Modelling Agglomeration and Dispersion in RHOMOLO

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Abstract

The dynamic 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.

Keywords: New economic geography, endogenous location, agglomeration, dispersion, general equilibrium, economic modelling.

JEL code: C63, C68, D58, F1, F12, H41, O1, O31, O40, R13, R3, R4.

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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) (see for example 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).\footnote{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
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.

First, as for the assumption *ubiquitous agents*, in RHOMOLO v.1 a consumption (re-
spectively, 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.

Second, 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 tech-
nological 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 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 v.2 model

The domestic economy (which corresponds to the EU) consists of $R - 1$ regions $r, q = 1, \ldots, R - 1$, which are included into $M$ countries $m = 1, \ldots, M$, plus one region accounting for the rest of the world, $R$. Each region is inhabited by $H_r$ households which can be mobile across, determining the size of regional markets. The income of households consists of labour revenue (wages), capital revenue and government transfers. It is used to consume final goods, pay taxes and save.

The final goods sector in the EU includes $s = 1, \ldots, S - 1$ different economic sectors in which $N_{s,r}$ firms operate under monopolistic competition à la Dixit and Stiglitz (1977). 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 EU firm produces imperfectly substitutable varieties of goods (which coincides with a sectors) that are 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 $N_{s,r}$ is large enough so that strategic interactions between firms are ruled out. The number of firms in each region is either set exogenously or endogenised to influence the spatial distribution of economic activity.

Trade between (and within) regions is costly, implying that the shipping 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 $q$ (see Krugman, 1991, for instance). Transport costs are assumed to be sector- and region-pair-specific. They are related to the distance separating regions $r$ and $q$ but can also depend on other factors, such as transport infrastructure or national borders. Note that transport costs can be asymmetric (i.e. the cost of shipping a good $s$ from region $r$ to $q$ $\tau_{s,r,q}$ may differ from the cost of sending it back, $\tau_{s,q,r}$). They 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.

Finally, in each country there is a public sector which levies taxes on consumption and on the income of local 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

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3See Brandsma et al. (2013) for a formal description of the model.
4Labour 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. (2014b).
production of R&D and innovation, and influences the capacity of the educational system to produce human capital with public consumption.

The detailed regional dimension and inter-regional flows of RHOMOLO imply that the number of (non-linear) equations to be solved simultaneously is relatively high. Therefore, in order to keep the model manageable from a computation point of view, its dynamics are kept relatively simple. Three types of factors (physical capital, human capital and knowledge capital) as well as three types of assets (equities, domestic government bonds and foreign bonds) are accumulated over time. 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, i.e. a sequence of short-run equilibria that are related to each other through the build-up of physical and human capital stocks.

RHOMOLO contains several endogenous agglomeration and dispersion forces affecting the location choices of firms (see Brandsma et al., 2013, for a formal description of endogenous location in RHOMOLO). Three mechanisms drive the 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 located in markets with many consumers or next to them can make higher profits by avoiding high transport costs, thus benefitting large/central 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 having many competitors not facing high transport costs in the market has a negative impact on the market shares of firms, for a given level of income and total consumption, thus creating the incentives for firms to locate in peripheral regions with few competitors.

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. 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). 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 1 and Figure 1, 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 (2007), and numerical values for behavioural parameters.

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

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

The base year (2007) data are compiled in the form of an inter-regional Social Accounting Matrix (SAM) (see Potters et al., 2014, for details). For the construction of all EU27 countries’ SAMs, the recently published data of the EU funded World Input Output Database (WIOD) project 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

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5 In the model also the regional unemployment rates enter the migration problem of workers.
6 Croatian regions have not been introduced yet for lack of data at the regional level in the model calibration years.
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 the six macro-sectors used in RHOMOLO. The aggregated SAMs are constructed at the national level – based on the Supply and Use tables, and regionalised by taking into account constraints, such as, regional data on value added, employment and other regional and sectoral information from EUROSTAT.

Figure 1: 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 in RHOMOLO as net changes in the regional labour force (see Brandsma et al., 2014b, for details). The net aggregate relocation of workers between any two regions is a function of 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. Together with data on regional/sector unemployment and wages – micro-estimated based on EUROSTAT’s labour force survey – this information provided the necessary input to the analysis of labour market and migration features in RHOMOLO model.

