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RHOMOLO V3:

A Spatial Modelling Framework

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Contents

Foreword

The Technical Report describes the recent features incorporated in the RHOMOLO model and shows in a practical fashion the flexibility of the new modelling framework by presenting the results of a number of simulation exercises. The paper illustrates the effect of permanent demand-side shock in the perturbed regions and the associated spillover effects in the non-perturbed regions. Furthermore, in this paper the authors test the extent to which a gradual increase in the upward pressure on wages generated by a domestic increase in demand can affect the magnitude of the economic impacts in the long-run through competitiveness effects and the degree to which this could results in changes in trade patterns.

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Abstract

In this paper we provide the mathematical presentation of the RHOMOLO model. In addition, we perform some stylized and illustrative simulations with the aim to make the reader familiar with the economic adjustment mechanisms incorporated into the model. Essentially, we attempt to offer the reader and the potential users of the model an intuition of the transmission channels existing in the current version RHOMOLO. The analysis is kept simple to facilitate a better understanding of the model's findings. We simulate a permanent demand-side shock implemented separately for each of the 267 regions contained in the model. We repeat the same simulation under three alternative labour market closures and three different imperfectly competitive product market structures.

Keywords: Numerical General Equilibrium Models, Regional Economic Adjustment, Regional spillover.

1. Introduction

RHOMOLO is a spatial computable general equilibrium model of the European Commission, developed by the Directorate-General Joint Research Centre (DG JRC) in collaboration with the Directorate-General for Regional and Urban Policy (DG REGIO) to support the EU policy makers providing sector-, region- and time-specific simulations on investment policies and structural reforms. The RHOMOLO model has been used with DG REGIO for the impact assessment of Cohesion Policy and structural reforms, and with the European Investment Bank for impact assessment of EU investment support policies.

The aim of the Technical Report is twofold. Firstly we fully describe the recent features incorporated in the RHOMOLO model, and secondly we use the model to run a number of simulation exercises with the purpose of testing the model's ability to generate results consistent with stylized facts arising from different assumptions about the underlying structure of the model and demonstrate in a practical fashion the flexibility of the new modelling framework.

Previous applications of the model were based on Mercenier et al., (2016). In this new version of the model we insert new features with the aim of making our modelling framework more consistent with the regional economic literature. Furthermore, some of the revisions we made reflect comments and feedbacks received from an external Review Board in April 2016.[1] Compared to Mercenier et al., (2016), the new version of the RHOMOLO model incorporates a number of labour market options, the possibility to easily switch among perfectly and imperfectly competitive commodity markets of various types, a new treatment of public capital expenditures and more thorough treatment of factor mobility.

On the labour market side we are now able to choose among a variety of options for wage setting. Among different ways of modelling imperfectly competitive commodity markets, the model can deploy both a simple monopolistic competition framework à la Dixit-Stiglitz (1977) and different forms of oligopolistic competition with endogenous number of firms.

In addition, in this new version of the model we differentiate between current and capital government spending. Both spending types are reported in the government budget, yet only capital spending is allowed to generate direct supply-side effects. Public capital stock enters the production function as an unpaid factor, therefore freely available to all firms. Yet, we take into account congestion effects arising from the contemporaneous, uncoordinated use of public goods[2], adjusting the public capital stock through a simple model of congestion (as in Edwards, 1990, Turnovsky and Fisher, 1995 and Fisher and Turnovsky, 1998).[3]

When modelling regional economies, within a CGE framework, one should take into account that typically regions are more open than their national counterparts. Hence, closures rules normally in operation in national economies can not necessarily be applied straightforwardly when modelling regional economies (see Lecca et al., 2013 and Partrige and Rickman, 2008). For this reason, as a default option, we separate the investment from saving decisions. Households' savings are determined as fixed shares of current income while regional investments are determined through a simple adjustment rule, according to which the additional level of investments in each region is governed by the gap between the desired level of capital and the actual level of capital. This is a typical

[1] https://ec.europa.eu/jrc/sites/jrcsh/files/review_of_the_rhomolo_model_final.pdf.
[2] Such as non-publicness of public goods (see e.g., Bergstrom and Goodman, 1973).
[3] A substantial part of public capital such as roads, highways, bridges, airports etc are clearly not public goods and individuals can be excluded at some cost from using the good (see e.g., Stiglitz and Rosengrand, 2015, Ch. 5). This maybe even more pronounced at the regional level.

accelerator model, as originally developed by Jorgenson and Stephenson (1969) and consistent with the capital adjustment rules of Uzawa (1969). Everything else equal, higher user costs of capital are associated with lower desired capital stock and disinvestments due to lower profits. In this framework, the balance of payments is satisfied by not imposing any constraints on net inflows from the rest of regions. This also means that the demand for investment in excess of domestic savings is fully compensated by external markets.

The migration module is now fully integrated in this new version of RHOMOLO. As in previous applications (see e.g., Brandsma et al., 2014), we assume that there is no natural population change in the baseline. However the labour force in each region adjusts according to a migration function originally developed in Persyn et al., (2014). The model starts with a zero net migration flow and in any period migration between each region pair is positively related to gaps in real wages (hence, not only nominal wages but also regional costs of living matter) and negatively related to gaps in unemployment rates. Since the relocation of workers across regions may have a significant impact on the pattern of the regional consumption and on local wages, labour mobility is likely to have a non-negligible impact on the spatial outcomes of the model.

All shift and share parameters of the model are calibrated to reproduce the base-year dataset, represented by new the inter-regional social accounting matrix for the year 2013 (Thissen et al., 2018). This is the most recent year for which regional social accounting matrices can be built with a sufficient degree of reliability due to data availability.

In line with their pedagogical objective, the simulations and analyses undertaken in the paper are deliberately simple, practically oriented, and reasonably comprehensive. At the risk of some oversimplifications, we perform simulations with demand-side implications only. Essentially, we focus on a raise in internal demand in each of the 267 regions constituting the model, undertaking analysis for each of the main labour market assumptions incorporated in the model. It is our intention to investigate to what extent alternative adjustment mechanisms associated to given labour market assumptions affect the long-run impact of each economy perturbed. Separately simulating shocks to each individual region, we analyse the extent to which a single regional economy is able to transmit the received shocks to the rest of the regions and the degree at which such spillovers vary according to the wage structure assumed.

