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

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Regional Policy

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Abstract

The paper presents the newly developed dynamic spatial general equilibrium model of European Commission, RHOMOLO. The model incorporates several elements from economic geography in a novel and theoretically consistent way. It describes the location choice of different types of agents and captures the interplay between agglomeration and dispersion forces in determining the spatial equilibrium. The model is also dynamic as it allows for the accumulation of factors of production, human capital and technology. This makes RHOMOLO well suited for simulating policy scenario related to the EU cohesion policy and for the analysis of its impact on the regions and the Member States of the union.

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.

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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. HERMIN was initially developed by scholars in the 1980's and has been regularly upgraded since then (Bradley *et al.*, 2003). QUEST is the model developed and used by the Directorate General for Economic and Financial Affairs (DG ECFIN) (Varga and in 't Veld, 2011). It adopts the most recent practices in DSGE 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 which would be suited for analysing the impact of cohesion policy at the NUTS 2 level, i.e. the most relevant geographical level for the policy.[1] 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 on 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, accessibility, etc.).

Finally, 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. Accordingly, the model should incorporate various agglomeration and dispersion forces as well as other possible sources of spatial spill-over and interdependencies.

First, a prototype of the model was elaborated by a private consultant (TNO) contracted by DG REGIO.[2] The prototype was then passed on to DG REGIO and Directorate General Join Research Centre (DG JRC) which developed a dynamic spatial general equilibrium

[1]In some cases, NUTS 2 regions are relatively small (like for instance some German Länders) and the NUTS 1 level was then considered as more appropriate.

[2]See Ivanova and Kancs (2010) for a formal description of the prototype model.

model covering the EU-27 at NUTS 2 level. The model has been named RHOMOLO, standing for Regional HOlistic MOdeL.

1.2. Main features of RHOMOLO

The domestic economy consists of R_{-1} regions $r = 1, \ldots, R_{-1}$, which are included into M countries $m = 1, \ldots, M$. Each region is inhabited by H_r households which are immobile.[3] The income of households consists in labour revenue (wages), capital revenue and government transfers. It is used to consume final good, pay taxes and accumulate savings.

The final good sector includes $s = 1, \ldots, S$ different economic sectors in which firms operate under monopolistic competition à la Dixit and Stiglitz (1977). Each firm produces a differentiated variety which is considered as an imperfect substitute to the other by households and firms. The number of firms in sector s and region r is denoted by $N_{s,r}$. It is large enough so that strategic interactions between firms is negligible. Goods are either consumed by households or used by other firms as intermediate input or as investment good. The rest of the world is introduced in the model as a particular region (indexed by R) and particular sector (indexed by S). Sector S differs from domestic sectors in that it only has one variety which is exclusively produced in region R. Formally, we have $N_{S,r} = 0$ and $N_{s,R} = 0$ for all r and s; and $N_{S,R} = 1$.

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 for instance (Krugman, 1991)). 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, final good firms use a high-tech good aggregate, denoted by Z. High-tech good is produced by specific (high-tech) firms whose market structure is also monopolistic competition. Each variety of high-tech good represents a singular process produced by high-tech firms.

[3]Labour mobility can be introduced through a 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.* (2013).

The structure of the labour market is also monopolistic competition. 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. Changing wages is assumed to be costly which introduces nominal wage rigidity in the model.

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 production of R&D and innovation, and influences the capacity of the educational system to produce human capital.

The detailed regional and sectoral dimensions of RHOMOLO implies 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 is 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 between periods. R&D development follows the semi-endogenous growth framework of Jones (1995). Agents are assumed to save a constant fraction of their income each period and to 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 static sub-models that are linked between periods by the laws of motion determining the time path of some key stock variables.

The model includes several agglomeration and dispersion forces determining the location choice of firms. Those include 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 Marshallian technological spill-over. Dispersion forces relate to competition on the goods market as well as competition for local labour.

This paper aims at presenting the theoretical specifications underlying RHOMOLO in order to document and clarify the main assumptions and micro-founded mechanisms it contains. Section 2 details the behaviour of households while section 3 focuses on firms in the final good sector. It also describes how the interplay between the R&D and the high-tech sector leads to technological progress. Section 4 is devoted to the public sector and explains how policy interventions are introduced in the model. Section 5 lays down the conditions to clear the product, labour and financial markets and elaborates on the notion of spatial equilibrium in the model. Finally, section 7 concludes.

2. Households

Households make decisions about consumption, savings and labour supply (see Figure 1). Each household supplies a differentiated variety of labour which contains a low, medium and high skilled component. Let $e = lo, me, hi$ denote the low-, medium- and high-skilled component respectively. The preference of the representative household h in region q is represented by a utility function which is additively separable in consumption and leisure:

$$U\left(C_{h,q}; \sum_{e=lo,me,hi} V(1 - l_{h,e,q})\right) = C_{h,q} + \sum_{e=lo,me,hi} V(1 - l_{h,e,q})$$

where $C_{h,q}$ is the consumption of final good and $l_{h,e,q}$ is the labour of type e supplied by the household. We assume that the sub-utility with respect to leisure takes the form of a CES with a standard labour supply elasticity (κ) and a skill specific weight (ω_e) on leisure in order to capture differences in participation to the labour market between skill groups. We have

$$\sum_e V(1 - l_{h,e,q}) = \sum_e \frac{\omega_e}{1-\kappa} (1 - l_{h,e,q})^{1-\kappa}$$

The budget constraint of household h, q can be written as

$$P_q^c C_{h,q} = (1 - s)\, YC_{h,q} \tag{1}$$

where P_q^c is the price of final good in region q, $YC_{h,q}$ is disposable income and s is the constant saving rate which is common to all households.

Disposable income is the sum of labour and capital income plus government transfers net of taxes:

$$YC_{h,q} = \sum_e (1 - t_m^w)\, w_{h,e,q}\, l_{h,e,q} + (1 - t_m^\pi)\, KI_{h,q} + \frac{TR_{H,m}}{\sum_{r=1}^{R_m} H_r}$$

where $w_{h,e,q}$ is the wage paid in region q to the skill level e, $KI_{h,q}$ is capital income, and $TR_{H,m}$ denotes government transfers to households in country m.

