al.*, 2014). Second, all parameters related to the elasticities of substitution both on consumer and producer sides are estimated based on micro-data. In the current version of RHOMOLO, the implemented elasticities of substitution are uniform for all sectors and regions. However, in future versions of RHOMOLO, they will be estimated by sector and region based on region- and sector-specific micro-data. The missing behavioural parameters are drawn from the literature (Okagawa and Ban, 2008).

Finally, as usual in computable general equilibrium models, all shift and share parameters are calibrated to reproduce the base year (2010) data in the SAMs. In order to determine the sensitivity of simulation results with respect to the implemented parameters in RHOMOLO, we perform extensive sensitivity analysis and robustness checks.

4. Agglomeration and dispersion

As noted by Krugman (1991), an endogenous modelling of industry location requires: (i) agglomeration and dispersion forces; and (ii) mechanism(s) based on which the agglomeration/dispersion are brought about. The theoretical literature identifies a considerable amount of potential agglomeration and dispersion forces (for surveys see Fujita *et al.* (1999); Fujita and Thisse (2002); Baldwin *et al.* (2003)). In the structure of RHOMOLO v.2 it is possible to identify two standard agglomeration forces (increasing returns to scale and localised externalities), and two relevant dispersion forces (trade costs and imperfect competition). These forces are captured in the model through three effects, running through market access, the price index and market crowding.

4.1. Agglomeration forces and effects

Here follows a discussion on the two agglomeration forces, increasing returns to scale and localised externalities, followed by a description of the effects associated with these forces, the *market access effect* and the *price index effect*.

4.1.1. Agglomeration forces

Increasing returns to scale. As noted by Koopmans (1957), without recognising the indivisibilities in human capital, residences, plants, equipment, and transportation, location problems cannot be fully understood. More generally, when studying location issues, it is important to understand to what extent increasing returns are at work, which is tantamount to indivisibilities of economic activities. Starrett (1978) has shown that, if production activities could be divided up to the point where trade costs are zero without any loss of efficiency, the absence of scale economies would turn each location into an autarky. On the one hand, in absence of fixed production costs, a sufficient number of firms could be located in each location of consumption. As a result, there would be no trade between locations. On the other hand, in absence of trade costs, a single location of firms would be enough to satisfy the entire demand of all locations (except for the case where the marginal cost of production would increase). As a result, each agent would prefer a self-subsistence economy, which Eaton and Lipsey (1977) refer to as a *backyard capitalism.*

In reality, however, neither trade costs are zero, nor goods are infinitely divisible. Hence, both trade costs and increasing returns to scale are fundamental to understand the location problems of economic activities, as they are among the most important determinants in the firm and worker location decisions.[9]

[9] In the presence of increasing returns, the resources available in the economy impose a limit on the number of firms and varieties capable of being produced. In general, this number depends on the entry barriers that firms face. In the framework of Chamberlin (1890), the fixed cost associated with firm entry / the launching of a new variety is the only effective barrier. Such an entry barrier is nonstrategic, because it cannot be manipulated by other firms.

In RHOMOLO v.2 increasing returns to scale are introduced via fixed costs, $FC_{i,s,r}$, in the firm value added production function (which is assumed to take the Cobb-Douglas form). We assume that a fixed amount of resources, $FC_{i,s,r}$, is needed to set up firms. Fixed costs are measured in quantity terms, and firms pay them at the beginning of each period (before starting to produce market output).

Localised externalities. Marshall (1890) has discussed how local interactions between firms and workers (knowledge spillovers, business communications, and social interactions) constitute an important source of agglomeration. The so-called Marshallian economies describe the advantages generated by the clustering of economic activities in space. Marshall distinguishes between three sources of external economies: (i) the distribution of specialised inputs, whose unit cost is low, when demand for that input is sufficiently high; (ii) large local labour market offering improved matching between jobs and workers, thus making both firms and workers more productive; and (iii) the more intense circulation of ideas and knowledge spillover effects, which also increases firm and worker productivity.

According to Scitovsky (1954), two types of external effects can be distinguished: technological externalities and pecuniary externalities. Whereas the former (Marshallian) are restricted to spillovers directly affecting individual utility or firms' production functions, the latter result from market interactions and affect firms or consumers/workers by means of exchanges. If competition is imperfect, pecuniary externalities may arise due to the fact that prices do not reflect the social value of individual decisions. Consequently, when agents move, they do not account for all the effects caused by their decisions. To put it another way, the relocation of agents unintentionally affects the welfare of the others through pecuniary externalities.

In RHOMOLO v.2 localised externalities enter through the stock of public capital, K_r^G, in the value added production function and through spillovers. Localised externalities are region-specific, they determine the relationship between the density of workers and firms in a region, and the productivity of particular inputs in the regions' value added production function (specialised inputs, capital and labour).[10]

[10] Externalities are also modelled through technological spillovers, D_m^{ϕ}. As noted in section 2, the production of ideas requires only the use of high skill labour as a remunerated input, $L_{R\&D,m}^{hi}$, but this input is augmented by the available stock of knowledge, D_m^{ϕ}, in country m. Given that these spillovers operate at the national level, strictly taken, they are not localised externalities.

4.1.2. Agglomeration effects

Market access effect. The so-called *market access effect*, which in the literature is also referred to as the *dominant market effect*, *demand linkage* or *backward linkage* (Fujita *et al.*, 1999; Fujita and Thisse, 2002; Baldwin *et al.*, 2003), results from differences in proximity to customers (consumers and other firms) across regions. It explains why large/central regions tend to have more firms and production than small/peripheral regions. Of course, market access does not depend only on the size of the region in itself, but also to its position vis-à-vis the other large regions and the cost of shipping goods to the other markets (which is why high trade costs are a dispersion force).