We perform the initial set of simulations assuming perfectly competitive product markets. However, in the rest of the paper we conduct a further set of experiments to evaluate how significant the distinction is between alternative market frameworks and whether perfectly or imperfectly competitive commodity markets can alter the transmission mechanisms, the direction and sign of the spillovers. Again, for heuristic reasons and for the sake of comparability with the previous set of simulations, the same demand-side shock is implemented under the different imperfectly competitive markets structure built in RHOMOLO. Besides, we track the resulting agglomeration (dispersion) effects that might occur in terms of firms' geographical concentration and evaluate how alternative labour market closures influence the size and the sign of the impact while switching among different market frameworks.

The reminder of the paper is organized as follows. In the next Section we outline the equations and adjustment mechanisms governing the model to help the reader to identify the main drivers and determinants of the spatial outcomes generated by the RHOMOLO model. In Section 3, we describe the alternative model options incorporated in this new version of RHOMOLO whilst in Section 4 the calibration strategy is discussed. Section 5 is dedicated to the discussion of the default assumptions used in RHOMOLO. Section 6 presents and discusses the results of the simulations and finally Section 7 offers some conclusions.

2. Detailed description of the RHOMOLO model

2.1 An overview of the model

The theoretical structure of the model is common to other numerical general equilibrium model. The economy consists of a set of 268 regions indexed by $s = 1, \ldots, R + 1$ of which a subset corresponds to R=267 endogenous EU NUTS2 regions, which we index as $r = 1, \ldots, R$; and one single exogenous region representing the Rest of the World.

The model has a set of different economic sectors (also called industries) indexed by $i \in \boldsymbol{I}$. A subset of these industries indexed by $f \in \boldsymbol{F} \subset \boldsymbol{I}$ operates -in the default configuration of the model- under monopolistic competition a la Dixit and Stiglitz (1977). In each region-sector (r, f) identical firms produce a differentiated variety, which is considered an imperfect substitute for the varieties produced within the same region and elsewhere. The number of varieties in the sectors ***F*** is endogenous and determined from the zero-profit equilibrium condition, according to which profits must be equal to fixed costs. In turn, this means that in equilibrium prices equal average costs. The rest of firms operate under perfect competition in sectors indexed by $c \in \boldsymbol{C} \subset \boldsymbol{I}$. Currently RHOMOLO is disaggregated into 267 EU regions and 10 NACE rev.2 economic sectors as reported in Table 1: A, B_E, C, F, G-I, J, K-L, M-N, O-Q, R-U.

Table 1. Sectoral classification used in RHOMOLO

CODE NACE REV 2	**Sectors Description**
A	Agriculture, Forestry and Fishing
B,D,E	Mining and Quarrying + Electricity, Gas, Steam and Air Conditioning Supply + Water Supply; Sewerage, Waste Management and Remediation Activities
C	Manufacturing
F	Construction
G-I	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles + Transportation and Storage + Accommodation and Food Service Activities
J	Information and Communication
K-L	Financial and Insurance Activities/ Real Estate Activities
M_N	Professional, Scientific and Technical Activities + Administrative and Support Service Activities
O-Q	Public Administration and Defence; Compulsory Social Security + Education + Human Health and Social Work Activities
R-U	Arts, Entertainment and Recreation + Other Service Activities + Activities of Households As Employers; Undifferentiated Goods- and Services-Producing Activities of Households for Own Use + Activities of Extraterritorial Organisations and Bodies

Final goods are consumed by Households, Governments and Investors (in the form of capital goods), whilst firms consume intermediate inputs. Regional goods are produced by combining the value added (labour and capital) with domestic and imported intermediates, creating vertical linkages between firms. This means that the spatial configuration of the system of regions has a direct impact on the competitiveness of regions because firms located in more accessible regions can source their intermediate inputs at lower price and thus gain larger market shares in local markets.

Trade between and within regions is costly, implying that the shipping of goods entails transport costs assumed to be of the iceberg type, with $1+\tau_{r,r',j} \geq 1$ representing the quantity of sector *j* goods that needs to be sent from region *r* in order to have one unit arriving in region *r'* (see Krugman, 1991, for instance). Transport costs are identical across varieties but specific to sectors and trading partners (region pairs). They are based on the transport costs estimation developed by Persyn et al., (2018) explained in section 4.2.

Typically, we assume the following sectors under perfectly competitive market structure: A, O-Q and R-U. The rest are normally treated as imperfectly competitive sectors.

The model distinguishes three different labour categories which correspond to the level of skill or education e={low, medium, high} For each labour type, the default wage setting relationship is represented by a wage curve (Blanchflower and Oswald, 1995), whose implication is that lower levels of unemployment increase workers' bargaining power, thereby increasing real wages.

The following sections provide a more detailed description of the model.

2.2 Households

In each period[4], *t* and in each region *r,* households receive utility from consumption of the composite good C_r. The household's problem consists in the maximisation of the utility (1) subject to the budget constraint (2):

$$U(C_r) \tag{1}$$
$$P_r^c C_r \leq (1-s_r)YC_r \tag{2}$$

where, P_r^c, s_r, YC_r are the consumer price index, the exogenous saving rate and the disposable income respectively. YC_r, is defined as the sum of labour and capital income adjusted for tax and net transfers of income:

$$YC_r = \sum_e (1-\tau_r^w) W_{r,e} L_{r,e} (1-u_{r,e}) + \sum_i \psi_r (1-\tau_r^\pi) K_{r,i}^P \, rk_{r,i} + TR_r \tag{3}$$

where ψ_r is the share of capital income paid directly to households and τ_r^w, τ_r^π are the average rate of labour and capital income tax, respectively. Factor payments are represented by $W_{r,e}$ and r_r, that is, the nominal wage rate differentiated by skill-types *e*, and the rate of return to capital, respectively. K_r^P is the private capital stock while $L_{r,e}$ and $u_{r,e}$ are the labour force and unemployment rate differentiated by skill-types, *e*. TR_r are net transfers from government.