Capital income corresponds to the returns linked to the holding of three different types of assets: equities (i.e. liability against the high-tech firms in the R_{-1} regions of the domestic economy), domestic bonds (i.e. liability against the M governments of the domestic economy) and foreign bonds (i.e. liability against the rest of the world). Let $B_{h,q}^{k,v,r}$, $B_{h,q}^{G,m}$, $B_{h,q}^{F}$ denote the stock of these assets held by the representative household respectively in firm v of region r, in government bonds of country m and in foreign bonds. The associated returns are respectively $r^k_{v,r}$, r^G_m, r^F. The holding of equities also gives right to a share of the high-tech firms profit. Finally, we assume that the firms in the final good sector are also owned by households who share their profits. Capital income then reads

$$KI_{h,q} = \sum_{r=1}^{R-1}\sum_{v=1}^{A_r} r^k_{v,r} B^{k,v,r}_{h,q} + \sum_{m=1}^{M} r^G_m B^{G,m}_{h,q} + r^F B^F_{h,q} + \sum_{r=1}^{R-1}\sum_{v=1}^{A_r} s^{k,v,r}_{h,q}\pi_{v,r} + \frac{1}{H}\pi^{FG} \tag{2}$$

where A_r is the number of high-tech firms in region r, $\pi_{v,r}$ is the profit of the high-tech firm v in region r, $H = \sum_{r=1}^{R-1} H_r$ is the domestic population and π^{FG} is the sum of profits of the final goods sector. $s^{k,v,r}_{h,q} = B^{k,v,r}_{h,q}/a_{v,r}$ is the share of total assets issued by firm v, r $(a_{v,r})$ held by the representative household. Except for H, these variables are endogenous and their determination is described in the next sections of the paper.

Finally, wages are subject to convex adjustment cost:

$$\Gamma_w(w_{h,e,q}) = \sum_e \frac{\gamma_w}{2} l_{h,e,q} \frac{\Delta w^2_{h,e,q}}{w_{h,e,q}}$$

The optimisation problem of the representative household is solved by maximising the associated Lagrangian

$$L = C_{h,q} + + \sum_e \frac{\omega_e}{1-\kappa}(1 - l_{h,e,q})^{1-\kappa} - \lambda\left(P^c_q C_{h,q} - (1-s)\, YC_{h,q} + \Gamma_w\right) \tag{3}$$

with respect to consumption, $C_{h,q}$, and labour supply, $l_{h,e,q}$.

2.1. Consumption

Maximisation of (3) with respect to $C_{h,q}$ implies that the aggregate consumption level is directly related to disposable income:

$$C_{h,q} = \frac{(1-s)\, YC_{h,q}}{P^c_q}$$

Households consume all varieties of final good available in the economy. In order to represent love for varieties, $C_{h,q}$ is assumed to be a CES index defined as

$$C_{h,q} = \left(\sum_{r=1}^{R}\sum_{s=1}^{S}\beta_s \sum_{i=1}^{N_{s,r}} \left(c^{i,s,r}_{h,q}\right)^{\theta}\right)^{\frac{1}{\theta}} \tag{4}$$

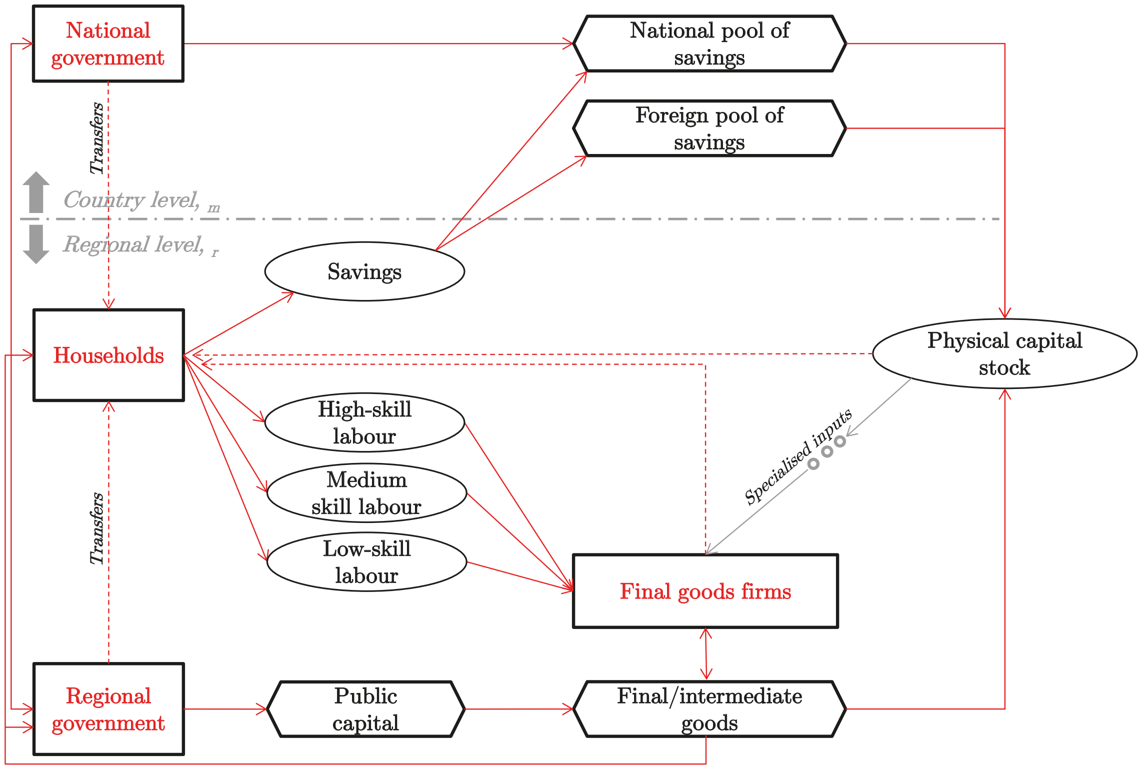

Figure 1: Households in the RHOMOLO model: labour supply, consumption and savings.

where $c_{h,q}^{i,s,r}$ is the consumption of variety i of sector s produced in regions r and β_s is the weight given to sector s in the household's preference.[4]

The representative household chooses a consumption bundle in order to maximise (4) subject to the following budget constraint:

$$\sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{i=1}^{N_{s,r}} \tau_{s,r,q}\left(1+t_{s,m}^{c}\right) p_{i,s,r}\, c_{h,q}^{i,s,r} = (1-s)\, YC_{h,q}$$

where $p_{i,s,r}$ is the price of variety i,s,r, $\tau_{s,r,q}$ is trade cost from region r to region q, and $t_{s,m}^{c}$ is the tax rate applied to consumption of sector s goods in country m (where region q is assumed to be located).