Inter-regional trade flows are estimated using inter-regional transport-based data from the Thissen et al. (2013). This data is brought in line with the available macro-constraints: the distribution of production and consumption over the EU regions and the national SAMs to ensure consistency with the rest of RHOMOLO’s data. For the construction of regional production and consumption constraints, data from the fully consistent regional SAMs were taken. Inter-regional trade costs come from the TRANSTOOLS database, which add up to the country level trade flows from the COMEXT international trade statistics.

3.3. Data for inter-temporal variables

Knowledge capital enters RHOMOLO through region-sector-specific R&D intensities (innovation expenditures, normalised by GDP), which are available at the national and 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 (note that these do not correspond to the six sectors in RHOMOLO). Given the sectoral aggregation adopted in RHOMOLO (see Table 1), most of these 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.\footnote{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.}

The regional stock of human capital is approximated in RHOMOLO by 3 different levels of education: low skill (ised0\_2), medium-skill (ised3\_4), and high skill (ised5\_6). Wages are differentiated on basis of the education levels in order to internalise the investment decision of the households on the amount of education to be invested in each period. Data
for this come from the Labour Force Survey (LFS) and the EU KLEMS database. The wage rate enters the relevant equations as income deciles.

The regional stock of physical capital data are 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. 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 by industry in 2007 by adding the yearly capital investments and depreciating the existing stock every year. For implementing this approach we used the following data: gross fixed capital formation on NUTS 2 level and by sector in current prices for the years 1995-2007; 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 and regionalised by the GVA share; depreciation rates are calculated by weighing the average service life of each of the six types of assets for each country, using the EAS95 classification.

3.4. Model parameters

In order to parameterise the RHOMOLO model, most of the underlying structural parameters are estimated econometrically, others, in particular the behavioural parameters, are drawn from the literature (Okagawa and Ban, 2008). The remaining part of RHOMOLO parameters is calibrated within the model.

All key structural parameters in RHOMOLO are estimated econometrically. In particular, 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., 2014b; Persyn et al., 2014). Second, all parameters related to the elasticities of substitution both on consumer and producer sides are taken from the literature. 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 micro-data.

Finally, as usual in CGE models, all shift and share parameters are calibrated to reproduce the base year (2007) 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. Among others, the sensitivity analysis allows us to establish confidence intervals (in addition to the simulated point estimates) for RHOMOLO’s simulation results.
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.\footnote{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 in the form of equity, $FC_{i,s,r}$, is needed to set up firms. This is financed by households’ savings, which are free to be allocated to any EU region (the extent of these flows can be drawn directly from the Social Accounting Matrices, SAMs). 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 move of an agent unintentionally affects the welfare of all other agents through pecuniary externalities.

In RHOMOLO v.2 localised externalities enter through the stock of public capital, $K^G_r$, 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).\(^9\)

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 its relative accessibility and the economic size of the region. This can be seen by combining the consumption and profit equations:

\[
\pi_{i,s,r} = \frac{p_{i,s,r}}{\beta_s} \left[ \left( \frac{1}{\tau_{s,r,q} p_{i,s,r}} \right)^{\frac{1}{\sigma - 1}} \left( P_{q}^c \right)^{\sigma - 1} I_q \right] \cdot \left( \frac{P_{c} q}{P_{u} i,s,r} \right) \cdot \frac{1}{\beta_s} \left( \frac{P_{c} q}{P_{u} i,s,r} \right) \cdot \frac{1}{\beta_s} \left( \frac{P_{c} q}{P_{u} i,s,r} \right)
\]

\[(1)\]

where \(\pi_{i,s,r}\) is profit of firm \(i\) located in region \(r\) operating in sector \(s\), \(P_{c}^c\) and \(P_{u}^u\) 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 \(r\), \(\beta_s\) 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 \(q\), \(\sigma\) is the elasticity of substitution between varieties, \(P_{i,s,r}^g\) 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

\(^9\)Externalities are also modelled through technological spillovers, \(D_{m}^\phi\). As noted in section 2, the production of ideas requires only the use of high skill labour as a remunerated input, \(L_{RD,D,m}^h\), but this input is augmented by the available stock of knowledge, \(D_{m}^\phi\), in country \(m\). Given that these spillovers operate at the national level, strictly taken, they are not localised externalities.
Leontief 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, $\pi_{isr}$, is increasing with lower trade costs, $\tau_{r,q}$, and with elasticity of substitution, $\sigma$. 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, $\pi_{isr}$.