The first order condition of this problem implies that the aggregate consumption level is directly related to the disposable income YC_r:

$$C_r = \frac{(1-s_r)YC_r}{P_r^c} \tag{4}$$

where, $(1-s_r)$ is the share of disposable income allocated to consumption. Households consume all varieties of final goods available in the economy. In order to represent love for variety, C_r is assumed to take the form of a CES function defined in Equation (5):

[4] For the sake of readability, we omit time indices when describing static equations.

$$C_r = \left(\sum_i N_{r,i} \vartheta_{r,i} \left(c_{r,i} \right)^{\rho^c} \right)^{\frac{1}{\rho^c}} \quad (5)$$

where $c_{r,i}$ is the consumption of each n=1…***N*** varieties of sector *i*, in region *r,* whilst $\vartheta_{r,i}$ is a share of expenditure parameter and $\rho^c = \frac{\sigma^c - 1}{\sigma^c}$, where $\sigma^c$is the elasticity of substitution. The consumption price index P_r^c is obtained through a weighted CES index defined over the Armington price for each of the varieties, $P_{r,i}$ (this is defined below in Equation (22)):

$$P_r^c = \left(\sum_i \vartheta_{r,i} \left(P_{r,i} \right)^{\rho^c} \right)^{\frac{1}{\rho^c}} \quad (6)$$

The nominal level of saving, S_r is determined in fixed share of disposable income:

$$S_r = s_r Y C_r \quad (7)$$

2.3 Government

Government expenditure comprises of current spending on goods and services $G_{r,j}$, capital expenditures dedicated to the construction of public infrastructure I_r^g and net transfers to households TR_r. Revenues are generated by labour and capital income taxes on household income at the rate of τ_r^w and τ_r^π, respectively, and indirect taxes on production $Z_{r,j}$ at the rate of τ_r^p. The government deficit (or surplus) is represented in Equation (8):

$$B_r = \sum_j G_{j,r} + I_r^g + Tr_r - \left(\tau_r^w \sum_e W_e L_{r,e} (1 - u_{r,e}) + \psi_r \tau_r^\pi K_r^P \, rk_r + \sum_j \tau_r^p Z_{r\prime,j} P_{r,j} \right) \quad (8)$$

In our default configuration we assume exogenous government consumption and no variations in tax rates, therefore no binding constraint on government budget applies. We assume current and capital government expenditure not dominated by endogenous mechanisms or government rational decisions. For the sort of simulations performed in RHOMOLO these variables are typically set as exogenous policy variables. However, when a balanced budget is applied, government deficit *B* is fixed, therefore either government consumption (current or capital expenditures) or any of the labor or capital income tax rates have to adjust residually in order to satisfy the government budget constraint. I_r^g is distributed among sectors in fixed shares:

$$I_{r,i}^{gS} = z_{r,i} I_r^g \quad (9)$$

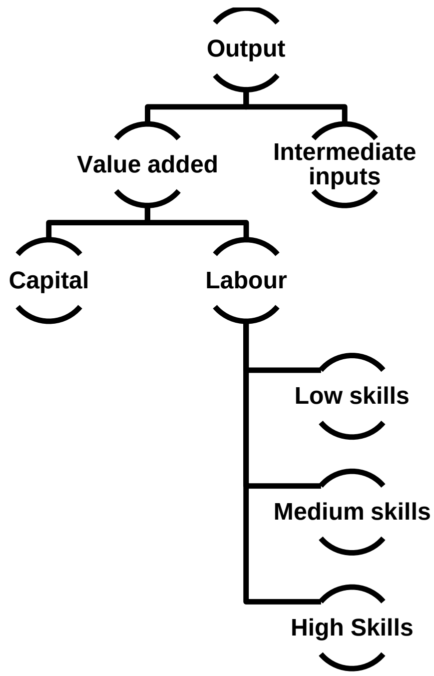
where, $I_{r,i}^{gs}$is the public sectoral capital good produced by sector *i* in region *r* according to the base year share $z_{r,i}$. Net transfers to Households are fixed in real terms, therefore the base year values $\overline{Tr_r}$ is simply augmented to reflect changes in prices:

$$Tr_r = \overline{Tr_r} \, P_r^c \quad (10)$$

2.4 Firms

At the level of firm, the production technology is represented by a multilevel CES function graphically represented in Figure 1.

Figure 1. Hierarchical Production structure



In each sector *j*, and region *r*, total production $Z_{r,j}$ is a CES combination of the value added $Y_{r,j}$ and intermediate inputs $V_{r,j}$:

$$Z_{r,j} = Ax_{r,j}\left[\delta_{r,j}^{x}\cdot V_{r,j}^{\rho_j^x} + \left(1-\delta_{r,j}^{X}\right)\cdot Y_{r,j}^{\rho_j^x}\right]^{\frac{1}{\rho_j^x}} \tag{11}$$

where $\delta_{r,j}^{x}$ is the calibrated share of intermediate inputs in sector *j* for region *r* in total production while $Ax_{r,j}$ is a scale parameter and ρ_j^x is the elasticity parameter obtained from the elasticity of substitution σ^x, according to $\rho_j^x = \frac{\sigma^x - 1}{\sigma^x}$. The corresponding demand equations for *Y* and *V* are described below in equation (12) and (13) respectively:

$$Y_{r,j} = \left(Ax_{r,j}^{\rho_j^x}\cdot(1-\delta_{r,j}^{x})\cdot\frac{Py_{r,j}}{Pz_{r,j}}\right)^{\frac{1}{1-\rho_j^x}}\cdot Z_{r,j} \tag{12}$$

$$V_{r,j} = \left(Ax_{r,j}^{\rho_j^x}\cdot\delta_{r,j}^{x}\cdot\frac{Pin_{r,j}}{Pz_{r,j}}\right)^{\frac{1}{1-\rho_j^x}} Z_{r,j} \tag{13}$$

where $Pz_{r,j}$, $Py_{r,j}$ and $Pin_{r,j}$ are the prices for the total production, the value added and the intermediate inputs, respectively.

In turn $Y_{r,j}$ and $V_{r,j}$ are defined as follow in equations (14) and (15) respectively:

$$Y_{r,j} = Ay_{r,j}\left[\left(K_{(g)}^{d}\right)^{\xi}\left[\delta_{r,j}^{Y}\cdot KD_{r,j}^{\rho_j^y} + \left(1-\delta_{r,j}^{y}\right)\cdot LD_{r,j}^{\rho_j^y}\right]^{\frac{1}{\rho_j^y}}\right] - FC_{r,j} \tag{14}$$

$$V_{r,j} = \left(\sum_i b_{r,i,j} v_{r,i,j}^{\rho^v}\right)^{\frac{1}{\rho^v}} \tag{15}$$

In equation (14), $Y_{r,j}$, is obtained combining private capital $KD_{r,j}$ and employment $LD_{r,j}$ in a CES function, net of fixed costs $FC_{r,j}$. The scale parameter $Ay_{r,j}$ represents the conventional Hicks neutral technical change parameter in this production function.

