Rhomolo: A Dynamic Spatial General Equilibrium Model for Assessing the Impact of Cohesion Policy

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The paper presents the newly developed dynamic spatial general equilibrium model of European Commission - RHOMOLO, in which the interplay of agglomeration and dispersion forces can be analysed in a novel and theoretically consistent way. A particular attention is paid to flows of goods, factors and services within and between regions that are generated by the stimulus to the regions. This will allow an assessment of the feedback to the Member States and regions and the possibility that in the longer run they will all benefit from the additional growth that is generated. In doing so, it sheds new light on how the success of cohesion policy can be measured.

Keywords: Economic modelling, spatial dynamics, policy impact assessment, regional development, economic geography, spatial equilibrium, DSGE.

JEL code: C63, C68, D58, F12, H41, O31, O40, R13, R30, R40.
1. Introduction

1.1. Why developing a new model?

For years, the Directorate General for Regional and Urban Policy of the European Commission (DG REGIO) had used economic models for analysing the impact of cohesion policy programmes. In particular, DG REGIO extensively relied on two models for the simulation of scenarios related to cohesion policy: HERMIN and QUEST III. HERMIN was initially developed by an external company in the 1980’s and has been regularly upgraded since then (Bradley et al., 2003). QUEST III is the model developed and used by Directorate General for Economic and Financial Affairs (DG ECFIN) (Varga and in ’t Veld, 2011). It is a model adopting the most recent practices in economic modelling, which is notably reflected in its high level of micro-foundations.

However, given that both these models produce results at the national level, it was felt that DG REGIO should extend its analytical capacities to also cover the regional level. After an in-depth literature review, it appeared that none of the existing models could fully respond to the need of DG REGIO which hence decided to develop its own regional model.

The objective was to build a dynamic spatial general equilibrium model that would allow for analysing the impact of cohesion policy at the NUTS 2 level, i.e. the most relevant geographical level for the policy. In order to cover the needs of DG REGIO, the model had to include several features. In particular, since cohesion policy mostly supports investments aiming at fostering economic growth in EU regions, the model should be well suited to capture the impact of the policy the main engines of endogenous growth. At the same time, it should account for local specificities which may affect the dynamics of the regional economies (factor endowment, local geography, etc.). Second, the model should incorporate regional linkages in the line of New Economic Geography and be capable of simulating the impact of policy shocks on the spatial equilibrium. This implies that model incorporated various agglomeration and dispersion forces as well as other possible sources of spatial spill-over and interdependencies.

In practice, a prototype model was first elaborated by a private consultant (TNO) contracted by DG REGIO. The prototype was then passed on to DG REGIO and DG JRC which closely collaborated for developing the dynamic spatial general equilibrium model for EU-27 and tested its robustness by running several simulations of various policy scenarios.

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1 In some cases, NUTS 2 regions are relatively small (like for instance in Eastern Germany Länder) and the NUTS1 level was then considered as more appropriate.

2 See Ivanova and Kancs (2010) for a formal description of the prototype model.
related to cohesion policy. The model has been named RHOMOLO for Regional HOlistic MOdeL.

1.2. Main features of RHOMOLO

The economy consists of \( R \) regions \( r = 1, \ldots, R \), which are included into \( M \) countries \( m = 1, \ldots, M \). Each region is inhabited by \( H_r \) households which are immobile in the short run, but mobile between regions in the long run. The income of households consists in labour (wages) and capital (profits and rents) revenues, and is spent to consume goods produced in \( R \) regions of \( M \) economies and in the rest of the world, to pay taxes and save.

Each region contains \( s = 1, \ldots, S \) different economic sectors producing \( i = 1, \ldots, N \) goods which are either sold to households or to the other sectors which use them either as intermediate goods or as investment goods. In each sector, firms operate under monopolistic competition à la Dixit and Stiglitz (1977) and produce a differentiated variety which is considered as an imperfect substitute to the other by households and firms. The number of firms, \( N_{s,r} \), in sector \( s \) and in region \( r \) is large enough such that none of them can exercise market power.

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 \( \tau_{s,r,q} \geq 1 \) 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 \( s \). Transport costs are assumed to be identical across varieties but specific to sectors and trading partners. 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. Finally, transport costs can be asymmetric (i.e. \( \tau_{s,r,q} \) may differ from \( \tau_{s,q,r} \)). 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.

In their production process, firms use a specialised input, denoted by \( Z \), which is produced by a specific sector whose structure is also monopolistic competition. Each variety of the specialised input represents a singular process produced by the R&D sector from which the corresponding licence must be bought.

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. Finally, in each country there is a public sector which levies taxes on the income of local households, firms and production factors. It provides public goods in form of public capital which is necessary for the operation of firms.
RHOMOLO is solved in a recursively dynamic framework. Because of the detailed regional and sectoral dimensions of RHOMOLO, computationally, it would be impossible to implement full dynamics, as it would exponentially increase the number of non-linear equations, which need to be solved simultaneously (the number of equations in the static model times the number of time periods). The recursive dynamic (sequential dynamic) framework contains a series of static models that are linked between periods by an exogenous and endogenous variable updating procedure, and are solved sequentially one period after other. Three types of factors (physical capital, human capital and knowledge capital) are accumulated endogenously between periods, according to the respective laws of motion. The formulation of the latter follows the semi-endogenous growth framework of Jones (1995). It is possible to add updating mechanisms for other variables, such as public expenditure, transfers, technological change or debt accumulation. As in all recursive dynamic models with myopic expectations, RHOMOLO assumes that the behaviour of inter-temporally optimising agents depends only on the current and past states of the economy, but not the result of inter-temporal optimisation of economic agents.

The model several various agglomeration and dispersion forces affecting the location choices of firms. These includes backward (firms prefer to have good access to output markets) and forward linkages (firms prefer to have good access to input markets) as well as consumer-driven mechanisms. Dispersion forces relate to competition on the goods market as well as competition for the local labour, part of which is assumed to be immobile.

Given that the endogenous growth and location features make the model very complex, the present paper aims at presenting the theoretical specifications underlying RHOMOLO in order to document and clarify the main assumptions and micro-founded mechanisms it contains.

2. Households

2.1. Consumption

In each period the households make decisions about consumption, savings and labour supply in order to maximise their utility subject to budget constraint. The utility function is assumed to be additively separable in consumption and leisure:

\[ \Gamma \left( U(C_{h,q}); \sum_{e=lo,me,hi} V(1 - l^h,q_e) \right) = U(C_{h,q}) + \sum_{e=lo,me,hi} V(1 - l^h,q_e) \]
where the total endowment of time = 1, and \( l^{h,q} \) is labour of household \( h \) in region \( q \) with skills \( e \) (\( e = lo, me, hi \) denote low-, medium- and high-skilled component respectively).