Indeed, there are two reasons for the concentration of production in large/central regions. First, due to positive trade costs, the demand for a region's output increases with it's relative accessibility and the economic size of the region. This can be seen by combining the consumption and profit equations:

$$\begin{aligned}\underbrace{\pi_{i,s,r}}_{\text{profits}} = \underbrace{p_{i,s,r}}_{\text{output price}} \cdot &\left[\underbrace{\left(\frac{1}{\beta_s}\tau_{s,r,q}p_{i,s,r}\right)^{\frac{1}{\sigma-1}}}_{\text{CIF price for variety}} \underbrace{\left(P_q^c\right)^{\sigma-1}}_{\text{price index}} \underbrace{I_q}_{\text{income}}\right] \\ &- \underbrace{P_{i,s,r}^y X_{i,s,r}}_{\text{value added costs}} - \underbrace{\sum_{u=1}^{S} a_s^{u-1} P_r^u X_{i,s,r}}_{\text{intermediate inputs}} - \underbrace{P_{i,s,r}^y FC_{i,s,r}}_{\text{fixed costs}} \qquad (1)\end{aligned}$$

where $\pi_{i,s,r}$ is profit of firm i located in region r operating in sector s, P_q^c and P_{isr}^u are the consumer price index and the intermediate input price index, respectively, $p_{i,s,r}$ is the price of variety i of sector s produced in regions r, β_s is the weight given to sector s in the household's (firm 's) preferences, $\tau_{s,r,q}$ is trade cost from region r to region q, σ is the elasticity of substitution between varieties, $P_{i,s,r}^y$ is the price of value added, $X_{i,s,r}$ is a CES aggregate over final (intermediate) good varieties, a_s are technical input coefficients in the production function, I_q is disposable household income in region q, and as above $FC_{i,s,r}$ is fixed cost. According to profit function (1), the total demand, $X_{i,s,r}$, for good i in sector s produced in region r, and hence profit, π_{isr}, is increasing with lower trade costs, $\tau_{r,q}$, and with elasticity of substitution, σ. The weighted average trade costs can be lower either due to large internal market (because $\tau_{rr} < \tau_{rq} \; \forall \; r, q$), or due to central location of a region (good accessibility), or both.

Second, the profitability of firms is further enhanced by increasing returns, since growth in their output reduces the average production costs. By combining the production function, the value added and the profit equations, one can see that, if everything else would stay constant (including the fixed cost, $FC_{i,s,r}$), then an increase in output, $X_{i,s,r}$, would reduce the share of fixed costs, $FC_{i,s,r}$, in average costs, and hence increase firm profits, π_{isr}.

Price index effect. The so-called *price index effect*, which in the literature is also known as the *cost-of-living effect*, *cost linkage* or *forward linkage* (Fujita *et al.*, 1999; Fujita and Thisse, 2002; Baldwin *et al.*, 2003), describes the impact of firm location and trade costs on the cost of living of workers, and the cost of intermediate inputs for producers of the final demand goods. Given that consumers in large/central regions with more firms have to import a narrower range of products, reducing in such a way trade costs, goods tend to be less expensive in large/central regions than in small/peripheral regions. This can be seen in the consumer price index (2), and the intermediate input price index (3), respectively:

$$\underbrace{P_q^c}_{\text{consumer price index}} = \underbrace{\left(\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{i=1}^{N_{s,r}} \beta_s^{\sigma} \left(\tau_{s,r,q} p_{i,s,r}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}_{\text{CES aggregation across final demand good varieties}} \tag{2}$$

$$\underbrace{P_{isr}^u}_{\text{intermediate input price index}} = \underbrace{\left(\sum_{q=1}^{R}\sum_{j=1}^{N_q^u} \beta_s^{\sigma} \left(\tau_{r,q} p_{j,q}^u\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}_{\text{CES aggregation across intermediate good varieties}} \tag{3}$$

where P_q^c and P_{isr}^u are the consumer price index and the intermediate input price index, respectively, $p_{i,s,r}$ is the price of variety i in sector s produced in regions r, β_s is the weight given to sector s in the household's (firm 's) preferences, $\tau_{s,r,q}$ is trade cost from region r to region q, $p_{j,u,q}$ is the price of variety j, u, q of final goods, and σ is the elasticity of substitution between varieties.

Both price indices suggest that the total trade costs in each sector, $\sum_{r=1}^{R}(\tau_{r,q} - 1)p_{r,q}$, and hence the cost of living and producing, are lower in large/central regions. The regional price index increases in trade costs. Because of lower costs of living/production, firms (purchasing intermediate inputs) and consumers (purchasing final goods) would prefer to locate in large/central regions.

In the absence of dispersion forces, the described *price index effect* could become self-sustained in the sense that the availability of more locally produced varieties lowers the regional price index, lowers prices in the region and, in turn, attracts more firms and workers.

4.2. Dispersion forces and effects

Here follows a discussion on the two dispersion forces, trade costs and imperfect competition, followed by a description of the effect associated with these forces, the *market crowding.*

4.2.1. Dispersion forces

Trade costs. In spatial economics it has been recognised for a long time that accessibility drives the location of economic agents to spatially dispersed markets Bosker and Garretsen (2010). Losch (1940) has shown that, when trade costs increase with distance, which formally is equivalent to the case in which a fixed cost coexists with a growing marginal cost, each production unit would supply consumers located within a certain radius, the length of which depends on the relative level of trade costs and the intensity of increasing returns.