The price of variety S, R produced in the rest of the world is assumed to be exogenous to

[4]The model as coded incorporates a nested CES utility function to allow for different elasticicities 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.

the domestic economy, i.e. $p_{S,R} = \bar{p}_{S,R}$. 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.

Solving this problem leads to the following demand for variety i,s,r:

$$c_{h,q}^{i,s,r} = \left(\frac{\tau_{s,r,q} \left(1 + t_{s,m}^{c}\right) p_{i,s,r}}{\beta_s P_q^c} \right)^{\frac{1}{\theta-1}} \frac{(1-s) \, YC_{h,q}}{P_q^c} \tag{5}$$

where P_q^c is the following CES price index:

$$P_q^c = \left(\sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{i=1}^{N_{s,r}} \beta_s^{\frac{1}{1-\theta}} \left(\tau_{s,r,q} \left(1 + t_{s,m}^{c}\right) p_{i,s,r}\right)^{\frac{\theta}{\theta-1}} \right)^{\frac{\theta-1}{\theta}} \tag{6}$$

According to (5), demand for variety i, s, r is a fraction of real income spent on final good. This fraction decreases with the relative price of this variety, the relevant transport cost and tax rate, while it increases with relative preference for sector s.

2.2. Labour supply

Each household decides which fraction of its time endowment will be devoted to leisure on the one hand and to labour in each types of skill on the other hand. Labour markets are characterised by monopolistic competition where, within each skill group, labour supplied by a particular household corresponds to a variety which is an imperfect substitute to the others. Maximising (3) with respect to $l_{h,e,q}$, we obtain the following wage setting rule:

$$\omega_e \left(1 - l_{h,e,q}\right)^{-\kappa} \frac{1}{\eta} = \left(1 - t_m^w\right) \frac{w_{h,e,q}}{P_q^c} \tag{7}$$

with

$$\eta = \left[\sigma (1-s) - \frac{\gamma_w (\sigma - 1) \, \pi_{h,e,q}^w}{\left(1 - t_m^w\right)} \right]$$

The real wage is set as a mark-up, $\frac{1}{\eta}$, over the reservation wage (i.e. the marginal utility of leisure divided by the marginal utility of consumption). The mark-up depends on the elasticity of substitution between the different varieties of labour in the firms production function, σ (see below). Because adjusting wages is costly, the mark-up also depends on the level of wage inflation, $\pi_{h,e,q}^w = \Delta w_{h,e,q} / w_{h,e,q}$, which implies that wages only adjust slowly to variation in prices.

It is further assumed that the representative household accumulates skill specific human capital, $b_{h,e,q}$, according to

$$\Delta b_{h,e,q} = b_{h,e,q}(e^{\Lambda}_{h,e,q} - 1) - \delta_{HC}\, b_{h,e,q}, \tag{8}$$

allowing to offer $b_{h,e,q}$ efficiency units. Λ represents the amount of time a household spends on education while δ_{HC} is the depreciation rate for human capital.

3. Firms

3.1. Final good firms

Final good firms produce horizontally differentiated varieties of the final good (see Figure 2). The final good sector is characterised by monopolistic competition. It includes S sectors in which each firm produces a variety which is an imperfect substitute to the others. The production function of a representative firm producing variety i of sector s located in region r is of the Leontieff type. The arguments are the quantities of intermediate inputs bought from all sectors and a Cobb-Douglas aggregate of the factors used in the production process, i.e. labour and high-tech good:

$$X_{i,s,r} = \min\{y_{i,s,r}, a^1_s X^1_{i,s,r}, \ldots, a^u_s X^u_{i,s,r}, \ldots, a^S_s X^S_{i,s,r}\} \tag{9}$$

where $X_{i,s,r}$ is the quantity produced, $y_{i,s,r}$ is the firm's value added, $X^u_{i,s,r}$ is an index of the intermediate inputs from sector u and a^u_s the associated technical coefficient, assumed to be common to all firms in sector s in country m, independently of their location within the country. The index $X^u_{i,s,r}$ is a CES aggregate of varieties produced in sector u:

$$X^u_{i,s,r} = \left(\sum_{q=1}^{R} \sum_{j=1}^{N_{u,q}} \left(x^{j,u,q}_{i,s,r} \right)^{\theta} \right)^{\frac{1}{\theta}}$$

with $\theta \in (0,1)$.

The firm's value added is a Cobb-Douglas of the two factors used in the production process:

$$y_{i,s,r} = Z^{\alpha_s}_{i,s,r}\, L^{1-\alpha_s}_{i,s,r}\, KG^{\alpha_G}_r - FC_{i,s,r} \tag{10}$$

where $Z_{i,s,r}$ and $L_{i,s,r}$ are CES aggregates of the varieties of high-tech good and of the various types of labour –low-, medium- and high-skilled– used by the firm.[5] Let KG_r denote the stock of public capital available in region r which is assumed to affect positively total factor productivity.[6] The firm also supports a fixed cost, $FC_{i,s,r}$, made of some of the firm's value added. [7] Finally, it benefits from subsidies of the national government ($Sub_m^{i,s,r}$) and of the EU ($Sub_{EU}^{i,s,r}$).