Households consume \( N_s \) differentiated goods from \( S \) sectors. Relative preferences for the respective sectors are represented by weight \( \beta_s \) with \( \sum_{s=1}^{N_s} \beta_s = 1 \). Each household has thus not only to decide about the total level of consumption but also about the composition of the consumption bundle, which consists of \( S \) goods and \( N \) varieties produced in \( R \) regions.

We assume a CES utility function,\(^3\) implying that consumer \( h \) located in region \( q \) has the following consumption related utility:

\[
U(C_{h,q}^{i,s,r}) = \left( \sum_{r=1}^{R} \sum_{s=1}^{S} \beta^s \left( \sum_{i=1}^{N_{s,r}} (C_{h,q}^{i,s,r})^\theta \right)^{\frac{1}{\theta}} \right)
\]

The representative household chooses a consumption bundle in order to maximise utility subject to the budget constraint:

\[
\sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_{s,r}} \tau_{s,r,q} p_{i,s,r} (1 - t_{s,r}) C_{h,q}^{i,s,r} = I_{c}^{h,q},
\]

where \( p_{i,s,r} \) is the price of consumption good \( i \) produced in sector \( s \) and in region \( r \), \( I_{c}^{h,q} \) is the disposable income household \( h \) located in region \( q \) spends on consumption, \( \tau_{s,r,q} \) is trade cost between \( r \) and \( q \), and \( t_{s,r} \) is tax rate on activity \( s \) in region \( r \).\(^4\)

The rest of the world is modelled as a particular region, with index \( r = R \), and a particular sector (indexed by \( S \)). Sector \( S \) differs from EU sectors in that it only has one variety which is exclusively produced in region \( R \). The price of this variety is assumed to be exogenous to the EU economy. Formally, we have \( N_{S,r} = 0 \) and \( N_{s,R} = 0 \) for all \( r \) and \( s \); \( N_{S,R} = 1 \) and \( p_{S,R} = \bar{p}_{S,R} \). We also assume that foreign households have the same type of preference regarding domestic goods and that the share of their disposable income devoted to the consumption of domestic goods is fixed.

The associated Lagrangian is:

\[
L = \left( \sum_{r=1}^{R} \sum_{s=1}^{S} \beta^s \sum_{i=1}^{N_{s,r}} (C_{h,q}^{i,s,r})^\theta \right)^{\frac{1}{\theta}} + \lambda \left( I_{c}^{h,q} - \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_{s,r}} \tau_{s,r,q} p_{i,s,r} (1 - t_{s,r}) C_{h,q}^{i,s,r} \right).
\]

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\(^3\)The model as coded incorporates a nested CES utility function to allow for different elasticities of substitution between varieties of a given sector on the one hand and sectors on the other hand. This feature is not introduced here to simplify notations.

\(^4\)Note that \( \tau_{s,r,q} p_{i,s,r} = p_{i,s,q} \), where \( p_{i,s,q} \) is consumer price.
The first order condition is given by:

\[
\frac{\partial U(C_{h,q})}{\partial C_{i,s,r}^{h,q}} - \lambda \tau_{s,r,q} p_{i,s,r} (1 - t_{s,r}) = 0
\]

for all \(i, s, r\). After rearranging terms and substituting in the budget constraint, the optimal consumption of good \(C_{i,s,r}^{h,q}\) is given by:

\[
C_{i,s,r}^{h,q} = \left( \beta_s \frac{I_{h,q}^c}{p_{i,s,r} \tau_{s,r,q}} \right)^{\frac{1}{\sigma}} \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_s} \frac{1}{\beta_s} \left( (1 - t_{s,r}) \tau_{s,r,q} \right)^{1 - \sigma}
\]

where \(\sigma = 1/(1 - \theta)\). Note that \(I_{h,q}^c\) is in nominal terms, while \(C_{i,s,r}^{h,q}\) is in real terms.

When introducing the consumption price index for region \(q\):

\[
P_{c,q} = \left( \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_s} \beta_s \left( (1 - t_{s,r}) \tau_{s,r,q} \right)^{1 - \sigma} \right)^{\frac{1}{1 - \sigma}}
\]

equation (2) can be rewritten as

\[
C_{i,s,r}^{h,q} = \left( \frac{1}{P_{c,q}} \frac{p_{i,s,r} (1 - t_{s,r}) \tau_{s,r,q}}{I_{h,q}^c} \right)^{-\sigma} \frac{I_{h,q}^c}{P_{c,q}^{1 - \sigma}}
\]

According to (4), the optimal amount of good \(C_{i,s,r}^{h,q}\) can be represented as a fraction of the total amount of income spent on consumption \(I_{h,q}^c\). This fraction obviously decreases in the price of that good and the related transport cost, and increases with the relative weight \(\beta_s\) and the overall price index level.

The budget constraint of household \(h\) in region \(q\) can then be written as:

\[
P_q C_{h,q} + S_{h,q} = I_{h,q},
\]

stating that total consumption and savings equal total income \(I_{h,q}\).

We assume that a constant fraction \(s\) of total disposable income is saved, i.e. \(I_{h,q}^c = (1 - s)I_{h,q}\). The total consumption in nominal terms can then be written as:

\[
P_q C_{h,q} = (1 - s)I_{h,q},
\]

where \(C_{h,q} = \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_s} C_{i,s,r}^{h,q}\), i.e. the aggregated consumption level of household \(h\). 

located in region \( q \).

Total disposable income \( I_{h,q} \) of household \( h \) located in region \( q \) is the sum of labour and capital income and government transfers after taxes:

\[
I_{h,q} = \sum_{e} w_{z,q}^{h,e,q} (1 - t_w) + (1 - t_\pi) KI + \frac{TR_{H,m}}{\sum_{r=1}^{R_m} H_r},
\]

where \( w_{e,q} \) is the wage paid in region \( q \) to the skill level \( e \), \( KI \) is capital income, and \( TR_{H,m} \) denote transfers to households in country \( m \).

Disposable income of foreign households is considered as given. Also, the price index relevant for foreign consumers, \( P^C_R \) is assumed to be independent both from domestic prices and from domestic transport costs. This implies that, while domestic prices and the structure of transport costs determine how exports from the rest of the world are distributed across regions and sectors, total export is exogenous to the model.