Effective public capital, $K_{(g)}^{d}$ enters the production function as unpaid factor of production (Barro, 1990; Baxter and King, 1993; Futugami et al., 1993 and Glomm and Ravikumar, 1994; 1997) meaning that all firms, in all sectors, enjoy the same level of public capital at no cost. In Equation (14) the conditions are such that the value added production function exhibits positive marginal productivity for all three factors and diminishing returns for each single input. This function exhibits constant return to scale between private-primary factors of production $\{KD, LD\}$, however $\{KD, LD, K_{(g)}^{d}\}$ combined together generate increasing return to scale. Substitution between the two types of primary factors is governed by the parameter of substitution $\rho_j^y = \frac{\sigma^y - 1}{\sigma^y}$ (where σ^y is the elasticity of substitution between labour and capital) and the share parameter δ_j^y. The output elasticity of public capital, ξ, is typically positive and less than 1.

The input-output relations are shown in equation (15) where the composite demand for intermediate inputs is again a CES combination of $v_{r,i,j}$ that is the purchase of intermediate inputs of each sectors *j* from the supplier sector *i*. Input substitution between sectors are determined by the elasticity of substitution $\rho^v = \frac{\sigma^v - 1}{\sigma^v}$ and the preference parameter related to the share of expenditure $b_{r,i,j}$.

The composite CES price index for the intermediate inputs is determined as follows:

$$Pin_{r,j}^{1-\sigma^v} = \sum_i b_{r,i,j} p_{r,i}^{1-\sigma^v} \tag{16}$$

The production price is then defined below:

$$Pz_{r,i} Z_{r,i} = Py_{r,i} Y_{r,i} + Pin_{r,i} V_{r,i} \tag{17}$$

From cost minimization and given equations (14) and (15) we obtain the demand for capital and labour in each sector *j*, represented in equation (17) and (18) respectively:

$$KD_{r,j} = \left(\left(\left(K_{(g)}^{d}\right)^{\xi} Ay_{r,j}\right)^{\rho_j^y} \cdot \delta_{r,j}^{y} \cdot \frac{rk_{r,j}}{Py_{r,j}}\right)^{\frac{1}{1-\rho_j^y}} \cdot Y_{r,j} \tag{18}$$

$$LD_{r,j} = \left(\left(\left(K_{(g)}^{d}\right)^{\xi} Ay_{r,j}\right)^{\rho_j^y} \left(1-\delta_{r,j}^{y}\right) \cdot \frac{W_r}{Py_{r,j}}\right)^{\frac{1}{1-\rho_j^y}} \cdot Y_{r,j} \tag{19}$$

where, $rk_{r,j}$ and W_r are respectively the price of capital and the wage rate. For each firms, labour is then further disaggregated. We distinguish between three types of skills, *e*: low, medium and high. The demand for different types of skill labour is identified in equation (20):

$$ld_{r,j,e} = \left(Al_{r,j,e}^{\rho_j^l} \cdot \delta_{r,j,e}^{l} \cdot \frac{w_{r,e}}{W_r}\right)^{\frac{1}{1-\rho_j^l}} \cdot LD_{r,j} \qquad e = le, me, he \tag{20}$$

where, $Al_{r,j,e}$, $\delta_{r,j,e}$ and $\rho_j^l$are the scale paramenter, the share parameter and the substitution parameter, respectively. $w_{r,e}$is the wage rate for each *e.*

2.5 Trade

Goods and services can be sold in the domestic economy or exported to other regions. On the other hand, firms and consumers can purchase inputs within the region or from external markets. We use a single Armington nest that differentiates between domestic and imported (intermediate inputs and final demand) goods and services. At the level of firm the demand for each good and services, *j*, supplied by region *s* to region *s*', $x_{s,s\prime,j}$, is defined as follows:

$$x_{s,s\prime,j} = d_{s,s',j}\left(\frac{P_{s\prime,j}}{p_{s,s\prime,j}}\right)^{\sigma_j} X_{s',j;} \qquad \sigma_j \geq 0; \tag{21}$$

where, $d_{s,s',i,}$ is a calibrated expenditure share, σ_j is the elasticity of substitution and $X_{s,i}$ is the Armington aggregate of outputs for each firm in region *s* defined below in equation (38). Having external prices fixed to one (such as, import prices from the Rest of the World), the price $P_{r\prime,j}$ is defined as a CES price index over the market price $p_{r,r\prime,j}$:

$$P_{r\prime,j} = \left(\sum_r N_{r,j} d_{r,r',i,}(1+\tau_{r,r',j})(1+\tau_r^p)p_{r,r',j}\right)^{1-\sigma_j} \qquad r \subset s \tag{22}$$

where the price $p_{r,r\prime,j}$ set by a firm of region *r* (net of trade cost τ and production taxes τ_r^p) selling to region *r'*, for a monopolistic competitive sectors *f*, is defined as the optimal mark-up $\left(\frac{1}{\varepsilon_{r,r',f}}\right)$ over the marginal cost $P_{r,f}^*$, is given as follows:

$$p_{r,s',f} = \frac{P_{r,f}^*}{1-\frac{1}{\varepsilon_{r,s',f}}} \tag{23}$$

where, $\varepsilon_{r,s\prime,f}$ is the perceived elasticity that in monopolistic competition is defined as follows:

$$\varepsilon_{r,s\prime,f} = \sigma_{s\prime,f}; \qquad f \in i; \tag{24}$$

For the perfectly competitive sectors the market price is equal to the marginal cost, that is:

$$p_{r,s',c} = P_{r,c}^*; \qquad c \in i; \tag{25}$$

In this default configuration of RHOMOLO we use a Dixit-Stiglitz formulation of the mark-up of firm-level product differentiation where the mark-up rate is kept constant. The elasticities of substitution that define the perceive elasticity in the Lerner formulation is equal for all firms and products in the model. The elasticity of substitution σ is the same in each node of the CES function (between home –and imported), therefore any possible combination between domestic and imported inputs will collapse to a single nest as represented in equation (21).

The marginal cost includes the cost of production factors and the intermediate price index:

$$P^*_{r,j} = a^y_{r,j} Py_{r,j} + a^{Int}_{r,j} Pin_{r,j} \tag{26}$$

$a^y_{r,j}$ and $a^{Int}_{r,j}$ are the share parameters attached to the value added and intermediate inputs respectively.