**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:

\[
P_c^q = \left( \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_{s,r}} \beta_s^q (\tau_{s,r,q} p_{i,s,r})^{1-\sigma} \right)^{\frac{1}{1-\sigma}}
\]

**Consumer price index**

\[
P_{usr}^q = \left( \sum_{q=1}^{Q} \sum_{j=1}^{u} \beta^q \left( \tau_{r,q} p_{j,u,q} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}
\]

**Intermediate input price index**

where $P_c^q$ and $P_{usr}^q$ 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 $r$, $\beta_s$ 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 $\sigma$ 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 transportation 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. 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

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10 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.
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, $\sigma$, 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, $\sigma$.

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. As firms set up in large/central regions, competition between firms intensifies. 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):

$$X_{C_{h,q}}^C = \left( \sum_{r=1}^{R} \sum_{s=1}^{S} \beta_s \sum_{i=1}^{N_{s,r}} \left( x_{i,s,r}^{i,s,r} \right)^{\theta} \right)^{\frac{1}{\theta}}$$

where $x_{i,s,r}^{i,s,r}$ is the demand of variety $i$ of sector $s$ produced in regions $r$ from household $h$ located in region $q$, $\beta_s$ 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, $X_{C_{h,q}}^C$, 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.¹¹ 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 2 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).

According to the second column in Table 2 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 2 shows the estimated accessibility improvements, the distribution of which is similar to the pattern of ECP expenditures on transport infrastructure.¹² We expect that agglomeration mechanisms will be more pronounced in the Less Developed Regions, where the trade cost reductions are the largest.

¹¹Note 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.
¹²The methodology is illustrated in detail in Brandsma et al. (2014a).
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 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 2, which shows percentage changes of GDP compared to the baseline.

Comparing the left map with the right map in Figure 2, 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. 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

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13See Brandsma et al. (2014b) for a detailed description of labour migration in RHOMOLO.
is difference between the incoming and outgoing migration, or

$$\sum_{o} L_o \cdot s_{or} - \sum_{d} L_r \cdot s_{rd}$$  \hspace{1cm} (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 3, which maps percentage changes in regions’ GDP compared to the baseline.

![Figure 3: 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.](image)

The simulation results reported in Figure 3 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 3, we can see that light-coloured 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 a given nominal wage in regions with improved accessibility more attractive (in real terms) than the same wage 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 implies that firms in regions with improved accessibility would have the tendency to pay a lower nominal wage in order to break even, while the opposite takes place in other regions. For a given cost-of-living, the market crowding effect makes regions with improved accessibility less attractive to workers.

The simulation results reported in Figure 3 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 addition 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.

On the other hand, an increase in the wage level (if not offset by an increase in immigration of labour force) implies higher labour costs (market crowding effect), which lies at the heart of many debates regarding the deindustrialisation of developed countries. In such a context, firms from regions with improved accessibility may be induced to relocate their activities to other regions, where lower wages more than offset lower demand.

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 4, which shows percentage changes of GDP compared to the baseline.

Similar to capital mobility, 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 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 dynamic spatial general equilibrium model with endogenous location. Allowing households and investments 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 a consistent capital market and the flexibility in terms of the choice of asset ownership scheme in particular 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 can 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 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 limitations, a general problem of the CGE approach is that almost all model data is used for calibration, whereas very little data is left for testing the model. Hence, a promising area for future research is to estimate dynamic spatial general equilibrium models instead of calibrating them. In particular, the estimation and testing of large dynamic spatial general equilibrium models, such as RHOMOLO, is still an open issue 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 careful 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. In this context, a particularly promising avenue for future research is saddle path stability and local properties around the steady state.

References


Table 2: Simulation scenario construction: ECP expenditure on INF in 2014-2020 (Million Euro) and the estimated impact in regions’ accessibility (percent).

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<th>Tcost</th>
<th>Region</th>
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Abstract

The dynamic 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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