When aggregating individual consumption \( C_{i,s,r}^{h,q} \) over all households \( H_q \) within region \( q \) and over all regions \( R \) we obtain the total demand for consumption of good \( i \) from sector \( s \).

\[
\sum_{r=1}^{R} \sum_{q=1}^{R} \sum_{h=1}^{H_q} C_{i,s,r}^{h,q} = C^{i,s}.
\]  

2.2. Labour supply

Each household supplies a differentiated variety of labour which contains a low, medium and high skilled component. Hence, each household has to decide which fraction of its time endowment will be devoted respectively to work and to leisure.

As noted above, the utility of households is assumed to be additively separable in consumption \( C_{h,q} \) and leisure \( 1 - l^{h,q}_e \). Preferences related to consumption are represented as a CES utility function of goods from all varieties, sectors and regions as given by (1). When rewriting (1) in terms of individual aggregated consumption \( C_{h,q} \) we obtain that \( U(C_{h,q}) = C_{h,q} \). The sub-utility with respect to leisure takes a CES form with a standard labour supply elasticity and a skill specific weight \( \omega_e \) on leisure in order to capture differences in employment levels across skill groups. So we have

\[
\sum_e V(1 - l^{h,q}_e) = \sum_e \frac{\omega_e}{1 - \kappa} (1 - l^{h,q}_e)^{1-\kappa}.
\]
The associated Lagrangian is

\[ L = C_{h,q} + \sum_e V(1 - t^h,q) + \lambda \left( P^c_q C_{h,q} - (1 - s) \sum_e w^q_e l^h,q_e (1 - t_w) + (1 - t_\pi) K I + \frac{TR_{H,m}}{\sum_{r=1}^{R_m} H_r} \right) \]

After deriving the first order conditions with respect to \( C_{h,q} \), \( 1 - l^h,q_e \) and \( \lambda \), and after rearranging terms we obtain the following expression for the optimal labour supply across skill groups:

\[ l^h,q_e = 1 - \frac{\omega_e P^c_q}{(1 - s) w^q_e} \tag{6} \]

Aggregating per skill group at the regional level we obtain:

\[ \sum_{h=1}^{H_q} l^h,q_e = H_q \left( 1 - \frac{\omega_e P^c_q}{(1 - s) w^q_e} \right) \tag{7} \]

Labour markets are characterised by monopolistic competition. Each worker/household sets its wage as a mark-up over the reservation wage (i.e. the marginal utility of leisure divided by the marginal utility of consumption) and the wage equation is given by equation (6). The employment level on market \( r \) is then given by total demand addressed to each skill group at the prevailing wage.

As unemployment decisions are not considered in the current version of RHOMOLO, the workers taking up the newly created jobs are either former non-participants, or new migrants into the region (Pissarides and Wadsworth 1989). Writing ‘ for the growth rate of a variable, the underlying labour market accounting rule implies that

\[ L'_{e,q} = \left( \frac{L_{e,q}}{H_{e,q}} \right)' + H'_{e,q} \tag{8} \]

such that the growth of employment, \( L'_{e,q} \), must equal the sum of the growth of the employment rate, \( (L_{e,q}/H_{e,q})' \), and the growth of the labour force, \( H'_{e,q} \), which occurs through

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5The code version of the model currently includes an inelastic short run labour supply curve. In the long run, however, labour supply reacts to changes in real wages through labour migration. The elastic version of the short run labour supply curve as presented in this paper will soon be introduced in the codes.

6In the next version of RHOMOLO (currently under development) both unemployment and participation will be present.
a combination of exogenous demographic changes, and endogenous migration (see Brandsma et al. (2013) for details). Inter-regional labour migration is an important channel of adjustment to macroeconomic and policy shocks. The population change in region \( r \) with labour force \( H_r \) due to migration is difference between the incoming and outgoing migration:

\[
\sum_r H_{e,r} \cdot s_{e,r,q} - \sum_q H_{e,q} \cdot s_{e,q,r}
\]  

where \( s_{e,r,q} \) and \( s_{e,q,r} \) are the shares of migrants in the total population in regions \( r \) and \( q \), respectively.\(^7\)

3. Firms

3.1. Final demand goods

The production function of a monopolistically competitive firm producing variety \( i \) of final demand good \( s \) located in region \( r \) is of the Leontieff type. The arguments are the quantities of intermediate goods bought from all sectors and a Cobb-Douglas aggregate of all inputs used in the production process, i.e. labour and a specialised input:

\[
X_{i,s,r} = \min\{y_{i,s,r}, a_s^1 X_{i,s,r}^1, a_u^u X_{i,s,r}^u, a_s^S X_{i,s,r}^S\}
\]  

where \( X_{i,s,r} \) is the quantity produced, \( y_{i,s,r} \) is firm \( i \)'s value added, \( X_{i,s,r}^u \) is the intermediate input from sector \( u \) and \( a_u^u \) the associated technical coefficient, assumed to be common to all firms in sector \( s \) independently of their location. Variable \( X_{i,s,r}^u \) is a CES aggregate of varieties produced in sector \( u \):

\[
X_{i,s,r}^u = \left( \sum_q \sum_{j=1}^{N_{u,q}} x_{i,s,r}^{u,j,q} \right)^{\frac{1}{\theta}} \quad \text{for } 0 < \theta < 1.
\]

Value added is a Cobb-Douglas aggregate of the two factors used in the production process:\(^8\)

\[
y_{i,s,r} = Z_{i,s,r}^\alpha L_{i,s,r}^{1-\alpha} K_{r}^{\alpha_G} - FC_r
\]  

\(^7\)See Brandsma et al. (2013) for a more detailed description of labour migration in RHOMOLO.

\(^8\)The model as coded currently assumes a Leontieff technology to describe value added. This will soon be changed to align with the specification adopted in this paper.
where \( Z_{i,s,r} \) and \( L_{i,s,r} \) are CES aggregates of the varieties of specialised inputs and of the various types of labour –low-, medium- and high-skilled– used by the firm.\(^9\) We write \( KG_r \) for the stock of public capital available in region \( r \) which is assumed to be positively related to total factor productivity.\(^10\) Finally, \( FC_r \) is a fixed cost made of some of the firm’s output.