2.6 Wage setting

The RHOMOLO model incorporates imperfect competition in the labour market. We assume a flexible framework that allows one to switch from a wage curve to a Phillips curve. Further parameterization also permits to use a dynamic or a static form of wage setting. The general formulation is expressed in logs as in Equation (27):

$$rw_{r,e,t} = a_e + \alpha\, rw_{r,e,t-1} - \beta\, u_{r,e,t} + \varsigma\, \Delta p_{r,t} - \theta \Delta u_{r,e,t} + \omega \Gamma_t \tag{27}$$

The real wage $rw_{e,t}$ is differentiated by skills, *e*, and it is negatively related to the unemployment rate, $u_{e,t}$ and the change in unemployment rate between two subsequent periods, $\Delta u_{e,t}$. The real wage is also positively affected by past real wages, changes in the price of output between two subsequent periods, $\Delta p_{r,t}$ and the productivity trend Γ_t. In the baseline model we assume $\Gamma_t = 0$ and the constant a is a calibrated parameter. [5]

With $\alpha = \varsigma = \theta = 0$ we have the case of a static wage curve where the real wage is solely affected by the unemployment rate, while for the case where $\alpha = 1$ the changes in real wages between two subsequent periods are dependent from current level of unemployment rate. In this last configuration, a Phillips curve is in operation in the model[6]. This implies that in the absence of migration or exogenous increases in labour forces, in the long-run the employment and the unemployment rate will return back to their previous steady-state.

For values $0 < \alpha < 1$ some inertia is captured in the way wages adjust in the model. Recent econometric evidence has shown value of α significantly less than 1 (Montuenga-Gómez, V.M., Ramos-Parreño, 2005). However the debate is still open and the issue currently remain controversial.

2.7 Investment

The optimal path of private I^P investments is consistent with the neoclassical firm's profit maximisation theory and defined as in Uzawa (1969):

$$I^P_{i,r} = \delta_r K^P_{i,r} \left(\frac{rk_{i,r}}{uck_r}\right)^v \tag{28}$$

[5] Currently the model does not incorporate any endogenous determination of the productivity parameter. However this could be exogenously fixed if estimates for the 267 NUTS 2 regions were available.

[6] If $\alpha, \varsigma, \theta > 0$ we are introducing a type of a dynamic adjustment over wage bargaining.

where, v is the accelerator parameter and δ is the depreciation rate. According to this formulation the investment capital ratio ($\varphi = I_r^P/K_r^P$) is a function of the rate of return to capital (rk) and the user cost of capital (uck), allowing the capital stock to reach its desired level in a smooth fashion over time:

$$\varphi = \varphi(rk_{i,r}, uck_r) \tag{29}$$

where

$$\frac{\partial\varphi}{\partial rk} > 0;\ \frac{\partial\varphi}{\partial uck} < 0 \tag{30}$$

The user cost of capital, *uck*, is derived from Hall and Jorgenson (1967) and Jorgenson (1963) as a typical no arbitrage condition, where:

$$uck_r = (r + \delta_r)p_{EU}^I + \Delta p_{EU}^I + rp_r \tag{31}$$

r, δ_r, p_{EU}^I and rp_r denote the interest rate, the depreciation rates, the investment price index at EU level and an exogenous risk premium respectively. Δp_{EU}^I is the change of the investment price index defined between two subsequent periods.

Given equation (30) and the production function (14) we can define the desired level of capital $K_{j,r}^*$ as follows:

$$K_{j,r}^* = N_{r,j}\left(\left(\left(K_{(g)}^d\right)^{\xi} Ay_{r,j}\right)^{\rho_j^y} \cdot \delta_{r,j}^y \cdot \frac{uck_{r,j}}{Py_{r,j}}\right)^{\frac{1}{1-\rho_j^y}} \cdot Y_{r,j} \tag{32}$$

Equation (32) is similar to Equation (18) except for the price associated to capital, which is in this case uck rather than rk.

In this configuration, it is the gap between the desired level of capital and the actual level of capital that determine the expected profit in the economy which in turn drive investment in a given period. This is governed by the differences between uck and rk, therefore. Dividing member by member Equation (32) with Equation (18) and totally differentiating, we have therefore: $\dot{K}^* - \dot{KD} = \dot{rk} - \dot{uck}$.

In Equation (31) the interest rate is fixed and equal for all regions; δ_r is fixed but we allow variations between regions in the base year; rp_r is a fixed calibrated parameter. Therefore changes in uck are only driven by changes in the cost of capital in the whole EU, p_{EU}^I. This is given as the price index over the Armington price weighted by the capital matrix *KM*:

$$p_{EU}^I = \frac{\sum_{i,j,r} KM_{i,j,r} P_{r,i}}{\sum_{i,j,r} KM_{i,j,r} \bar{P}_{r,i}} \tag{33}$$

As depicted in Equation (28) the allocation of investments between regions is driven by the differences between regional and EU average returns that mimic, a capital flow mobility rule between regions. In the long-run, we should expect changes in capital returns in all regions to equalise.

Private capital stock in each region updates period by period through investments adjusted by depreciation:

$$\Delta K_{j,r}^P = -\delta_r K_{j,r}^P + I_{j,r}^P \tag{34}$$

The demand for investments $I_{j,r}^{P}$ in sector j is translated to the production of investment goods produced by sectors *i*, $I_{j,r}^{S}$, through the capital matrixes $KM_{i,j,r}$as follows:

$$I_{i,r}^{S} = \sum_{j} KM_{i,j,r} I_{j,r}^{P} \tag{35}$$

Official statistics typically do not provide a capital matrix at regional level. The capital matrixes $KM_{i,j,r}$ is therefore obtained and estimated for each region through a method of minimization of distances detailed in Section 4.2.

2.8 Public capital accumulation and congestion

Public capital stock accumulates through public investment in infrastructure, I_{r}^{G}, set exogenously by each government starting from an initial positive capital stock. Public capital stock accumulates in accordance with the following formula:

$$\Delta K_{(g),r}^{s} = -\delta_{r}^{g} K_{(g),r}^{P} + I_{r}^{G} \tag{36}$$

where government capital depreciates at the rate δ_{r}^{g}.