The accessibility of a location is determined by two components: its spatial location and transport costs. Whereas the former is exogenous and fixed, the latter can be changed by policy makers, which explains the large interest that trade costs have triggered in the economic literature. Trade costs capture all the costs generated by the various types of spatial frictions that economic agents face in a spatial exchange process. According to Bairoch (1974) and Spulber (2011), there are four key components of trade costs: (i) spatial transaction costs that result from doing business at a distance due to differences in consumer tastes, business practices, as well as political and legal institutions; (ii) tariff and non-tariff barriers, such as different environmental standards, anti-dumping practices, and the different market regulations that restrict trade and investment between regions and countries; (iii) transportation costs per se, as goods have to be transported from their production place to their consumption place, while many services remain non-tradable or can be transported at a comparably low cost; and (iv) time costs as, despite significant advances in communication technologies during the last decades, there are still important communication impediments across dispersed distribution of producers and consumers that slow down reactions to changes in market conditions, while the time needed to ship certain types of goods or access certain types of services has an increasing value.

In RHOMOLO v.2 trade between (and within) regions is assumed to be costly, implying that the shipment of goods between (and within) regions entails transport costs, which are assumed to be of the iceberg type, with $\tau_{s,r,q} > 1$ representing the quantity of sector's s goods which needs to be sent from region r in order to have one unit arriving in region q. Higher trade costs make it more difficult for firms to serve distant markets and thus represent a strong dispersion force.

Imperfect competition. Imperfect competition implies that firms do not consider prices as given but are price-makers. Given that the level of prices depends on the spatial distribution of firms and consumers, the resulting interdependence between firms and workers may yield agglomerations. Two types of imperfect competition have been used in economic models: monopolistic competition and oligopolistic competition. Whereas monopolistic competition involves a modest departure from the competitive framework by allowing firms to be price-makers by producing differentiated goods under increasing returns, oligopolistic competition involves a small number of large agents that interact strategically. Due to its convenience in terms of modelling, we follow the framework of monopolistic competition in RHOMOLO v.2.

The concept of monopolistic competition goes back to Chamberlin (1890), it can be described by means of the following six assumptions: (i) differentiated products, (ii) a high number of firms of negligible size, (iii) free entry and exit in the market, (iv) independent decision making, (v) market power, and (vi) imperfect information.[11] Chamberlin's ideas were formalised by Spence (1976) and Dixit and Stiglitz (1977), who brought them into applied economic modelling by proposing a simple and analytically tractable framework of general equilibrium with monopolistic competition, as opposed to Spence (1976), who developed them in a partial-equilibrium setting.

In RHOMOLO v.2 imperfect competition is modelled in the monopolistic competition framework of Dixit–Stiglitz, as it makes it possible to integrate both increasing returns and imperfect competition in a tractable and elegant way. First, we assume that each firm produces a differentiated product (variety), which are not perfect substitutes. In the same time, we assume that the real or perceived non-price differences are small enough to eliminate other varieties as substitutes. Product differentiation is captured by the elasticity of substitution between varieties, σ, which is larger than one, but smaller than infinity. Second, we assume that there is free entry and exit on each market, implying that firm profits are zero in the long run. Third, the number of firms, $N_{s,r}$, operating in industry s located in region r is sufficiently large, such that each of them is negligible with respect to the total number of firms. This is ensured by the choice of fixed cost, $FC_{i,s,r}$, and the elasticity of substitution, σ.

[11] These assumptions bear a strong resemblance with those of perfect competition, the main difference being in the fact that in monopolistic competition each firm sells a specific product and chooses its own price. This endows each firm with a specific market, in which the firm has some monopoly power. However, the existence of similar varieties implies that the size of this market depends on the behaviour of other firms, thus constraining each producer in their price choice. Hence, a monopolistically competitive firm is neither in a situation of perfect competition, not in a situation of 'pure' monopoly.

4.2.2. Dispersion effect

Market crowding effect. The so-called *market crowding effect*, which in the literature is also referred to as the *competition effect* (Fujita *et al.*, 1999; Fujita and Thisse, 2002; Baldwin *et al.*, 2003), reflects the fact that, because of higher competition on input and output markets, firms prefer to locate in small/peripheral regions with fewer competitors. When the number of firms in large/central regions increases, the consumption of differentiated goods is fragmented over a larger number of varieties (firms), implying that each firm's output and profit decrease. Given that the entry of new firms has a negative effect on profitability of incumbents in more crowded regions, the *competition effect* works against the tendency to agglomerate.

The impact of the *market crowding effect* on output can be seen in equation (4):

$$\underbrace{X_{h,q}^{C}}_{\text{total demand}} = \underbrace{\left(\sum_{r=1}^{R} \sum_{s=1}^{S} \beta_s \sum_{i=1}^{N_{s,r}} \left(x_{h,q}^{i,s,r} \right)^{\theta} \right)^{\frac{1}{\theta}}}_{\text{CES aggregation of consumption across firms}} \tag{4}$$

where $x_{h,q}^{i,s,r}$ is the demand of variety i of sector s produced in regions r from household h located in region q, β_s is the weight given to sector s in the household's (firm 's) preferences. For a given level of total consumption, function (4) shows that the demand for $x_{h,q}^{i,s,r}$, the output produced by firm i in sector s in region r decreases in the sales of competitors in region q. In (4) this can be seen by holding the total demand, $X_{h,q}^{C}$, fixed. If $N_{s,r}$ increases, then $x_{h,q}^{i,s,r}$ must decrease, everything else constant. Lower output, and hence profits, would induce firms to move away from large/central regions to small/peripheral regions with fewer competitors.

The *market crowding effect* also affects input markets through prices of spatially immobile (semi-mobile in the short-run) production factors. Agglomeration of firms in large/central regions would bid up prices for immobile (semi-mobile) production factors, making production more costly, which would reduce firm profits.