Specialised inputs and labour are assumed to be non-tradable which implies that firms in regions \( r \) can only obtain those two factors on the local market. The respective CES indices then read

\[
Z_{i,s,r} = \left( \sum_{k=1}^{A_r} z_{k,i,s,r}^{\rho} \right)^{\frac{1}{\rho}}
\]

\[
L_{i,s,r} = \left( \sum_{e=lo,me,hi} \gamma_e \sum_{h=1}^{J_r} \phi_{h,e}^{\sigma} \right)^{\frac{1}{\sigma}}
\]

where \( \rho, \sigma \in (0, 1) \). Factor \( \gamma_e \) accounts for difference in labour productivity between low, medium and skilled labour, with \( \gamma_{lo} < \gamma_{me} < \gamma_{hi} \).

Profit maximisation leads the firm to set the output price as a mark-up over marginal cost, where the mark-up depends on the elasticity of the total demand it faces which. This includes demand from consumers as well as demand from other firms either for intermediate goods or for investment goods. Given our assumptions concerning the utility function and the CES aggregates of intermediate inputs and of physical capital (see below), the elasticity of total demand is \( 1/(\theta - 1) \) and the price-making rule is

\[
p_{i,s,r} (1 - t_{s,r}) = \frac{MC_{i,s,r}}{\theta}
\]

The marginal cost includes the cost of production factors and the cost of intermediate inputs:

\[
MC_{i,s,r} = P^y_{i,s,r} + \sum_{u=1}^{S} a_u \cdot P^n_{i,s,r}
\]

where \( P^y_{i,s,r} \) is the price of value added. Given the specification adopted for valued added,

\(^9\) The firm uses effective units of labour which includes both physical units of labour and the associated human capital.

\(^10\) Note that according to this specification, each firm can benefit from the whole stock of public capital available in the region where it is located. This reflects the public good nature of public capital and in particular that it is non-rivalrous. We also assume it is non-excludable in that its use by firms does not incur direct payment but only indirect ones (the provision of public capital is financed by taxes) which are not internalised by the firm.
\( P_{y,i,s,r} \) is common to all firms in sector \( s \) and region \( r \) and corresponds to a Cobb-Douglas of the factors’ price:

\[
P_{y,i,s,r} = KG^{-\alpha_G} \cdot \left( \frac{P_{Z,i,s,r}}{\alpha_s} \right)^{\alpha_s} \cdot \left( \frac{W_{i,s,r}}{1 - \alpha_s} \right)^{1-\alpha_s}
\]

\( P_{u,i,s,r} \), \( P_{Z,i,s,r} \) and \( W_{i,s,r} \) are the price indices corresponding to the CES aggregates of respectively of intermediate inputs, specialised inputs and labour varieties:

\[
P_{u,i,s,r} = \left( \sum_{q=1}^{R} \sum_{j=1}^{N_{u,q}} \left(p_{j,u,q} (1 - t_{s,r}) \cdot \tau_{u,q,r} \right)^{\frac{\alpha_s}{\sigma}} \right)^{\frac{\sigma - 1}{\sigma}}
\]

\[
P_{Z,i,s,r} = \left( \sum_{k=1}^{A_r} \left( p_{k,r} \right)^{\frac{\alpha_s}{\sigma}} \right)^{\frac{\sigma - 1}{\sigma}}
\]

\[
W_{i,s,r} = \left( \sum_{e=lo,me,hi} \gamma_{e} \frac{1}{\sigma} \sum_{h=1}^{J_r} w_{h,r,e} \right)^{\frac{1}{\sigma}}
\]

where \( p_{j,u,q} \) is the price set by firm \((j, u, q)\), \( p_{k,r} \) is the price of variety \((k, r)\) of the specialised input and \( w_{h,r,e} \) is the wage of household \((h, r)\) for his labour service of skill \( e \). We assume symmetry across firms (resp. households) in terms of the technology (resp. preferences) which implies that the price (resp. wage) set by each firm (resp. household) within one given region is the same. Accordingly, one easily verifies that \( P_{u,i,s,r} = P_{u,r} \) for all \((i, s)\), \( P_{Z,i,s,r} = P_{Z,r} \) for all \((i, s)\), \( W_{i,s,r} = W_{r} \) for all \((i, s)\), and \( P_{y,i,s,r} = P_{y,s,r} \) for all \( i \). Note that we also assume that specialised inputs are not subject to transport costs (i.e. \( \tau_{Z,r,r} = 1 \)).

The demand of the firm for each variety of intermediate input, specialised input and labour then take, respectively, the following form:

\[
x_{j,u,q}^{i,s,r} = \left( \frac{p_{j,u,q} (1 - t_{s,r}) \tau_{u,q,r}}{P_{r}} \right)^{\frac{1}{\sigma - 1}} X_{i,s,r}^u
\]

\[
x_{k,r}^{i,s,r} = \left( \frac{p_{k,r}}{P_{r}^{Z}} \right)^{\frac{1}{\sigma - 1}} Z_{i,s,r}
\]

\[
x_{h,e}^{i,s,r} = \left( \frac{w_{h,r,e}}{\gamma_{e} W_{r}} \right)^{\frac{1}{\sigma - 1}} L_{i,s,r}
\]

3.2. R&D sector

There are \( M \) national R&D sectors which produce new designs \( \Delta D_m \) using all varieties of skilled labour available on the national labour market. The production process features
learning by doing, as labour productivity is positively related to the pre-existing stock of designs. Finally, there are international technological spill-over in the sense that the national R&D sector absorbs part of the technology produced within the $M$ countries. The production function of the R&D sector of country $m$ reads

$$\Delta D_m = (D^*)^\omega \cdot D_m^\phi \cdot (L^h_{R&D,m})^\epsilon$$

where $D^*$ is the stock of design in the $M$ economies and $L^h_{R&D,m}$ is a CES aggregate of the national skilled labour varieties

$$L^h_{R&D,m} = \left( \sum_{r=1}^{Rm} \sum_{h=1}^{Jr} \left( \frac{D_{h,r}}{L^h_{R&D}} \right)^{\sigma} \right)^{\frac{1}{\sigma}}$$

Perfect competition prevails on each national market for designs and firms maximise profits by choosing the level of new designs and the corresponding quantity of skilled labour employed in each variety:

$$\Delta D_m = \left( \frac{\epsilon}{\Xi} \cdot \frac{P_{D,m}}{W_{R&D,m}} \right)^{\frac{1}{1-\epsilon}}$$

where $\Xi = ((D^*)^{-\omega}D_m^{-\phi})^{1/\epsilon}$, $P_{D,m}$ is the price of new designs, and $W_{R&D,m}$ is the CES wage index for the R&D sector:

$$W_{R&D,m} = \left( \sum_{r=1}^{Rm} \sum_{h=1}^{Jr} w_{h,r} \frac{\epsilon}{\sigma} \right)^{\frac{\sigma-1}{\sigma}}.$$  

Note that given the constant return to scale technology of the R&D sector, the average cost corresponds to the marginal cost and there is no profit at equilibrium. However, licences generate a rent which is supposed to be distributed to the skilled labour employed in the R&D sector.