In RHOMOLO we take into account of congestion effects arising from *non-publicness* of public goods (see e.g., Bergstrom and Goodman, 1973; Stiglitz and Rosengrand 2015); therefore the public capital stock, $K_{(g),r}^{s}$ is adjusted following a simple model of congestion (see e.g. Edwards, 1990, Turnovsky and Fisher, 1995 and Fisher and Turnovsky, 1998)[7]. The congestion model we use follows the traditional formulation of decreasing marginal congestion. The aggregate public capital service appearing in equation (14) is adjusted for congestion by aggregated production:

$$K_{(g),r}^{d} = K_{(g),r}^{s} \left(\sum_{i} N_{r,i} Y_{r,i} \right)^{\gamma} \qquad \gamma = \frac{\eta - 1}{\eta}, \gamma \in (0, -\infty); \qquad \eta \in (0,1) \tag{37}$$

where, γ is the congestion parameter. The increase in production reduces the effective quantity of public capital stock enjoyable by all firms and the magnitude of this effect depends on the level of η. When $\eta = 1\ (\gamma = 0)$ we have the case of a pure public good, which is available equally to each firm and its use would not reduce its usefulness to others and firms will enjoy full benefits from its use (non-rival and non-excludable). If $\eta = 05\ (\gamma = -1)$ public capital still remains non-excludable but loses the property of non-rivalry[8].. The quantity of public services available to a producer declines if production increases. The higher is the use of primary factors the lower is the contribution of public capital in production. Such a crowding effect is stronger the lower is η. For $\eta < 0.5$ there is a situation of "over-crowding" (see e.g., Edwards, 1990) such that the decline in public services is faster than the increase in growth. The extreme case is generated when η =0, (the smallest value according to the constraints assumed) where $\gamma \to -\infty$.

The public capital efficiency strictly depends to the value assigned to η. In general we have that $\frac{\partial K_{(g)}^{d}}{\partial \eta} > 0$ implying that:

- For $\eta = 1$, congestions effects are neglected, therefore $\frac{\partial K_{(g)}^{d}}{\partial Y} = 0$;
- For $\eta < 1$we have that $\frac{\partial K_{(g)}^{d}}{\partial Y} < 0$
- For $\eta \to 0$, the implication are such that $K_{(g)}^{d} \to 0$

[7] See e.g. Glomm and Ravikumar (1994, 1997), Judd (1999) for alternative congestion modelling approaches in the context of growth models.

[8] This corresponds to the case described in Fisher and Turnovsky, (1998) called *proportional congestion*.

Typically, we would expect that for a positive exogenous shock, $I_r^G > 0$, and assuming no offsetting mechanism (manna from heaven), the elasticity of public capital determines the nature of the shock and the return to scale of the production function (14), therefore:

- For $\xi = 0$, production function (14) exhibits constant return to scale therefore the investment expenditure has the effect of a simple increase in current consumption, that is while $\frac{\partial Y}{\partial I} > 0$, $\frac{\partial Y}{\partial K_{(g)}} = 0$.
- For $\xi > 0$, increasing return are in operation in the model hence conventional supply-side effects are in place.

2.9 Commodity balance and closing the system

The total absorption equation provides equilibrium in the commodity market:

$$X_{r\prime,i} = \sum_j N_{r,i}v_{r,i,j} + N_{r,i}c_{r,i} + I_{i,r}^S + G_{r,j} + I_{i,r}^{gS} \tag{38}$$

As for the capital market, capital demand equals the capital stock:

$$N_{r,j}KD_{r,j} = K_{r,j}^P \tag{39}$$

The labour market is equilibrated:

$$\sum_j N_{r,j}ld_{r,j,e} = (1 - u_{r,e})L_{r,e} \tag{40}$$

where,

$$L_{r,e} = \bar{L}_{r,e} \tag{41}$$

By default, we consider the labour supply exogenous and no natural population change. Furthermore mobility of workers across regions is not permitted in the baseline model. Migration however can be turned as described in the section below, but even in this case migration acts retrospectively, with the current labour supply depending on past unemployment and wage differentials, and being exogenous from a contemporaneous perspective.

The zero profit condition that link output price and average price determine the number of firms in the system for the ***f*** sectors:

$$FC_{r,f}P_{r,f}^*N_{r,f} = \sum_{r\prime} N_{r,f}x_{r,r\prime,f}\, p_{r,r\prime,f} - P_{r,f}^*N_{r,f}\big(Y_{r,f} + V_{r,f}\big) \tag{42}$$

Furthermore the regional output should be equal to the overall goods and services traded domestically and outside the region:

$$Pz_{r,i}Z_{r,i} = \sum_{s\prime} x_{r,s\prime,i}p_{r,s\prime,i}\left(1 + \tau_{i,r}^p\right) \tag{43}$$

Definition of Equilibrium. Given initial factors' endowment $\bar{L}_{r,e}, \bar{K}_{i,r}^P, \bar{K}_{(g),r}^s$ the equilibrium of the economy is determined for each region *r* and each sector *i*, as a set of consumers' decision $\{C,S\}$, investors' decisions (I^P), firms' decision $\{Z,Y,V,v,N,KD,LD,ld,X,x\}$ that along with price formation $\{P^c, P^I, P^*, Pz, Py, Pin, P, p, rk, W, w, uck\}$, all markets clear (goods and service market, labour and capital market, payment account), satisfy the low of motion for public and private capital and the labour market conditions through the unemployment rates for each region and sectors.

In its default configuration RHOMOLO ensures an unconstrained inflow of capital to sustain investment whenever required (this is a typical regional macroeconomic closure), not imposing any constraints on the balance of payments. Typically, no binding constraints are imposed to regional government balance. However, foreign savings from the Rest of the World in the model are passive, hence maintaining equilibrium in the payment accounts with the ROW.

The high dimensionality of RHOMOLO in terms of regions and sectors imply that the number of (nonlinear) equations to be solved simultaneously is very large (in the order of the hundreds of thousands). Therefore, in order to keep the model manageable from a computation point of view, its dynamics are kept relatively simple. The model is solved in a recursively dynamic mode, where a sequence of static equilibria is linked to each other through the law of motion of state variables. This implies that economic agents are not forward-looking and their decisions are solely based on current and past information.

Steady-State

In the steady-state, ***T***, we have that:

$$\delta_r K_{i,r}^P = I_{r,T}^P \tag{44}$$

$$\delta_r^g K_{(g),r,T}^s = I_{r,T}^G \tag{45}$$

$$m_{r,e,T} = 0 \tag{46}$$

This implies that, by substituting Equation (44) into Equation (28) we have $rk_{i,r}, = uck_r$, which implies that in steady-state $\Delta\varphi = 0$.