High-tech good and labour are assumed to be spatially immobile which implies that firms in regions r can only obtain those two factors on the local market. The respective CES indices then read

$$\begin{aligned} Z_{i,s,r} &= \left(\sum_{v=1}^{A_r} (z_{i,s,r}^{v,r})^{\rho}\right)^{\frac{1}{\rho}} \\ L_{i,s,r} &= \left(\sum_{e=lo,me,hi} \sum_{h=1}^{H_r} (b_{h,e,r}\, l_{i,s,r}^{h,e,r})^{\sigma}\right)^{\frac{1}{\sigma}} \end{aligned}$$

where $\rho, \sigma \in (0,1)$. Factor γ_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. This includes demand from households, from other firms for intermediate inputs, from high-tech firms for investment goods and from the government. Given our assumptions concerning the preferences of these agents and the CES aggregates for intermediate inputs and for physical capital (see below), the elasticity of total demand is $1/(\theta - 1)$ and the price-making rule is

$$p_{i,s,r} = \frac{MC_{i,s,r}}{\theta} \tag{11}$$

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

[5]The firm uses effective units of labour which includes both physical units of labour and the associated human capital.

[6]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 pubic capital is financed by taxes) which are not internalised by the firm.

[7]The model also incorporates a fixed cost in terms of labour. It is not inlcuded here in order to simplify the presentation.

inputs:

$$MC_{i,s,r} = P^y_{i,s,r} + \sum_{u=1}^{S} a^u_s \cdot P^u_{i,s,r}$$

where $P^y_{i,s,r}$ is the price of value added. Given the specification adopted for valued added, $P^y_{i,s,r}$ is common to all firms in sector s and region r and corresponds to a Cobb-Douglas of the factors' price:

$$P^y_{i,s,r} = KG_r^{-\alpha_G} \cdot \left(\frac{P^z_{i,s,r}}{\alpha_s}\right)^{\alpha_s} \cdot \left(\frac{W_{i,s,r}}{1-\alpha_s}\right)^{1-\alpha_s}$$

$P^u_{i,sr}$, $P^z_{i,sr}$ and $W_{i,s,r}$ are the price indices corresponding to the CES aggregates respectively of intermediate inputs, high-tech good and labour varieties:

$$P^u_{i,s,r} = \left(\sum_{q=1}^{R}\sum_{j=1}^{N_{u,q}} (\tau_{u,q,r}\, p_{j,u,q})^{\frac{\theta}{\theta-1}}\right)^{\frac{\theta-1}{\theta}} \tag{12}$$

$$P^z_{i,s,r} = \left(\sum_{v=1}^{A_r} p^z_{v,r}{}^{\frac{\rho}{\rho-1}}\right)^{\frac{\rho-1}{\rho}} \tag{13}$$

$$W_{i,s,r} = \left(\sum_{e=lo,me,hi}\sum_{h=1}^{J_r} b_{h,e,r}^{\frac{\sigma}{1-\sigma}} w_{h,e,r}^{\frac{\sigma}{\sigma-1}}\right)^{\frac{\sigma-1}{\sigma}} \tag{14}$$

where $p_{j,u,q}$ is the price of variety j, u, q of the final good, $p^z_{v,r}$ is the price of variety v, r of the high-tech good 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 high-tech good is not subject to transport costs (i.e. $\tau_{Z,r,r} = 1$) and that consumption taxes do not apply to intermediate inputs.

The demand of the firm for each variety of intermediate input, high-tech goods and labour then take the following form, respectively:

$$x_{i,s,r}^{j,u,q} = \left(\frac{\tau_{u,q,r}\, p_{j,u,q}}{P_r^u} \right)^{\frac{1}{\theta-1}} X_{i,s,r}^u \tag{15}$$

$$z_{i,s,r}^{v,r} = \left(\frac{p_{v,r}}{P_r^z} \right)^{\frac{1}{\rho-1}} Z_{i,s,r} \tag{16}$$

$$l_{i,s,r}^{h,e,r} = \left(\frac{w_{h,e,r}}{b_{h,e,r}^{\sigma}\, W_r} \right)^{\frac{1}{\sigma-1}} L_{i,s,r} \tag{17}$$

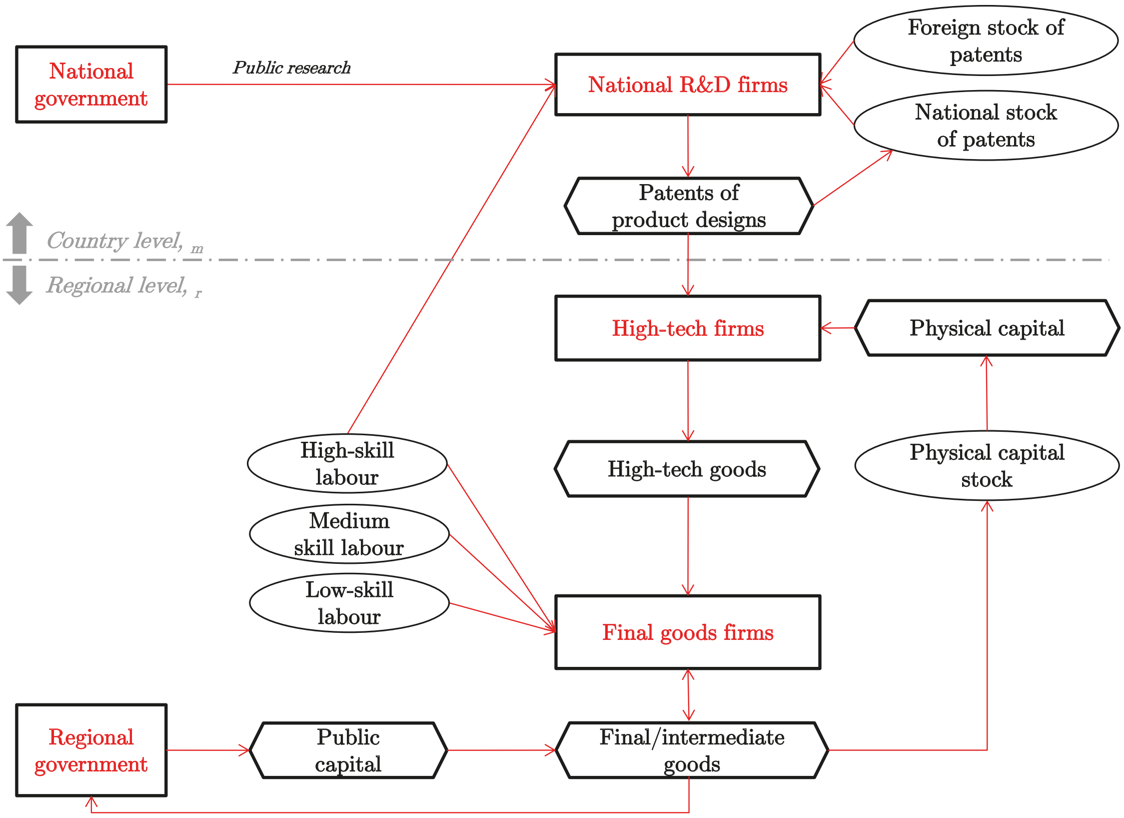

Figure 2: Firms and production structure in the RHOMOLO model: final good firms, national R&D firms and high-tech firms.