3.3. Specialised input sector

In order to start operating, representative firm $v$ in the specialised input sector of region $r$ must acquire one design and transform it into a new production process. The firm can only obtain designs from its national R&D sector by buying a licence which must be renewed each period. It must also support a fixed cost denoted by $FC_{v,r}$. The firm operates under
monopolistic competition and produces one variety of specialised input using physical capital:

\[ z_{v,r} = K_{v,r} \]  

(19)

Capital is financed by selling assets \( a_{v,r} \) on the \( M \) national financial markets, which implies that \( a_{v,r} = P^k_r K_{v,r} \), with \( P^k_r \) being the price of physical capital. Asset \( a_{v,r} \) yields a gross return \( r^k_{v,r} P^k_r \) which corresponds to the rental price for one unit of capital. We assume capital to depreciate at rate \( \delta \).

Each unit of capital is a CES aggregate of varieties of goods bought in all regions:

\[ K_{v,r} = \left( \sum_{q=1}^{R} \sum_{s=1}^{S} \beta_s^\theta \sum_{i=1}^{N_{s,q}} \left( k_{i,s,q}^{v,r} \right)^\theta \right)^{\frac{1}{\theta}} \]  

(20)

This corresponds to the CES aggregate representing preferences of consumers which implies that price of capital is equal to the consumer price index, i.e. \( P^k_r = P^C_r \). Importantly, note that the price of capital is region-specific. This reflects the fact that varieties constituting physical capital must partly be imported. Given the existence of transport cost, this means that physical capital is more costly in small/peripheral regions.

Transforming designs into an effective new production process is uncertain. We assume the probability to succeed in using a new design \( \phi \) depends on some regional characteristics, namely the existing stock of processes which also corresponds to the number of specialised input firms \( A_r \) and the stock of human capital \( h_{hi} \):

\[ \phi_r = \left( \frac{A_r}{\sum_{r=1}^{R_m} A_r} \right)^\nu \left( \frac{H_r}{\sum_{r=1}^{R_m} H_r} \right)^{1-\nu}. \]  

(21)

The regional stock of human capital is defined as the number of effective units of high skilled labour available in region \( r \), i.e \( h_{hi} = \sum_{h=1}^{H_r} h_{hi} f_{hi,r} \).

The expected profit of the specialised input firm then reads:

\[ \pi_{v,r} = \phi_r \cdot \left[ p^r_{v,r} z_{v,r} - r^k_{v,r} P^C_r K_{v,r} - P_{D,m} - FC_{v,r} \right] \]  

(22)

Profit maximisation under the constraint (19) leads the specialised input firm to address
the following demand for each variety of good:

\[ k_{i,s,q}^{v,r} = \left( \frac{P_{i,s,q} \cdot \tau_{s,q,r}}{\beta_s \cdot P^C_r} \right)^{\frac{1}{\sigma+1}} K_{v,r} \]  

(23)

The firm also sets its price as a mark-up over marginal cost with

\[ p_{v,r} = \frac{MC_{v,r}}{\theta} \]  

(24)

where \( MC_{v,r} = r_{v,r}^k P^C_r \). This implies that production of the specialised input firm and hence its demand for capital depends negatively on the rental price of capital and positively on the demand addressed to the firm (accelerator mechanism). Investment corresponds to the variation in the stock of capital net of depreciation:

\[ I_{v,r} = \Delta K_{v,r} - \delta K_{v,r} \]

It is financed by the issuance of new assets; i.e. \( P^C_r \cdot I_{v,r} = \Delta a_{v,r} \).

4. Public sector

4.1. Government

We assume a multi-level governance framework where the national government interacts with the EU level. The expenditure of the national government consists in consumption of goods and services \( GC_m \), transfers to households \( TR_{H,m} \) and government investment \( GI_m \). These components of government expenditure are all assumed to be fixed at exogenous levels, they can serve as variables for modelling policy shocks.

Let \( G_m \) denote the sum of government consumption and investment. We assume government consumption and investment to be distributed among the regions of country \( m \) according to the shares of the population:

\[ G_q = \frac{J_q}{J_m} \cdot G_m \]

where \( G_{q,m} \) corresponds to public consumption and investment taking place in region \( q \) (assumed to be in country \( m \)).

Analogously to households and firms, the regional governments have CES preference
defined over the set of varieties produced in the domestic economy and abroad. We have:

$$G_q = \left( \sum_{r=1}^{R} \sum_{s=1}^{S} \beta_s \sum_{i=1}^{N_{s,r}} (c_{i,s,r}^q)^\theta \right)^{\frac{1}{\theta}}$$

The demand addressed by the public sector of region $q$ to firm $i,s,r$ is then:

$$c_{i,s,r}^q = \left( \frac{\frac{1}{\beta_s} p_{i,s,r} \tau_{r,q} P_{c}^q}{P_{c}^q} \right)^{-\sigma} G_q$$

The government contributes to the EU budget and in particular to cohesion policy funding $COH$ proportionally to its weight in the EU GDP:

$$TR_{EU,m} = \frac{GDP_m}{GDP} \cdot COH$$

where $GDP_m = \sum_{r=1}^{R_m} \sum_{s=1}^{S_m} \sum_{i=1}^{N_{s,r}} y_{i,s,r}$ and $GDP = \sum_m GDP_m$.

The government levies taxes on consumption, production as well as on capital and labour income which constitutes its revenues:

$$T_m = t_C \sum_{r=1}^{R_m} P_r^C \cdot C_r + t_{i,s,r} \cdot X_{i,s,r} + t_W \left( \sum_{r=1}^{R_m} \sum_{\epsilon=l_o,m,e} \sum_{h=1}^{J_r} w_{h,\epsilon,r} \cdot l_{h,r,\epsilon} \right)$$

$$+ \left( t_{\pi} \sum_{r=1}^{R_m} \left\{ \sum_{s} \sum_{i=1}^{N_{s,r}} \pi_{i,s,r} + \sum_{v=1}^{A_r} A_r \pi_{v,r} \right\} \right)$$

where $\pi_{i,s,r}$ and $\pi_{v,r}$ are the profits of the representative firms producing respectively a variety of goods and specialised inputs.