3. Model's options

3.1. Labour Market

From equation (27) we have seen we can easily switch between a wage curve and Phillips curve modelling of the labour market by changing the related parameter of interest. However, the model could also be run assuming the more conventional neoclassical rule that implies perfect competition in the labour market. Assuming no changes in labour force a vertical labour supply applies to each period of the model. Therefore, the wage rate for each type of skill is determined endogenously and we drop Equation (27) and prevent adjustment in unemployment rate in Equation (40). The long-run equilibrium obtained under full flexible wage is expected then to be the same as the long-run equilibrium generated under the Phillips curve.

Furthermore the model can also account for wage rigidities by assuming fixed real or nominal wages. In this case we should drop Equation (27) fixing the wage (either the nominal or the real wage) allowing labour market adjustments through unemployment rate.

3.2 Migration within the EU

Labour force is fixed at the EU level. However, we can allow workers to migrate between regions. Workers' migration is governed by expected differences in the real incomes, and is also dependent to the probability to be employed in a given region as originally modelled in Persyn et al., 2014. The labour forces $L_{r,e}$, in each region and for different type of skills, *e*, evolve according to the net migration rates ($m_{r,e}$) expressing incoming minus outgoing workers, relative to the original size of the labour force, defined as follows:

$$m_{r,e} = \frac{\sum_{r'} s_{r,',r,e}\, L_{r,e} - \sum_{r'} s_{r,r',e}\, L_{r',e}}{L_{r,e}} \quad (47)$$

where $s_{r',r}$ is the share (or probability) of workers moving from region *r*' to *r* determined as (see Persyn et al., 2014):

$$s_{r,r',e} = \frac{exp\left(\Psi_{r,r'}\beta\right)}{\sum_{s} exp\left(\Psi_{r,r'}\beta\right)} \quad (48)$$

where $\Psi_{r,r'}$is a vector of characteristics of the regions such as, wages, unemployment and distance between regions while β is the vector of coefficients related to these characteristics as estimated in Persyn et al. (2014).

The labour supply thus evolves as follows:

$$L_{r,e,t} = L_{r,e,t-1}(1 + m_{r,e}) \quad (49)$$

3.3 Alternative mark-ups definitions

In order to introduce any type mark-up modelling frameworks, firms' pricing behaviour is generically characterised by a Lerner-type mark-up equation that relates equilibrium price-cost margins to the perceived elasticity of demand. In equation (24) the perceived elasticity $\varepsilon_{r,r\prime,j}$ is a function of the fixed elasticity of substitution $\sigma_{r\prime,j}$. This implies that the relative market power of region *r* in region *r'* is not transferred through changes in the prices in that region. This means that a region sells their goods and services to all the other regions at the same price. Alternative price settings such as Cournot or Bertrand oligopolistic competition can then be easily introduced by relating firms' market power (and hence mark-ups) to local market statistics. For example, under Cournot conjectures, the perceived elasticity is defined in equation (50):

$$\varepsilon_{r,r',f} = \sigma_{r\prime,f} + (\Omega - \sigma_{r\prime,f})s_{r,r\prime,f} \quad (50)$$

where Ω is the conjectural variation. For simplicity, we generally assume $\Omega = 1$.

Under Bertrand, the perceived elasticity is:

$$\varepsilon_{r,r\prime,j} = \frac{1}{\sigma_{r\prime,f}} - \left(\frac{1}{\sigma_{r\prime,j}} - \Omega\right) s_{r,r\prime,f} \quad (51)$$

With

$$s_{r,r\prime f} = \frac{S_{r,r\prime,f}}{N_{r,f}}$$

$S_{r,r',j}$ is the market share of region *r* on the market of region *r'*.

Both oligopolistic competition frameworks share the intuition that firms with large market shares in local markets are aware of the impact of their pricing choices on the local price index and therefore find it optimal to charge a higher price than they would if their market share were negligible (and thus not affecting the local price index).

4. Data, calibration and elasticities

4.1 Structural parameters and elasticity of substitutions

The model calibration process assumes the regional economies to be initially in steady-state equilibrium. This means that the capital stock is calibrated to allow depreciation to be fully covered by investments. All shift and share parameters are calibrated to reproduce the base year (2013) data in the EU interregional SAM derived from Thissen et al.,, 2018. In this work Supply and Use Tables at country level have been regionalized through a commodity balance approach while trade data are estimated using freight transport data. The number of firms in each region and sector are derived from the European Structural Business Statistics (Eurostat, 2017) while fixed costs are computed using the equilibrium condition in Equation (42) and subsequently added to production.[9]

For illustrative purposes, regional average and associated standard deviation of selected calibrated share parameters are reported in Table 2.[10] The structural and behavioural parameters of RHOMOLO are either borrowed from the literature or estimated econometrically. These are summarized in Table 3 and discussed further in this Section.

The interest rate faced by producers, consumers and investors is set to 0.04, the rate of depreciation for private capital is set to 0.15, while that of public capital equates to 0.05 (Kamps, 2006 and Gupta (2014). The risk premium is a calibrated parameter and determined as a residual from equation (31).

The parameters related to the elasticities of substitution both on the consumer and on the producer sides are based on similar models or derived from the econometric literature. Typically, we assume a rather low elasticity of substitution in production and consumption, and a fairly high for trade between regions.

Table 2. Selected calibrated shares in RHOMOLO

	Average across regions	**Standard deviation**
Wage rate	34.35	17.67
Export total/GDP	0.78	0.79
Export to ROW/GDP	0.15	0.17
Import total/GDP	0.82	0.25
Import from ROW/GDP	0.11	0.09
Labour income shares	0.58	0.10
Share value added in total production	0.39	0.08
Investment/GDP	0.19	0.07
Consumption/GDP	0.83	0.17
Iceberg Transport Costs (average)	0.33	0.23

[9] The relationships between number of firms and value added for each of the imperfectly competitive sectors are plotted in Annex II, Figure A1.

[10] In the Annex the reader can find the trade relationships integrated in the model. In Figure A2 we compare the share of total import (vertical axes) with the share of total export (horizontal axes). While in Figure 3A import and export shares are plotted only for international trade (ROW). We observe high positive correlation between import and export when international trade are considered whilst slightly less correlated results in the overall trade.