3.2. National R&D firms

There are M national R&D sectors which produce new designs ΔJ_m using all varieties of skilled labour available on the national labour market (see Figure 2). The production process features learning by doing, as labour productivity is positively related to the pre-existing stock of designs (patents). There are international technological spill-overs in the sense that the national R&D sector absorbs part of the technology produced within the M countries. Finally, the R&D sector is supported by the national government and the EU which provid subsidies, $Sub_m^{R\&D}$ and $Sub_{EU}^{R\&D}$, proportional to the production of new designs. The production function of the R&D sector of country m reads

$$\Delta J_m = (J^*)^\omega \cdot J_m^\zeta \cdot L_{R\&D,m}^{hi} \qquad \omega, \zeta < 1$$

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

$$L_{R\&D,m} = \left(\sum_{r=1}^{Rm} \sum_{h=1}^{H_r} (b_{h,hi,r}\, l_{R\&D}^{h,hi,r})^\sigma \right)^{\frac{1}{\sigma}}$$

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

$$\Delta J_m = \left(\Omega \cdot \frac{P_{J,m} + Sub_m^{R\&D} + +Sub_{EU}^{R\&D}}{W_{R\&D,m}} \right)^{\frac{\epsilon}{1-\epsilon}}$$

where $\Omega = D^{*\omega} \cdot D_m{}^\phi$, $P_{J,m}$ is the price of new designs and $W_{R\&D,m}$ is the CES wage index for the R&D sector:

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

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, even in the short run.

The demand of the R&D sector for each variety of highly skilled labour from region q then takes the following form:

$$l_{R\&D}^{h,hi,r} = \left(\frac{w_{h,hi,r}}{b_{h,hi,r}^\sigma\, W_{R\&D,m}} \right)^{\frac{1}{\sigma-1}} L_{R\&D,m} \qquad (18)$$

3.3. High-tech good firms

High-tech good firms use the output of national R&D firms and supply input to final good firms (see Figure 2). In order to start operating, the representative firm v in the high-tech 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 $FC_{v,r}$ and receives subsidies from the national government ($Sub_m^{v,r}$) and of the EU ($Sub_{EU}^{v,r}$). The firm operates under monopolistic competition and produces one variety of high-tech good using physical capital:

$$z_{v,r} = K_{v,r} \tag{19}$$

Capital is financed by selling assets $a_{v,r}$ to households on the M national financial markets, which implies that $a_{v,r} = P_r^k K_{v,r}$, with P_r^k being the price of physical capital. Asset $a_{v,r}$ yields a gross return $r_{v,r}^k P_r^k$ which corresponds to the rental price for one unit of capital. We assume capital to depreciate at a rate δ_K. This in fact corresponds to the mobile capital framework of Martin and Rogers (1995) which assumes that (i) capital is mobile between regions and (ii) the revenue of capital is repatriated to the owner's region.

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

$$K_{v,r} = \left(\sum_{q=1}^{R} \sum_{s=1}^{S} \beta_s \sum_{i=1}^{N_{s,q}} (k_{v,r}^{i,s,q})^{\theta} \right)^{\frac{1}{\theta}} \tag{20}$$

This index is equivalent to the one representing preferences of households which implies that price of capital is equal to the consumer price index, i.e. $P_r^k = P_r^c$. 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, physical capital is more costly in small/peripheral regions.

Transforming designs into an effective new production process is uncertain. We denote the probability to succeed in using a new design by ϕ. It depends on some regional characteristics, namely the existing stock of operational processes which also corresponds to the number of high-tech firms, A_r, and the stock of human capital, HC_r:

$$\phi_r = \left(\frac{A_r}{\sum_{r=1}^{R_m} A_r} \right)^{\nu} \left(\frac{HC_r}{\sum_{r=1}^{R_m} HC_r} \right)^{1-\nu}. \tag{21}$$

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

The expected profit of the high-tech firm then reads

$$\pi_{v,r} = \phi_r \left[p^z_{v,r}\, z_{v,r} - r^k_{v,r}\, P^c_r K_{v,r} - P_{J,m} - FC_{v,r} + Sub^{v,r}_m + Sub^{v,r}_{EU} \right] \tag{22}$$

Profit maximisation under the constraint (19) leads the high-tech firm to address the following demand for each variety of final good:

$$k^{i,s,q}_{v,r} = \left(\frac{\tau_{s,q,r} \left(1 + t^c_{s,m}\right) p_{i,s,q}}{\beta_s \cdot P^c_r} \right)^{\frac{1}{\theta-1}} K_{v,r} \tag{23}$$

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

$$p_{v,r} = \frac{MC_{v,r}}{\theta} \tag{24}$$

where $MC_{v,r} = r^k_{v,r} P^c_r$. This implies that production of the high-tech 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 plus depreciation:

$$I_{v,r} = \Delta K_{v,r} + \delta_K\, K_{v,r}$$

It is financed by the issuance of new assets, i.e. $P^c_r\, I_{v,r} = \Delta a_{v,r}$.

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 of country m consists in consumption of final good GC_m, transfers to households $TR_{H,m}$, subsidies to firms Sub_m, and government investment GI_m. These components of government expenditure are all assumed to be fixed at exogenous levels, although 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. The regional government also receives resources from the EU which we denote by $TR_{EU,q}$. The amount of public consumption and investment taking place in region q (assumed to be in country m) then reads[8]

$$G_q = \frac{H_q}{H_m} \cdot G_m + TR_{EU,q}$$

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

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

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

$$c_{G,q}^{i,s,r} = \left(\frac{\tau_{s,r,q} \left(1 + t_{s,m}^{c}\right) p_{i,s,r}}{\beta_s P_q^c} \right)^{\frac{1}{\theta-1}} G_q \tag{25}$$

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

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

where $GDP_m = \sum_{r=1}^{Rm} GDP_r$ and $GDP = \sum_m GDP_m$. GDP_r is GDP of region r and is defined in the next section.