The public deficit in country $m$ is the difference between government expenditures, including interests on the outstanding debt, and revenues:

$$PD_m = \sum_{q=1}^{R_m} P_q^c \cdot G_q + TR_{H,m} + TR_{EU,m} + Sub_m - T_m$$

where $Sub_m$ are government subsidies which reduce the fixed cost of specialised input firms.
4.2. Modelling policy intervention

In order to model the European Cohesion Policy (ECP) interventions, we regroup the different ECP expenditure categories into 4 (5) broader groups of policy instruments (see Table 1). R&D related policy measures are modelled either as a reduction of fixed costs in R&D sector, $Sub_m$, or as a reduction of physical capital’s transport costs, $\tau^k_{rq}$. Policy instruments aimed at increasing human capital are modelled either as an education investment in skill-specific human capital, $h_e$, or as a reduction of skill-specific labour taxes, $t^l_{er}$. Transport infrastructure investments are modelled as a reduction of trade costs, $\tau_{rq}$. Other infrastructure investments are implemented in RHOMOLO as an increase of the stock of public capital, $KG_r$. Those ECP policy measure affecting particular industries or services are modelled either as a reduction of output taxes (increase of output subsidies), $t^y_{rs}$, or as a reduction of capital taxes, $t^k_{rs}$. The latter measures would increase the stock of capital in the subsidised industries.

<table>
<thead>
<tr>
<th>Field</th>
<th>Implementation in Rhomolo</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD</td>
<td>Reduction of fixed costs in specialised input sector</td>
<td>$Sub_m$</td>
</tr>
<tr>
<td></td>
<td>Reduction of physical capital’s transport costs</td>
<td>$\tau^k_{rq}$</td>
</tr>
<tr>
<td>Human resources</td>
<td>Education investment in skill-specific human capital</td>
<td>$h_e (\Lambda_e)$</td>
</tr>
<tr>
<td></td>
<td>Reduction of skill-specific labour taxes</td>
<td>$t^l_{er}$</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Reduction of trade costs</td>
<td>$\tau_{rq}$</td>
</tr>
<tr>
<td></td>
<td>Increase of the stock of public capital</td>
<td>$KG_r$</td>
</tr>
<tr>
<td>Industry and services</td>
<td>Reduction of output taxes (increase of subsidies)</td>
<td>$t^y_{rs}$</td>
</tr>
<tr>
<td></td>
<td>Reduction of capital taxes</td>
<td>$t^k_{rs}$</td>
</tr>
</tbody>
</table>

Notes: The presented policy interventions are illustrative. Many more policy instruments and their combinations can be implemented in RHOMOLO. Category 'Technical Assistance' is not considered currently.

In order to translate particular policy measures into model variables, we make use of complementary models at the European Commission, or employ estimates from the literature. For example, in order to simulate the TEN-T investments in transport infrastructure, we run two models (TRANSTOOLS and RHOMOLO) and use the output of the former as input in the latter. In the first step, the improvements in the transport network due to transport infrastructure investments are simulated in the transport model (TRANSTOOLS), where the units of measurement are kilometres of new infrastructure, number of additional lanes, maximum speed, etc. In the second step, the changes (improvements) in the accessibility
(market access) of regions are simulated in the economic model (RHOMOLO), where the units of measurement are relative prices, wages, employment, GDP, etc.

In addition to supply-side effects listed in Table 1, the ECP interventions have also demand-side effects. Both the demand and supply side effects together with the induced general equilibrium effects determine the net policy impact and hence all are important for policy incidence. The demand-side effects are implemented as additional government expenditure of final demand and investments goods. The government expenditure shares of different sectors are the same as in the base year.

5. Market equilibrium and closure rules

5.1. Goods, input and innovation markets

All households and all firms within a given sector are assumed to be symmetric, which implies that, in a specific regions r, wages and quantities consumed are identical for all households while prices and quantities produced are identical for all firms.

The firm producing variety i of good s in region r faces demand from four types of agents: households (domestic and foreign) $D_{H}^{i,s,r}$, other firms producing goods $D_{F}^{i,s,r}$, firms producing specialised inputs $D_{K}^{i,s,r}$ and the domestic public sector $D_{G}^{i,s,r}$:

\[
D_{H}^{i,s,r} = \sum_{q=1}^{R} J_{q} \cdot c_{h,q}^{i,s,r}
\]

\[
D_{F}^{i,s,r} = \sum_{u=1}^{S} \sum_{q=1}^{R} (J_{u,q} \cdot x_{j,u,q})^{i,s,r}
\]

\[
D_{K}^{i,s,r} = \sum_{q=1}^{R} (A_{q} \cdot k_{v,q})^{i,s,r}
\]

\[
D_{G}^{i,s,r} = \sum_{q=1}^{R} -1c_{G,q}^{i,s,r}
\]

where $c_{h,q}^{i,s,r}$, $x_{j,u,q}^{i,s,r}$ and $k_{v,q}^{i,s,r}$ are respectively given by equations (4), (16) and (23). The four components of the total demand feature the same price elasticity and the firm sets its price, $p_{i,s,r}$, according to the rule given by equation (12), thereby equating demand and supply:

\[
X_{i,s,r} = D_{H}^{i,s,r} + D_{F}^{i,s,r} + D_{K}^{i,s,r} + D_{G}^{i,s,r}
\]
GDP of region \( r \) then corresponds to \( \sum_{s=1}^{S} N_{s,r} \cdot P_{y}^{i,s,r} \cdot y_{i,s,r} = \sum_{s=1}^{S} N_{s,r} \cdot \frac{P_{y}}{y_{i,s,r}} \cdot X_{i,s,r} \), where \( X_{i,s,r} = D_{i,s,r}^{C} + D_{i,s,r}^{F} + D_{i,s,r}^{K} \).

On the market for specialised inputs of region \( r \), the representative firm \( v \) faces the following demand:

\[
D_{v,r}^{F} = \sum_{u=1}^{S} N_{s,r} \cdot z_{v,s,r}^{u}
\]

where \( z_{v,s,r}^{u} \) is specified by equation (17). The price setting rule (24) ensures that supply equals demand so that

\[
z_{v,r} = D_{v,r}^{F}
\]

Finally, the demand for new designs addressed to the R&D sector corresponds to the number of new firms entering the marker for specialised input \( \sum_{r=1}^{R} \Delta N_{r}^{z} \). The number of entrants, \( \Delta N_{r}^{z} \), depends on the price of new design, \( P_{D,m} \), so that at equilibrium \( \Delta D_{r}^{m} = \Delta N_{r}^{z} \).