5. Mechanisms of agglomeration and dispersion

5.1. Setup

The agglomeration and dispersion forces determine the location choices of economic agents in RHOMOLO through the effects detailed in the previous section. However, because of factor mobility, vertical integration of markets, and other endogenous location mechanisms, the optimal location choice of an agent affects the decisions of all other agents with which it interacts, which may create self-reinforcing circular causality effects. This section introduces such endogenous location mechanisms bringing the agglomeration and dispersion of economic activity about in RHOMOLO v.2: capital mobility, the labour mobility, and vertical linkages.

In order to illustrate their impact on location choices of economic agents in RHOMOLO v.2, we perform numerical simulations on the example of regional market integration in the EU.[12] In particular, we reduce trade costs between EU regions in line with the approved transport infrastructure investments of the EU Cohesion Policy (ECP) for the financial programming period 2014-2020 (see Table 3 in the Appendix). Trade costs are of particular interest for studying location decisions of economic agents because they are inherent attributes of exchanges across space and play an important role in spatial transactions (Anas *et al.*, 1998; Broecker *et al.*, 2001).

According to the second column in Table 3 in the Appendix, there are large inter-regional differences in the ECP expenditure on infrastructure ranging from few million EUR to several billion EUR per region. In line with the overall objectives of the ECP, the largest amounts are allocated to the Less Developed Regions. The third column in Table 3 shows the estimated accessibility improvements, the distribution of which is similar to the pattern of ECP expenditures on transport infrastructure.[13] We expect that agglomeration mechanisms will be more pronounced in the Less Developed Regions, where the trade cost reductions are the largest.

5.2. Mobility of capital

The canonical framework featuring the *home market effect* was proposed by Krugman (1980), where the location of economic activities is driven by firm creation/destruction. Martin and Rogers (1995) extended the framework of Krugman (1980), by assuming that capital is mobile, just as goods are, which allows to study the impact of the economic size and accessibility of a region on the spatial distribution of economic activity. As noted by Krugman (1980), both market size is one of the key determinants of firms' location choices, and regions' accessibility to other markets is a crucial element in determining the attractiveness of a region.

Following the mobile capital framework of Martin and Rogers (1995), we make two assumptions in order to implement capital mobility in RHOMOLO v.2: (i) capital is mobile

[12]Note that we can only run simulations to show the impact of capital mobility because, due to the complexity of the model, analytical derivations are not possible.

[13]The methodology is illustrated in detail in Kancs and Persyn (2014).

between regions; and (ii) the mobile capital repatriates all of its earnings to its region of origin.

In order to illustrate the impact of capital mobility on location choices of economic agents, we perform numerical simulations of trade cost reduction. In addition to the base run, we solve the model for two scenarios: one with capital mobility and one without capital mobility. The two other mechanisms of endogenous location (labour mobility and vertical linkages) are excluded from this exercise. The results on regional GDP are reported in Figure 4, which shows percentage changes of GDP compared to the baseline.

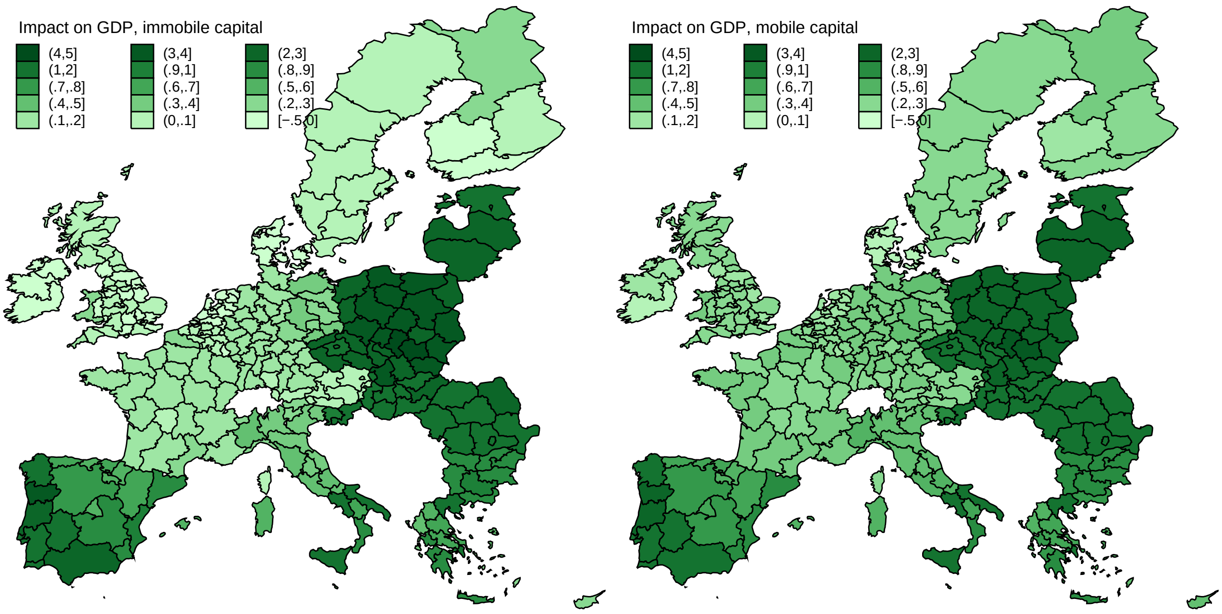

Figure 4: Simulated impact of cohesion policy investment in transport infrastructure on real GDP in 2050, percentage changes from the baseline. Left panel: immobile capital; right panel: mobile capital.

Comparing the left map with the right map in Figure 4, we can see that differences in the policy impact between regions decrease substantially, when capital mobility is allowed for in the model. Whereas the standard deviation of the simulated policy impact is 1.005 (left map) without capital mobility, it decreases to 0.703 when we introduce capital mobility between regions (right map). Also the amplitude of the simulated policy impact across regions decreases (the minimum value increases from -0.22% to 0.06% of GDP, and the maximum value decreases from 4.57% to 3.41% of GDP). Hence, our results suggest that, by equalising the returns to capital, capital mobility has the tendency to spread the positive growth impact from regions with the highest intervention to other regions in the EU.