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

$$\begin{aligned} T_m &= \sum_{q=1}^{R_m} H_q \sum_{r=1}^{R} \sum_{s=1}^{S} t_{s,m}^{c} \, N_{s,r} \, p_{i,s,r} \, \tau_{r,q,s} \, c_{h,q}^{i,s,r} \\ &+ t_m^w \left(\sum_{q=1}^{Rm} \sum_{e=lo,me,hi} \sum_{h=1}^{H_q} w_{h,e,q} \, l_{h,e,q} \right) \\ &+ t_m^{\pi} \sum_{q=1}^{Rm} H_q \, KI_{h,q} \end{aligned}$$

[8]Note that by limiting public consumption and investment in a given region to the allocation of resources received from the central government and the EU, we rule out the possibility for regional governments to finance their expenditure by raising their own taxes or issuing their own debt.

The public deficit in country m is the difference between government expenditure, including interests on the outstanding debt, and revenue:

$$D_m = \sum_{q=1}^{Rm} P_q^c G_q + TR_{H,m} + TR_{m,EU} + r_m^G B_{G,m} + Sub_m - T_m - \sum_{q=1}^{R_m} TR_{EU,q}$$

where $B_{G,m}$ and Sub_m are respectively the public debt and government subsidies in country m, with[9]

$$Sub_m = \sum_{r=1}^{Rm} \sum_{s=1}^{S} N_{s,r}\, Sub_m^{i,s,r} + Sub_m^{R\&D} + \sum_{r=1}^{Rm} A_r Sub_{EU}^{v,r}$$

Finally, the stock of public capital in region q increases with the level of public investment of the regional government and decreases with depreciation:

$$\Delta KG_q = GI_q - \delta_K\, KG_q$$

4.2. Modelling policy intervention

In order to model the European cohesion policy (ECP) interventions, we regroup the different ECP expenditure categories into 5 broader groups of policy instruments (see Table 1). R&D related policy measures are modelled as subsidies ($Sub_{EU,q}^{R\&D}$) reducing fixed costs in the R&D sector. Policy instruments aimed at increasing human capital are modelled as an education investment in skill-specific human capital, Λ_e and increases public consumption in the regions benefiting from the intervention. Transport infrastructure investments are modelled as a reduction of trade costs, $\tau_{s,r,q}$. Other infrastructure investments are implemented in RHOMOLO as an increase of the stock of public capital, KG_r. These interventions also increase the level of public consumption. ECP policy measure affecting particular industries or services are modelled as government subsidies reducing fixed costs in the final good and/or in the high-tech goods sector ($Sub_{EU,q}^{FG}$ and $Sub_{EU,q}^{z}$). Finally, technical assistance is assumed to increase government consumption.

In order to translate the impact of a particular policy measure on the model variables, we make use when relevant of complementary models or employ estimates from the literature. For example, in order to simulate the TEN-T investments in transport infrastructure, the improvements in the transport network due to transport infrastructure investments are first

[9]This formulation does not prejudge how subsidies change with the number of firms. According to the policy scenario envisaged, the total amount of subsidies could increase/remain constant with the number of firms while subsidies allocated to individual firms remain constant/decrease with the number of firms.

Table 1: Modelling of policy intervention in RHOMOLO

Field	Implementation in Rhomolo	Variables
RTD	Reduction of fixed costs in R&D sector	$Sub^{R\&D}_{EU,q}$
Human resources	Education investment in skill-specific human capital	Λ_e, $TR_{EU,q}$
Infrastructure	Reduction of trade costs	$\tau_{s,q,r}$, $TR_{EU,q}$
	Increase of the stock of public capital	KG_q, $TR_{EU,q}$
Industry and services	Reduction of fixed costs in final good sector	$FC_{i,s,q}$, $Sub^{FG}_{EU,q}$
	Reduction of fixed costs in high-tech sector	$FC_{v,q}$, $Sub^{z}_{EU,q}$
Technical assistance	Increase in public consumption	$TR_{EU,q}$

Notes: The presented policy interventions are illustrative. Many more policy instruments and their combinations can be implemented in RHOMOLO.

simulated with the transport model TRANSTOOLS, where the units of measurement are kilometres of new infrastructure, number of additional lanes, maximum speed, etc. In a second step, the impact of the changes in the accessibility of regions on economic variables is simulated with RHOMOLO, where the units of measurement are relative prices, wages, employment, GDP, etc.

In addition to supply-side effects, the ECP interventions have also demand-side effects (see listed in Table 1). 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.

5. Market equilibrium and closure rules

5.1. Goods, labour 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 representative firm i, s, r faces demand from four types of agents: households (domestic and foreign) $D_H^{i,s,r}$, firms of the final good sector $D_F^{i,s,r}$, firms of the high-tech sector

$D_K^{i,s,r}$ and the domestic public sector $D_G^{i,s,r}$:

$$\begin{aligned} D_H^{i,s,r} &= \sum_{q=1}^{R} H_q \, c_{h,q}^{i,s,r} \\ D_F^{i,s,r} &= \sum_{u=1}^{S} \sum_{q=1}^{R} N_{u,q} \, x_{j,u,q}^{i,s,r} \\ D_K^{i,s,r} &= \sum_{q=1}^{R} A_q \, k_{v,q}^{i,s,r} \\ D_G^{i,s,r} &= \sum_{q=1}^{R} c_{G,q}^{i,s,r} \end{aligned}$$

where $c_{h,q}^{i,s,r}$, $x_{j,u,q}^{i,s,r}$, $k_{v,q}^{i,s,r}$ and $c_{G,q}^{i,s,r}$ are respectively given by equations (5), (15), (23) and (25). The four components of total demand feature the same price elasticity and the firm sets its price, $p_{i,s,r}$, according to the rule given by equation (11), 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 $\sum_{s=1}^{S} N_{s,r} \cdot P_{i,s,r}^{y} \cdot y_{i,s,r} = \sum_{s=1}^{S} N_{s,r} \cdot P_{i,s,r}^{y} \cdot X_{i,s,r}$.