5.2. Financial markets

We select a saving driven closure rule where private saving is determined as a constant fraction of households’ income (see above). At equilibrium, (i) private saving must finance private investment, the public deficit and the deficit of the trade balance; and (ii) returns on the three types of assets held by households must be equal. Finally, we assume that financial markets are fully integrated at the level of the \( m \) countries.

Private investment in region \( r \) is the sum of investment of firms of the specialised input sector: \( I_{r} = \sum_{r=1}^{A_{r}} P_{r}^{C} \cdot I_{v,r} = A_{r} \cdot P_{r}^{C} \cdot I_{v,r} \).

The trade balance deficit of each country \( (TB_{m}) \) corresponds to the value of its exports minus the value of its imports, \( TB_{m} = X_{m} - M_{m} \) where:

\[
X_{m} = \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_{s,r}} p_{i,s,r} \cdot \left( c_{R}^{i,s,r} \right)^{i,s,r} \quad (25)
\]
\[
M_{m} = \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_{s,r}} p_{R,R} \cdot \left( \tau_{R,R} \cdot c_{h,r} \right)^{R,R} \quad (26)
\]

The trade balance of the domestic economy then corresponds to the sum of the national trade balances with respect to the rest of the world:

\[
TB = \sum_{m=1}^{M} TB_{m} = 0
\]
We therefore have

\[ \sum_{r=1}^{R} \sum_{h=1}^{H_r} S_{h,r} = \sum_{r=1}^{R} A_r P_r^C \cdot I_r + \sum_{m=1}^{M} P D_m. \]

Finally, arbitrage on the financial markets equalises net returns on financial assets. The net return for holding capital in firm \( v, r \) is \( (r^k_{v,r} - \delta)P_r^C + (1 - \delta)\Delta P_r^C \). Firms are symmetric and hence \( r^k_{v,r} = r^k_r \) for all \( v \). Letting \( r_{G,m} \) denote the return on government bonds of country \( m \) and \( r_F \) the return on foreign bonds, the arbitrage condition is

\[ (r^k_r - \delta)P_r^C + (1 - \delta)\Delta P_r^C = r_{G,m} = r_F \]

for all \( m \) and for all \( r \). Note that the required gross return for physical capital \( r^k_r P_r^C \) is higher in regions where the price of capital \( P_r^C \) is high. This reflects the fact that depreciation incurs a higher financial loss when the resources needed to acquire capital are more important, which is for instance the case in remote regions.

6. Location and spatial equilibrium

6.1. Agglomeration and dispersion forces

In order to model the location of economic agents endogenously, two agglomeration forces (increasing returns to scale and localised externalities), and two dispersion forces (trade costs and imperfect competition) are introduced in RHOMOLO.\(^{11}\)

Both consumers and producers face positive trade costs for importing final demand goods and intermediate inputs, respectively. On the consumer side, trade costs enter the consumer price index (3). On the producer side, trade costs enter the intermediate goods price index (13). As usual, inter-regional trade costs, \( \tau_{rq} \), are modelled as iceberg costs of trade. However, departing from the new economic geography literature, the bilateral trade costs between regions are not symmetric, the internal trade costs are positive, and the inter-regional trade costs come from the data, instead of being calibrated or proxied by distance.

Increasing returns to scale are introduced via fixed costs, \( FC_r \), in firm production functions (11) and (22). Following Venables (1996), they are made of part of the firms output. Fixed costs are measured in quantity terms, and firms pay them at the beginning of each period (before starting to produce market output). In contrast to the iceberg trade costs, fixed costs,

\(^{11}\)See Kancs (2013) for a detailed description of agglomeration and dispersion forces and mechanisms in RHOMOLO.
Localised externalities enter RHOMOLO through the stock of public capital, $KG_p$, in the value added production function (11), technological spillovers, $D_{m}^{\phi}$, and probability to succeed in transforming designs into a new production process, $\phi_r$, which depends on the existing stock of processes, $A_r$, and the stock of human capital, $h_{hi}$, in region $r$ (equation 21). Localised externalities are region-specific, and 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).

Imperfect competition is modelled in the monopolistic competition framework of Dixit–Stiglitz. First, we assume that each firm produces a differentiated product (variety), which is an imperfect substitute for other products. In the same time, we assume that the real or perceived non-price differences are not large 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 (equation 28).

6.2. Spatial equilibrium

In the short run, pure profit may exist. However, in the long run, this will trigger the entry of new firms on the market which will decrease the demand addressed to each firm and hence reduce the level of profit. This process takes place until pure profits are completely exhausted. The profit of firm $i, s, r$ reads

$$\pi_{i,s,r} = p_{i,s,r} (1 - t_{i,s,r}) \cdot X_{i,s,r} - P_{i,s,r}^{y} \cdot y_{i,s,r} - \sum_{u=1}^{S} P_{u}^{y} \cdot X_{u,i,s,r}^{u} - P_{i,s,r}^{y} \cdot FC_{r}^{r}$$

$$= p_{i,s,r} (1 - t_{i,s,r}) \cdot X_{i,s,r} - P_{i,s,r}^{y} \cdot X_{i,s,r} - \sum_{u=1}^{S} a_{u}^{u-1} \cdot P_{r}^{u} \cdot X_{r,i,s,r} - P_{i,s,r}^{y} \cdot FC_{r}^{r}$$  \hspace{1cm} (27)

Pure profit is equal to zero when the price equals average cost, i.e.

$$0 = p_{i,s,r} (1 - t_{s,r}) - P_{i,s,r}^{y} - \sum_{u=1}^{S} a_{u}^{u-1} \cdot P_{r}^{u} - P_{i,s,r}^{y} \cdot FC_{r}/X_{i,s,r}$$  \hspace{1cm} (28)

The expressions describing total demand are relatively complicated but one can indeed show that it is a decreasing function of the number of firms. In the simple case where there is only one sector and one region, the demand addressed to the representative firm by consumers is $1/N \cdot I/p$ where $I$ is the income devoted to consumption

$$19$$
Using the price setting rule (12), one obtains the level of production corresponding to zero pure profit:

\[ X_{i,s,r}^* = \frac{P^y_{i,s,r} \cdot FC_r}{\frac{1-\theta}{\theta} \cdot \left[ P^y_{i,s,r} - \sum_{u=1}^{S} a^u_{i,s} \cdot P^u_r \right]} \]