Notice that the adopted capital mobility (Martin and Rogers, 1995) contains two effects that affect firm location decisions: *market access effect* and *market crowding effect*. The relative strength of the two effects determines the degree of agglomeration of mobile firms, which may magnify or dwarf the initial size advantage of large/central regions (in the literature, this effect is known as the *home market effect*, and goes back to Corden (1970)).

5.3. Mobility of labour

Krugman (1991) proposed a framework where the mobility of labour force bring the agglomeration/dispersion about. In addition to the *market access effect* and *market crowding effect*, in the mobile labour framework also the *cost-of-living effect* plays an important role in location decisions of firms and workers.

Following the mobile labour framework of Krugman (1991), we make three assumptions in order to implement labour mobility in RHOMOLO v.2.[14] First, we assume that workers are spatially mobile (though the mobility is not perfect). Second, mobile workers not only produce in the region where they settle (as the mobile capital does), but they also spend their income there (which is not the case with capital owners). Third, workers' migration is governed by expected differences in real income, therefore differences in the costs of living between regions matter (the mobility of capital is driven solely by differences in the nominal rates of return).

Formally, the simulated workforce change in region r with labour force L_r due to migration is difference between the incoming and outgoing migration, or

$$\sum_{o} L_o \cdot s_{or} - \sum_{d} L_r \cdot s_{rd} \tag{5}$$

where s_{or} is the share of migrants from o to r, and s_{oo} is the share of stayers in region o.

In order to illustrate the impact of labour mobility on spatial distribution of economic activity, as above, we perform numerical simulations of trade cost reduction. In addition to the base run, we solve the model for two scenarios: one with labour mobility and one without capital mobility. The two other mechanisms of endogenous location (capital mobility and vertical linkages) are excluded from this exercise. The results on regional GDP are reported in Figure 5, which maps percentage changes in regions' GDP compared to the baseline.

The simulation results reported in Figure 5 suggest that differences in the policy impact between regions increase substantially, when labour mobility is allowed for in the model. Comparing the left map with the right map in Figure 5, we can see that light-coloured

[14]See Brandsma *et al.* (2014) for a detailed description of labour migration in RHOMOLO.

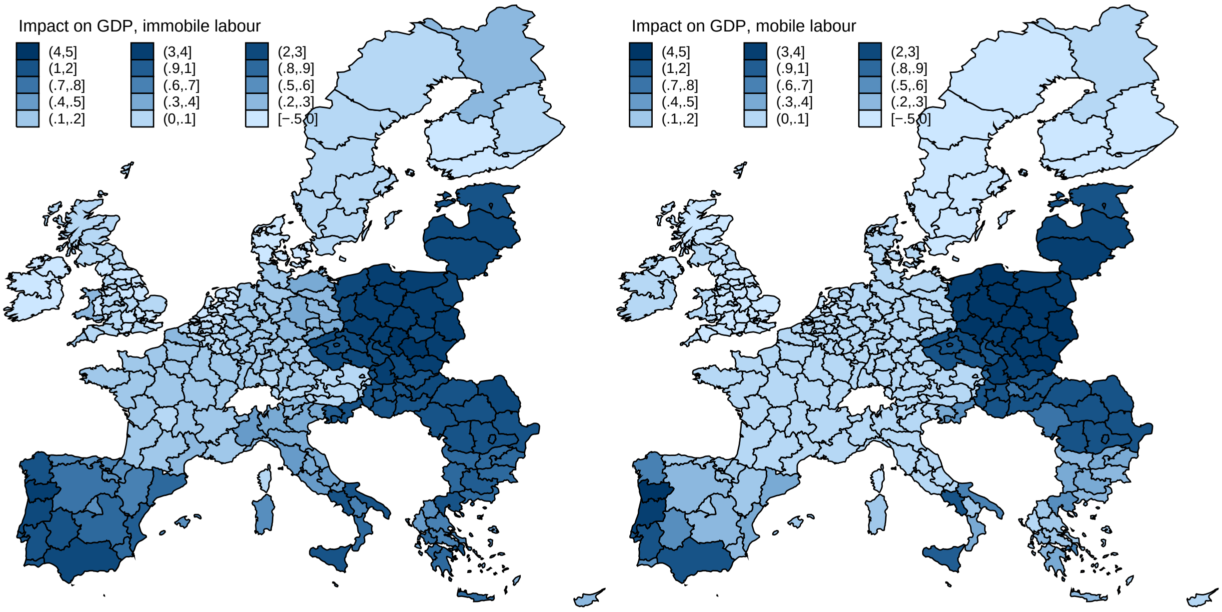

Figure 5: Simulated impact of cohesion policy investment in transport infrastructure on real GDP in 2050, percentage changes from the baseline. Left panel: immobile labour; right panel: mobile labour.

regions become lighter, whereas the dark-coloured regions have become even darker, implying that labour mobility in RHOMOLO magnifies the increase of labour force, local demand and economic activity in those regions benefitting the most from improved accessibility due to transport infrastructure investments.

These results are not surprising in light of the underlying theoretical framework of mobile labour, which contains one additional agglomeration force, compared to the above discussed mobile capital framework. When mobile workers migrate between regions, they spend their income in the destination region, where the final demand increases, while it decreases in the origin region. An increase in the market size tends to increase firm profits, and attracts firms in regions with improved accessibility vis-a-vis other regions. This in turn triggers two further effects in RHOMOLO v.2. On the one hand, a concentration of firms makes nominal wages in regions with improved accessibility more attractive (in real terms) than the same nominal wages in other regions, because of lower weighted average trade costs (*cost-of-living effect*). Hence, the *cost-of-living effect* may stimulate further migration. On the other hand, the concentration of firms in regions with improved accessibility increases the competition for local inputs and customers, while it reduces the competition in other regions. As in the mobile capital framework, the *market crowding effect* partly offsets the *cost-of-living effect*.