In the representative region q, H_q different varieties of low, medium and high skilled labour are supplied on the labour market. Labour supply of skill level e by on household h in region q, denoted as $l_{h,e,q}$ is given by equation (7).

Labour demand stems from the final good sector on the one hand and from the national R&D sector on the other hand. Labour demand from the final sector is obtained by aggregating individual fimrs demand for for labour of skill level e and variety h, denoted by $l_{i,s,q}^{h,e}$, is given by equation (17). Labour demand from the national R&D sector for highly skilled labour of variety h from region q is denoted by $l_{R\&D}^{h,hi,q}$ and given by equation (18).

Prices and quantities adjust so as to obtain equilibrium on the labour market, i.e.:

$$\begin{aligned} l_{h,e,q} &= \sum_{s=1}^{S} \sum_{i=1}^{N_{s,q}} l_{i,s,q}^{h,e} \qquad \text{for } e = lo, me \\ l_{h,hi,q} &= \sum_{s=1}^{S} \sum_{i=1}^{N_{s,q}} l_{i,s,q}^{h,hi} + l_{R\&D}^{h,hi,q} \end{aligned}$$

On the market for high-tech good of region r, the representative firm v faces the following demand:

$$D_F^{v,r} = \sum_{s=1}^{S} N_{s,r} \cdot z_{i,s,r}^{v,r}$$

where $z_{i,s,r}^{v,r}$ is specified by equation (16). The price setting rule (24) ensures that supply equals demand so that

$$z_{v,r} = D_F^{v,r}$$

Finally, the demand for designs addressed to the R&D sector corresponds to the number of firms willing to operate in the high-tech sector $\sum_{r=1}^{Rm} N_r^z$. As described in the next section, this number depends on the price of designs, $P_{J,m}$, so that at equilibrium we have

$$J_m^r = \sum_{r=1}^{Rm} \frac{A_r}{\phi_r}$$

5.2. Financial markets

We select a saving driven closure rule where private saving is determined as a constant fraction of households' income (see equation 1). At equilibrium, (i) private saving must finance private investment, public deficits 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 high-tech sector: $P_r^C\, I_r = \sum_{v=1}^{A_r} P_r^C\, I_{v,r} = A_r\, P_r^C\, I_{v,r}$.

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:

$$X_m = \sum_{r=1}^{Rm} \sum_{s=1}^{S-1} \sum_{i=1}^{N_{s,r}} \tau_{S,r,R}\, p_{i,s,r}\, c_R^{i,s,r} \quad (26)$$

$$M_m = \sum_{r=1}^{Rm} \sum_{h=1}^{H_r} \tau_{S,R,r}\, p_{R,R}\, c_{h,r}^{R,R} \quad (27)$$

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:

$$TB = \sum_{m=1}^{M} TB_m$$

We therefore have

$$\sum_{r=1}^{R}\sum_{h=1}^{H_r} S_{h,r} = \sum_{r=1}^{R} A_r\, P_r^C\, I_r + \sum_{m=1}^{M} D_m + TB$$

Finally, arbitrage on the financial markets equalises net returns on financial assets. The net return for holding capital in firm v, r is $(r^k_{v,r} - \delta_K)P^C_r + (1-\delta_K)\Delta P^C_r$. 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

$$(r^k_r - \delta_K)P^C_r + (1-\delta_K)\Delta P^C_r = r_{G,m} = r_F$$

for all $m = 1 \dots M$ and for all $r = 1 \dots R-1$. Note that the required gross return for physical capital $r^k_r\, P^C_r$ is higher in regions where the price of capital P^C_r 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. Why does space matter in RHOMOLO?

The model breaches a number of the conditions identified by Starrett (1978) for having perfectly homogenous distribution of economic activity in space. In particular, agents and factors of production are partly immobile, locations are not uniforms (because population and accessibility varies from one regions to the other), the economy is open, there is imperfect competition on product and labour markets and the introduction of knowledge spill-over makes some markets incomplete. There are however two sets of elements without which the issue of location and space would not exist in the model: the combination of trade cost and increasing returns on the one hand, and the combination of knowledge spill-over and localised externalities on the other hand.[10]

Both consumers and producers face positive *trade costs* for importing final/investment goods and intermediate inputs. On the consumer side, trade costs enter the consumer price index (6). On the producer side, trade costs enter the intermediate goods price index (12) and the investment price index (similar to the consumer price index). However, departing from the standard framework of the new economic geography literature, bilateral trade costs

[10] See Kancs (2013) for a detailed description of agglomeration and dispersion forces and mechanisms in RHOMOLO.

between regions are assumed to be asymmetric and the internal trade costs to be positive. Values for 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 in firms production functions (10) and (22). Following Venables (1996), they are made of part of the firms output. In contrast to trade costs, fixed costs is strictly speaking not a parameter that can be calibrated but they can be used for policy simulations.

The combination of increasing returns, - preventing the endless division of the scale of economic activities and hence the emergence of so-called backyard capitalism -, and of transport cost, - without which the issue of space would be irrelevant -, makes access to large markets a determinant of the firms performance. Access to large markets allows the exploitation of economies of scale and hence increase profits. Location (close to a large market) then becomes a decision variable.

Localised externalities enter RHOMOLO trough technological and knowledge spillovers whose scope is assumed to be limited in space to the boundary of the region. Indeed, localised externalities are region-specific and determine the relationship between the density of workers and high-tech firms in a region on the one hand and the performance of the local high-tech sector and hence the productivity of factors on the other hand. When the number of high tech firms increases in one region,the total productivity of factors used in the industry also increases. This leads to an increase in the number of firms in the final good sector which in turn increases demand for high tech goods and hence profits in the high tech sector. This type of Marshallian externality (see for instance Marshall (1890) or Scitovsky (1954)) implies that R&D and technological progress tends to be spatially concentrated in a limited number of places.