The same mechanism applies to the specialised input sector. For a representative firm of the sector, pure profits are exhausted when demand is such that the price it sets is equal to average cost:

\[ p_{v,r} = r^k_{v,r} P^C_r + P_{D,m}/z_{v,r} + FC_{v,r}/z_{v,r} \]

By equation (24), the price is a mark-up over marginal cost which, combined to the expression above, gives the production level which annihilates pure profit:

\[ z_{v,r}^* = \frac{P_{D,m} + FC_{v,r}}{1-R} \cdot \left[ r^k_{v,r} P^C_r \right] \]

We then have a system of \(sxr\) equations of the type \(X_{i,s,r}^* = D_i^{s,r} + D_F^{i,s,r} + D_K^{i,s,r}\) plus \(r\) equations \(z_{v,r}^* = D_{v,r}^m\) with \(sxr + r\) unknowns corresponding to the long term number of firms in each sector and in each region, \(N_{s,r}^*\) and \(N_{r}^z\).

Transition to the long term number of firms is not immediate and is described by the following law of motion, which is assumed to be the same in every region and sector: \(\Delta N = \lambda \cdot (N - N^*)\). The change in the number of specialised firms also determines the demand for new designs addressed to the R\&D sector with:

\[ \Delta D_{m}^r = \Delta N_{r}^z \]

The number of firms in each region determines the spatial distribution of economic activity in model. It is fully endogenous and incorporates several agglomeration and dispersion forces.

6.3. Endogenous location effects

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 explains why firms in large/central regions tend to have higher profits 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.

There are two sources for higher profits 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 equations (4), (5) and (27), according to which the total demand, $C_{isr}$, for good $i$ in sector $s$ produced in region $r$, and hence profit, $\pi_{isr}$, is increasing with lower trade costs, $\tau_{rq}$, with elasticity $\sigma$. The weighted average trade costs can be lower either due to large internal market (because $\tau_{rr} < \tau_{rq} \forall rq$), 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. This can be seen by combining equations (10), (11) and (27), according to which, if everything else would stay constant (also fixed cost, $FC_r$), then an increase in output, $X_{isr}$, would reduce the share of fixed costs, $FC_r$, in average costs, and hence increase firm profits, $\pi_{isr}$.

The price index effect describes 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. Given that large/central regions with more firms 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 (3), and the intermediate input price index (13), respectively. Both price indices suggest that the total trade costs, $\sum_{r=1}^{R} \tau_{rq}$, and hence the cost of living and producing, respectively, would be lower in large/central regions. The regional price index decreases in trade costs with elasticity 1: reducing trade costs by one unit would reduce regional price by one unit. Because of lower costs of living/production, firms (purchasing intermediate inputs) and consumers (purchasing final goods) would prefer to locate in large/central regions.

The market crowding effect 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 gets fiercened there (market crowding effect). 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 profits decrease. Given that the entry of new firms has a negative effect on profitability of incumbents in large/central regions, this competition effect works against the tendency to agglomeration.

The competition effect on output markets can be seen in equation (2), according to which, the demand of output produced by firm $i$ in sector $s$ in region $r$ is decreasing in the number of firms selling their output in region $q$ with elasticity 1. For example, a 10% increase in the number of firms selling good $s$ in region $q$ would reduce demand for firm $i$’s output by
10%. Lower output, and hence profits, would induce firms to move away from large/central regions to small/peripheral regions with fewer competitors.

The competition effect on input markets works 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.

6.4. Mechanisms of agglomeration and dispersion

The model contains three endogenous location mechanisms that bring the agglomeration and dispersion about: the mobility of capital, the mobility of labour, and vertical linkages (see Table 2).

Table 2: Mechanisms and forces of agglomeration and dispersion in RHOMOLO

<table>
<thead>
<tr>
<th>mobility of capital</th>
<th>mobility of labour</th>
<th>vertical linkages</th>
</tr>
</thead>
<tbody>
<tr>
<td>market access effect</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>price index effect</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>market crowding effect</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>

Notes: ↑ denotes agglomeration, ↓ denotes dispersion.

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 its region of origin.

Following the mobile labour framework of Krugman (1991), in RHOMOLO, 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 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).13

Following the vertical linkage framework of Venables (1996), 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.

13In the model also the regional unemployment rates enter the migration problem of workers.
7. Conclusions

Cohesion policy shifts the spatial equilibrium at the regional level within the EU and the Member States by increasing the capacity for growth in the regions that are lagging behind and to some extent also by mobilising the unused capacity in other regions. It does so by supporting investments in the trans-European infrastructure networks connecting the regions as well as by stimulating measures fostering the development of human resources, research and innovation and, in general, improving the standard of living and attractiveness of the regions. Although the room for public funding and redistribution is limited by balanced budget requirements, the impact on the less developed regions can be very substantial if the forces of agglomeration and dispersion of economic activity, as they are laid out in the New Economic Geography literature, are taken into account.

This paper presents a spatial general equilibrium framework in which the interplay of agglomeration and dispersion forces, including the ones set in motion by cohesion policy can be analysed in a novel and theoretically consistent way, including the impact in the net contributing Member States. Particular attention is paid to income, migration flows and capital movements within and between regions that are generated by the stimulus to the regions. This will allow an assessment of the feedback to the Member States and regions and the possibility that in the longer run they will all benefit from the additional growth that is generated.

The paper carefully analyses the implications of different assumptions on capital and labour mobility within and between Member States on the spatial equilibrium in terms of income and employment. In doing so, it sheds new light on how the success of cohesion policy can be measured. A greater focus on unemployment and other indicators of structural deficiencies may be warranted, instead of on income per capita. The paper recognises the limitations of a comparative static approach and advocates further work and extensions of the model and its potential use in the direction of dynamics, in particular by incorporating the results of research on long-term productivity developments and migration between regions.

References


Abstract
The paper presents the newly developed dynamic spatial general equilibrium model of European Commission - RHOMOLO, in which the interplay of agglomeration and dispersion forces can be analysed in a novel and theoretically consistent way. A particular attention is paid to flows of goods, factors and services within and between regions that are generated by the stimulus to the regions. This will allow an assessment of the feedback to the Member States and regions and the possibility that in the longer run they will all benefit from the additional growth that is generated. In doing so, it sheds new light on how the success of cohesion policy can be measured.
As the Commission’s in-house science service, the Joint Research Centre’s mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.