The simulation results reported in Figure 5 suggest that the two agglomeration effects (*market access* and *cost-of-living*) are stronger than the dispersion effect (*market crowding*), because labour migration triggers additional agglomeration of workers and firms, resulting in more mobile workers and firms located in those regions, which benefit from improved accessibility the most. Our simulation results also suggest that workers' migration seems to be self-correcting, as the dispersion effect becomes stronger at higher levels of agglomeration. Because of partially immobile demand and production factors, the entire workforce does not end up agglomerated in few central EU regions. Consider also that, since varieties are imperfectly substitutable, goods produced in peripheral regions always have a certain demand to satisfy and if too many productive factors moved away from the region, the effect on prices and quantities would be such to make it appealing again for firms and workers to move to the periphery.

5.4. Vertical linkages

It is well known that the final demand for consumer goods only accounts for a part of firms' sales, the rest being demand for intermediate goods. The share of intermediate inputs in the total world trade is gaining in importance over time (Venables and Limao, 2002). An alternative mechanism for driving the endogenous location decision of economic agents can thus be based on the vertical-linkage framework of Venables (1996), who shows how spatial agglomeration/dispersion of economic activities can emerge due to input-output linkages in vertically integrated markets. When making their location choices, the intermediate goods producers consider where the final goods producers are located, and the final goods producers will likely choose their location close to the intermediate goods suppliers.

Following the vertical-linkage framework of Venables (1996), we make three assumptions in order to implement vertical linkages in RHOMOLO v.2. First, we assume that, in additional to primary factors, firms use intermediate inputs in the production process. Second, similarly to final goods consumers, firms value the variety of intermediate inputs. Third, the trade of intermediate inputs is costly.

Because of improved market access, firms of the final goods sector tend to move to regions with improved accessibility vis-a-vis other regions. Higher demand for intermediate goods in regions with improved accessibility attracts producers of intermediate goods from other regions. Due to lower average trade costs, these intermediate goods can be supplied at a lower cost in regions with improved accessibility (*price index effect*), triggering more firms of the final goods sector to move to regions with improved accessibility. Such a cumulative causation process can reinforce itself, so that the resulting agglomeration can be driven solely by the demand for intermediate goods.

In order to illustrate the impact of vertical linkages on location choices of economic agents, we perform numerical simulations of trade cost reduction in RHOMOLO. As above, we simulate the trade cost reduction scenario under two alternative assumptions: one with vertical-linkages and one without vertical-linkages, excluding the two other mechanisms of endogenous location for clarity. The results on regional GDP are reported in Figure 6, which shows percentage changes of GDP compared to the baseline.

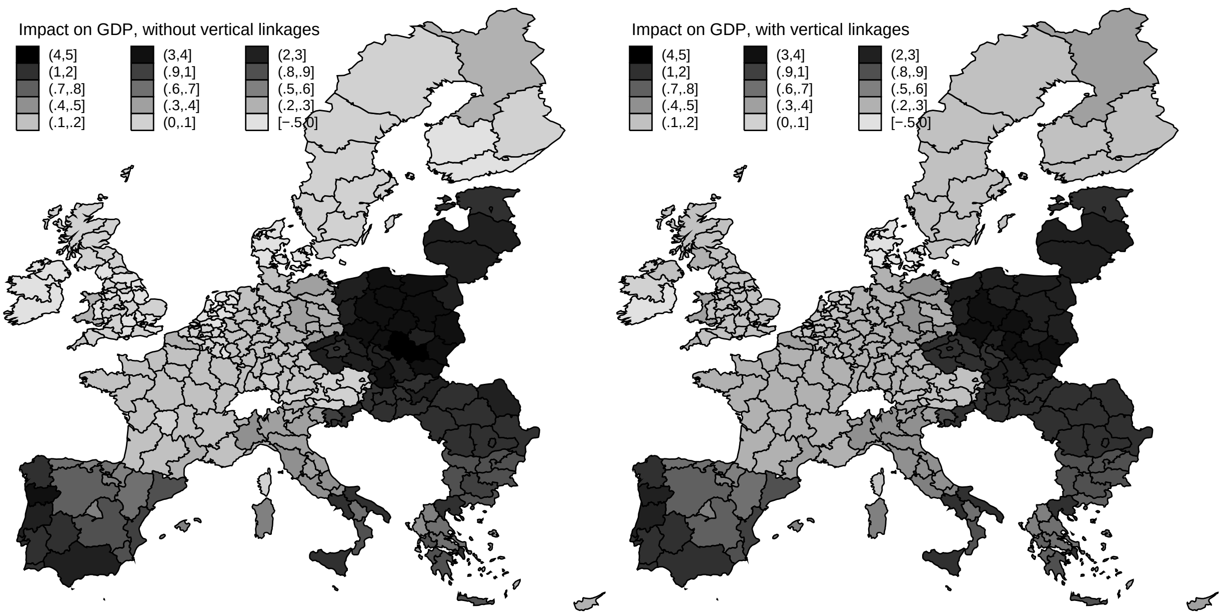

Figure 6: Simulated impact of cohesion policy investment in transport infrastructure on real GDP in 2050, percentage changes from the baseline. Left panel: without vertical linkages; right panel: with vertical linkages.