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.[11] This process takes place until pure profit is completely

[11] 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

exhausted. The profit of firm i, s, r reads

$$\begin{aligned}\pi_{i,s,r} &= p_{i,s,r}\, X_{i,s,r} - P^y_{i,s,r}\, y_{i,s,r} - \sum_{u=1}^{S} P^u_r\, X^u_{i,s,r} - P^y_{i,s,r}\, FC_r \\ &= p_{i,s,r}\, X_{i,s,r} - P^y_{i,s,r}\, X_{i,s,r} - \sum_{u=1}^{S}\, a_s^{u-1}\, P^u_r\, X_{i,s,r} - P^y_{i,s,r}\, FC_r \end{aligned} \tag{28}$$

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

$$0 = p_{i,s,r} - P^y_{i,s,r} - \sum_{u=1}^{S} a_s^{u-1}\, P^u_r - P^y_{i,s,r}\, FC_r / X_{i,s,r} \tag{29}$$

Using the price setting rule (11), one obtains the level of production corresponding to zero profit:

$$X^*_{i,s,r} = \frac{P^y_{i,s,r}\, FC_r}{\frac{1-\theta}{\theta}\left[P^y_{i,s,r} - \sum_{u=1}^{S} a_s^{u-1}\, P^u_r\right]}$$

The same mechanism applies to the high-tech sector. For a representative firm of the sector, pure profit is exhausted when demand is such that the price it sets is equal to average cost:

$$p_{v,r} = r^k_{v,r}\, P^C_r + P_{J,m}/z_{v,r} + FC_{v,r}/z_{v,r}$$

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:

$$z^*_{v,r} = \frac{P_{J,m} + FC_{v,r}}{\frac{1-\rho}{\rho}\left[r^k_{v,r}\, P^C_r\right]}$$

We then have a system of $s \times r$ equations of the type $X^*_{i,s,r} = D_H^{i,s,r} + D_F^{i,s,r} + D_K^{i,s,r} + D_G^{i,s,r}$ plus r equations $z^*_{v,r} = D_F^{v,r}$ with $s \times r + r$ unknowns corresponding to the long term number of firms in each sector and in each region, $N^*_{s,r}$ and A^*_r.

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 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. Agglomeration and dispersion forces

Four effects drive the mechanics of endogenous agglomeration and dispersion of economic agents in RHOMOLO: the *market access effect*, the *price index effect*, the *market crowding effect* and the the *localised externalities effect*.

The *market access effect* is based on the fact that, due to the presence of increasing returns and transport costs, firms in large/central regions tend to have higher profits than firms in small/peripheral regions. Firms therefore prefer to locate in large/central regions and export to small/peripheral regions. Due to positive trade costs, the demand for a region's output increases with its relative accessibility and its economic size. This can be seen in equations (5), (15), (23) and (25), according to which total demand addressed to firm i, s, r, and hence its profit decreases with trade costs, $\tau_{s,r,q}$, decrease with an elasticity $\frac{1}{1-\theta}$. The weighted average trade costs can be lower either due to large internal market (low value of $\tau_{s,r,r}$) or due to good accessibility of/central location of a region (low value of $< \tau_{s,r,q}$), or both.

The profitability of firms facing larger demand is enhanced due to the existence of increasing returns, as growth in output reduces the average production costs. This can be seen by combining equations (9), (10) and (28), according to which an increase in output, $X_{i,s,r}$, reduces the share of fixed costs in average costs, and hence increases the firm's profit.

The *price index effect* describes the impact of firms' location and trade costs on the cost of intermediate inputs and of high-tech good for producers of final demand goods. This follows the vertical linkage framework of Venables (1996). Large/central regions with more firms import a narrower range of products, which reduces trade costs. Therefore, intermediate inputs are less expensive in large/central regions than in small/peripheral regions. This can be seen in the intermediate input price index (12) which decreases in trade costs with elasticity 1. This suggests that that total trade costs, $\sum_{r=1}^{R} \tau_{s,r,q}$, and hence the cost of production is lower in large/central regions. Moreover, production costs are also lower in regions with a large number of high-tech firms. Indeed, one easily checks that the high-tech good price index (13) decreases with the number of high-tech firms A_r. Because of lower production cost, firms purchasing intermediate inputs and using high-tech good as a factor of production would prefer to locate in large/central regions.

The *market crowding effect* capture the fact that, because of higher competition for input and output markets, firms prefer to locate in small/peripheral regions with fewer competitors than in large/central regions where competition is fiercer. Indeed, when the number of firms in large/central regions increases consumption of differentiated goods is fragmented over a larger number of varieties, implying that each firm's output and profit decreases. Given that the entry of new firms has a negative effect on profitability of incumbents in large/central regions, this *market crowding effect* works as a dispersion force.

The effect of competition on output markets can be seen in equation (5), according to which the demand of output produced by firm i, s, r is decreasing in the number of final good firms. Lower output, and hence profit, gives the incentive to firms to move away from large/central regions to small/peripheral regions with fewer competitors.

The effect of competition on input markets works through prices of spatially immobile production factors, namely labour and high tech goods. Agglomeration of firms in large/central regions bids up prices for such production factors which reduces the incentive to locate in places where the number of firms is large.

The *local externalities effect* works through the probability to succeed in transforming designs into a new production process, ϕ_r, which depends on the pre-existing regional stock of high-tech firms, A_r, and the stock of human capital, HC_r (see equation 21). In particular, the probability to operationalise a new design is higher in regions where the number of high-tech firms is large. As a result, the accumulation of technology is facilitated in regions largely endowed with high-tech firms, creating the conditions for R&D and technological progress to agglomerate in places where the stock of knowledge and of technology is already large.

The table below summarises the endogenous location mechanisms which drive the geographical distribution of final good and high-tech firms and foster their agglomeration or dispersion in space.

Table 2: Agglomeration and dispersion in RHOMOLO

	Final good firms	high-tech firms
Market access effect	⇑	⇑
Price index effect	⇑	
Market crowding effect	⇓	⇓
Local externalities effect	⇑	⇑

Note: ⇑ denotes agglomeration, ⇓ denotes dispersion.

Note that the agglomerations of final good and of high-tech firms reinforce each other. A large number of final good firms means a large market for high-tech firms which enhances the market access effect for the high-tech sector. A large number of high-tech firms implies that a large number of varieties of high-tech good are available for final good firms which enhances the price index effect for the final good sector.

7. Conclusion

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 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 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 employment 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.

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