Similar to capital mobility, comparing the left map with the right map in Figure 6, we can see that differences in the policy impact between regions decrease substantially, when vertical linkages are introduced in the model. Whereas without vertical linkages the standard deviation of the simulated policy impact is 1.005 (left map), it decreases to 0.804 when we introduce vertical linkages (right map). Also the amplitude of the simulated policy impact across regions decreases (the minimum value increases from -0.22% to -0.04% of GDP, and the maximum value decreases from 4.57% to 3.80% of GDP. Hence, our results suggest that, vertical linkages have the tendency to spread the positive growth impact from regions with the highest intervention to other regions.

6. Conclusions

RHOMOLO v.2 contains two agglomeration forces (increasing returns to scale and localised externalities) and two dispersion forces (costly trade and imperfect competition) in a spatial general equilibrium model with endogenous location. Allowing households and capital to move across regions, and allowing firms to source their inputs from other firms inside or outside the region, the spatial distribution of economic activities is determined endogenously and can be affected by policy intervention.

The distinction of goods, factors, firms, and households by location, and the incorporation of trade costs in RHOMOLO can be used to capture a variety of issues in regional and transport economics. The inclusion of assets and a process of research and innovation enables the model to be used for the study of regional investment subsidies. Furthermore, the model can be connected to a dynamic stochastic macroeconomic model such as QUEST, or to a transport network model such as TRANSTOOLS, to study the long-run dynamic effects of transport infrastructure improvements.

Illustrative simulations suggest that EU labour mobility across EU regions magnifies the *home market effect* and the *market access effect*. In contrast, the *market crowding effect* dominates the *market access effect* for capital mobility and vertical linkages. These results are not surprising because the endogenous location mechanism of labour mobility entails a strong additional agglomeration effect as compared to capital mobility: the lower cost-of-living luring workers towards more agglomerated regions to enjoy higher real incomes because of lower prices.

Turning to the limitations, a general problem of the adopted spatial general equilibrium approach is that almost all model data is used for calibration, whereas very little data is left for testing the model. Hence, its estimation and testing are still open issues to be addressed in the future.

Our results have important implications for future research. First, our simulations focused on one endogenous channel of adjustment at the time because of the infeasibility of solving the model, analytically or numerically, in presence of multiple asymmetric regions and multiple endogenous channels. Hence, as presented in the present paper, numerical simulations may be necessary to identify the impact of each agglomeration and dispersion forces on spatial equilibrium of economic activities. Second, the RHOMOLO model shows that a thorough modelling of the spatial interactions between agents can prevent the system from reaching corner solutions in spatial equilibrium. Finally, our results advocate more research to be devoted to the uniqueness and stability of spatial equilibrium in empirically implemented new economic geography models with multiple asymmetric regions and multiple endogenous channels of adjustment.

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Appendix

Table 3: Simulation scenario construction: ECP expenditure on INF in 2014-2020 (Million Euro) and the estimated impact in regions' accessibility (percent).

Region	EUR	Tcost	Region	EUR	Tcost	Region	EUR	Tcost	Region	EUR	Tcost
AT11	0.7	1.664	DEC0	2.6	1.506	GR25	51.0	2.507	PT11*	359.6	9.045
AT12	3.9	1.751	DED1	49.0	2.810	GR30	232.1	6.683	PT15	17.9	1.655
AT13	2.1	1.773	DED2	53.4	2.930	GR41	17.7	1.675	PT16*	210.3	5.820
AT21	1.1	1.552	DED3	26.8	2.236	GR42	16.2	1.659	PT17	111.5	3.668
AT22	2.0	1.641	DEE0	57.2	2.964	GR43	55.5	2.464	PT18*	53.2	2.418
AT31	1.7	1.612	DEF0	6.7	1.622	HU10	161.0	5.602	PT20*	31.4	1.587
AT32	0.7	1.549	DEG0	50.1	2.765	HU21*	148.1	5.301	PT30	30.7	1.638
AT33	1.9	1.536	DK01	1.9	1.470	HU22*	124.4	4.693	RO11*	126.0	4.119
AT34	0.6	1.493	DK02	1.6	1.452	HU23*	156.2	5.331	RO12*	114.1	3.782
BE10	1.3	1.455	DK03	1.6	1.478	HU31*	217.0	6.873	RO21*	199.6	5.538
BE21	2.2	1.480	DK04	1.5	1.454	HU32*	269.7	8.046	RO22*	139.4	4.220
BE22	2.9	1.490	DK05	0.7	1.420	HU33*	224.5	6.947	RO31*	160.0	4.711
BE23	1.1	1.431	EE00*	221.9	6.196	IE01	15.3	1.333	RO32	52.1	2.507
BE24	0.5	1.425	ES11	176.3	5.122	IE02	9.1	1.226	RO41*	114.5	3.801
BE25	1.6	1.434	ES12	25.7	1.905	ITC1	32.0	2.174	RO42*	79.8	3.120
BE31	0.8	1.452	ES13	8.6	1.529	ITC2	1.0	1.460	SE11	1.3	1.198
BE32	7.3	1.583	ES21	22.7	1.860	ITC3	10.0	1.644	SE12	2.6	1.215
BE33	3.5	1.512	ES22	4.9	1.457	ITC4	22.0	1.951	SE21	3.5	1.229
BE34	1.1	1.461	ES23	2.6	1.411	ITD1	2.8	1.548	SE22	2.4	1.261
BE35	1.5	1.461	ES24	24.5	1.886	ITD2	1.3	1.505	SE23	2.4	1.240
BG31*	65.6	2.943	ES30	28.4	1.971	ITD3	22.9	2.016	SE31	8.8	1.299
BG32*	64.9	2.904	ES41	55.4	2.557	ITD4	6.9	1.651	SE32	7.8	1.245
BG33*	65.3	2.895	ES42	45.0	2.308	ITD5	8.4	1.627	SE33	10.5	1.251
BG34*	73.5	3.050	ES43*	106.2	3.640	ITE1	27.4	2.045	SI01*	93.2	3.700
BG41*	84.0	3.322	ES51	78.3	3.105	ITE2	9.0	1.647	SI02	68.8	3.110
BG42*	105.9	3.781	ES52	105.5	3.645	ITE3	10.3	1.664	SK01	35.1	2.569
CY00	23.7	1.673	ES53	7.6	1.452	ITE4	41.4	2.353	SK02*	285.3	8.708
CZ01	69.1	3.737	ES61	407.3	9.936	ITF1	7.5	1.594	SK03*	267.9	8.227
CZ02*	137.0	5.381	ES62	57.2	2.580	ITF2	3.0	1.493	SK04*	356.8	10.222
CZ03*	150.9	5.436	ES63	1.9	1.335	ITF3*	339.7	9.023	UKC1	5.1	1.465
CZ04*	160.0	5.703	ES64	3.1	1.291	ITF4*	223.4	6.389	UKC2	6.5	1.492
CZ05*	203.2	6.780	ES70	122.8	3.272	ITF5*	30.3	2.113	UKD1	1.0	1.356
CZ06*	193.7	6.507	FI13	6.8	1.234	ITF6*	97.7	3.520	UKD2	1.4	1.394
CZ07*	176.8	6.152	FI18	5.2	1.252	ITG1*	297.5	7.782	UKD3	7.9	1.555
CZ08*	167.3	5.989	FI19	6.2	1.240	ITG2	33.3	2.054	UKD4	4.2	1.451
DE11	1.0	1.486	FI1A	7.0	1.200	LT00*	396.5	10.233	UKD5	4.8	1.474
DE12	0.9	1.460	FI20	0.1	1.126	LU00	1.2	1.199	UKE1	1.6	1.398
DE13	1.0	1.458	FR10	3.8	1.227	LV00*	278.9	7.445	UKE2	0.6	1.369
DE14	0.6	1.473	FR21	9.1	1.370	MT00	47.1	1.907	UKE3	2.2	1.418
DE21	4.2	1.591	FR22	11.2	1.403	NL11	1.2	1.464	UKE4	4.7	1.472
DE22	2.2	1.596	FR23	14.4	1.454	NL12	1.7	1.469	UKF1	0.7	1.386
DE23	2.1	1.592	FR24	5.6	1.254	NL13	1.3	1.479	UKF2	0.7	1.396
DE24	2.0	1.571	FR25	7.3	1.294	NL21	2.8	1.529	UKF3	0.5	1.382
DE25	2.6	1.569	FR26	10.9	1.390	NL22	4.0	1.536	UKG1	1.8	1.415
DE26	1.8	1.526	FR30	38.5	2.025	NL23	1.4	1.478	UKG2	4.1	1.468
DE27	3.5	1.557	FR41	16.8	1.555	NL31	0.9	1.469	UKG3	9.8	1.622
DE30	11.5	1.876	FR42	3.6	1.283	NL32	1.9	1.462	UKH1	2.8	1.454
DE41	29.6	2.252	FR43	4.9	1.290	NL33	3.3	1.492	UKH2	1.0	1.416
DE42	7.2	1.724	FR51	14.0	1.404	NL34	0.3	1.414	UKH3	2.7	1.465
DE50	1.0	1.496	FR52	18.9	1.482	NL41	2.9	1.491	UKI1	3.0	1.473
DE60	0.2	1.506	FR53	14.4	1.422	NL42	1.9	1.485	UKI2	4.0	1.502
DE71	2.7	1.523	FR61	21.7	1.555	PL11*	335.4	9.783	UKJ1	0.2	1.394
DE72	0.8	1.485	FR62	25.7	1.627	PL12	344.7	9.832	UKJ2	0.6	1.413
DE73	1.0	1.504	FR63	5.1	1.246	PL21*	447.6	12.453	UKJ3	0.6	1.402
DE80	50.4	2.705	FR71	19.8	1.556	PL22*	526.3	14.553	UKJ4	0.7	1.430
DE91	7.0	1.658	FR72	6.3	1.280	PL31*	351.4	9.849	UKK1	1.7	1.420
DE92	8.6	1.679	FR81	28.9	1.711	PL32*	352.5	9.955	UKK2	1.4	1.405
DE93	13.9	1.808	FR82	16.6	1.476	PL33*	189.0	6.273	UKK3*	16.3	1.737
DE94	6.9	1.595	FR83	2.6	1.166	PL34*	188.4	6.046	UKK4	2.9	1.425
DEA1	8.7	1.636	GR11*	77.9	3.148	PL41*	408.2	11.563	UKL1*	44.6	2.418
DEA2	4.8	1.541	GR12*	219.4	6.325	PL42*	221.1	6.947	UKL2	3.7	1.449
DEA3	3.1	1.508	GR13	14.9	1.770	PL43*	139.0	5.059	UKM2	4.6	1.419
DEA4	2.1	1.507	GR14*	80.2	3.210	PL51*	323.7	9.698	UKM3	15.2	1.667
DEA5	6.9	1.602	GR21*	47.2	2.464	PL52*	142.9	5.331	UKM5	0.8	1.310
DEB1	1.2	1.462	GR22	23.2	1.892	PL61*	283.7	8.456	UKM6	2.8	1.317
DEB2	0.5	1.438	GR23*	93.3	3.449	PL62*	219.8	6.780	UKN0	11.1	1.535
DEB3	1.7	1.481	GR24	24.8	1.956	PL63*	281.9	8.233			

Source: Authors' estimates based on the European Commission (2014) data. Notes: Aggregate Cohesion Policy expenditure on INF for the entire 2014-2020 period in Million EUR, Tcost: estimated reduction in transportation costs (weighted across all regions) in percent. * indicates Less Developed Regions.