Table 3. Elasticity parameters in RHOMOLO

σ^c	0.3
σ^x	0.3
σ^y	0.4
σ^v	0.2
ξ	0.1
σ_j	4
α	0 (default case) or 0.1 under dynamic adjustment over wage bargaining
β	0.1
ς	0 (default case) or 0.25 under dynamic adjustment over wage bargaining
θ	0 (default case) or 0.03 under dynamic adjustment over wage bargaining
v	1
η	0.5
ir	0.15 (annual interest rate)
δ_r	0.15
δ_r^g	0.05

As for the capital-labour substitution elasticity, the literature provides a wide range of estimates. However, there is a strong evidence in support of elasticity lower than 1.[11] The elasticity of substitution between capital and labour has been found significantly lower than 1 in Krussel et al., 2000. In a recent study, Koesler and Schymura (2015), using the World-Input–Output Database found capital labour substitution elasticities significantly lower than one, averaging around 0.13. Okagawa and Ban (2008), van der Werf (2008) and Kemfert (1998) similarly estimate this elasticity to be in the neighbourhood of 0.5. Chirinko (2008) provides an exhausting summary of the empirical literature concluding that evidence suggest this elasticity in between 0.4 – 0.6. Finally, Chirinko et al., (2011) estimated an elasticity of 0.40 using a panel of 160 firms while in Leon Ledesma et al., (2011) the elasticity takes the value of around 0.5. In light of this empirical evidence we fairly set this elasticity equal to 0.4.

We set the elasticity between labour types to 1.5. Justification for this value came from evidence in the empirical literature. For instance Katz and Murphy (1992), found point estimates for the elasticity of substitution between skilled and unskilled labour of 1.4 while Krussel et al. (2000), Heckman et al. (1998) and Ciccone and Peri (2005) found estimates in the neighbour of 1.6. In Leon Ledesma et al (2011), high substitutability between skill types has been found.

Existing studies on the estimation of Armington trade elasticities provide results mainly for the US and very few for Europe. In general, these analyses display substantial variations. They diverge for the level of aggregation, the estimation techniques or whether time series or cross-sectional data are used.[12] Our default Armington elasticity is set equal to 4. This value finds justification from econometric estimates obtained using European dataset derived from the work of Németh et al., (2011), Olekseyuk and Schürenberg-Frosch (2016) and Aspalter (2016) where elasticities range from around 2 to 5, in the interval of 3 - 4.2 and 0.3 – 3.7, respectively. These elasticities appear to be consistent with other studies where single European countries are considered (Welsch, 2008, Imbs and Méjean, 2015 and 2010). However elasticities might be different across industries and across countries. Variation between 'micro-elasticities' and 'macro elasticities' could be significant (typically the former lower than the latter). This is for

[11] See Acemoglu (2003).

[12] For a survey on US Armington elasticities see McDaniel and Balistreri (2003).

example the case of the US (Feenstra et al., 2014 and Imbs and Mejean, 2015) and to a less extent in Europe as shown in Aspalter (2016); therefore sensitivity analysis around the trade elasticities is of utmost importance to deliver a range of results to policy makers that are not bias in one direction.

As for the wage curve parameterization, we typically run a long-run wage curve assuming β=0.1[13] (Nikjamp and Poot, 2005). However, if dynamics over the wage is introduced α, ς and θ are different than zero. In this case, we set $\alpha = 0.1$ where recent econometric evidence has shown value of α significantly less than 1 (Montuenga-Gómez, and Ramos-Parreño, 2005). However the debate is still open and the issue currently remain controversial. For all regions the default value of ς is set to 0.25 and θ=0.03. These values are derived from the study of Nymoen and Rødseth, 2003.

The speed of adjustment in the model it is captured by the elasticity of the cost of capital ρ. In our default simulations this parameter takes the value of 1 as in Uzawa (1969). Estimates of the speed of convergence or adjustment are not easy to find in the literature. The dynamic response of the model to policy shocks might depends on the specific nature of the policy simulated, the market at which the policy is targeted and the number of agents (large or small) the policy is addressed (Caballero and Engel, 2003). Estimates of the elasticity of the capital costs can thus vary widely; for instance in Caballero et al (1995), it can take the value in the range 0.01-2 while in the study of Caballero and Engel (2003) is in the range of 0.2-2.5.

In our default configuration, typically public investment is exogenous, and the public capital stock is treated as an unpaid factor of production subject to congestion, where $\eta = 0.5$. In other CGE models, as for example in Alonso-Carrera *et al*, (2009), the congestion parameter is set equal to 0.36 while three levels of congestion parameter (high, medium and low) are analysed in Seung and Kraybill (2001). Since we do not have specifically estimated parameters, in these circumstances we take the intermediate situation of *proportional congestion* ($\eta = 0.5$) as a benchmark. However, we normally handle the uncertainty associated with the value of this parameter performing appropriate sensitivity analysis.

Finally, the parameters related to the interregional labour migration are estimated in a panel data setting for each country separately and can be found in Brandsma et al., 2014 and Persyn et al., 2014.

4.2 Construction of the Transport Cost Matrix

As mentioned before, Persyn et al., (2018) estimate a novel database of road transport costs for the EU regions at the NUTS2 level. The costs are estimated as the population-weighted average costs of road transport between pairs of cities within the 267 regions. These costs correspond to the generalized transport costs (GTC) in euros, capturing the distance and time-related costs of the optimal route between each pair of regions for a representative truck. For distance-related costs, they consider fuel prices and fuel consumption, tolls, taxes and maintenance costs. For the time-related costs, they focus on salaries in the transport sector, maximum national speeds and European transport regulations on resting times. Additionally, actual geography is controlled by the use of a European digital elevation map that modifies the fuel consumption, speed and travel times according to the gradients of each road-segment. Any change in the components of

[13] Most of the studies on the relationship between unemployment and wages find an elasticity close to -0.1 as summarized by the meta-analysis carried out by Nikjamp and Poot (2005). This confirms the original stiedis of Blanchflower and Oswald (1994, 1995).

this composite indicator converts into changes in transport costs that can be directly implemented in the RHOMOLO model.

For use in the model, the generalized transport costs between origin-destination pairs are translated into a matrix of iceberg transport costs using the trade flows database from Thissen et al., (2018), in combination with information on the average load of trucks from the European Road Freight Transport survey (Eurostat, 2017a). As result, bilateral positive and asymmetric transport-costs are obtained between all regions (i.e. $\tau_{r,r',j} \neq \tau_{r',r,j}$).

Figure 2. Average Generalized Transport Cost for each EU region. Euros.

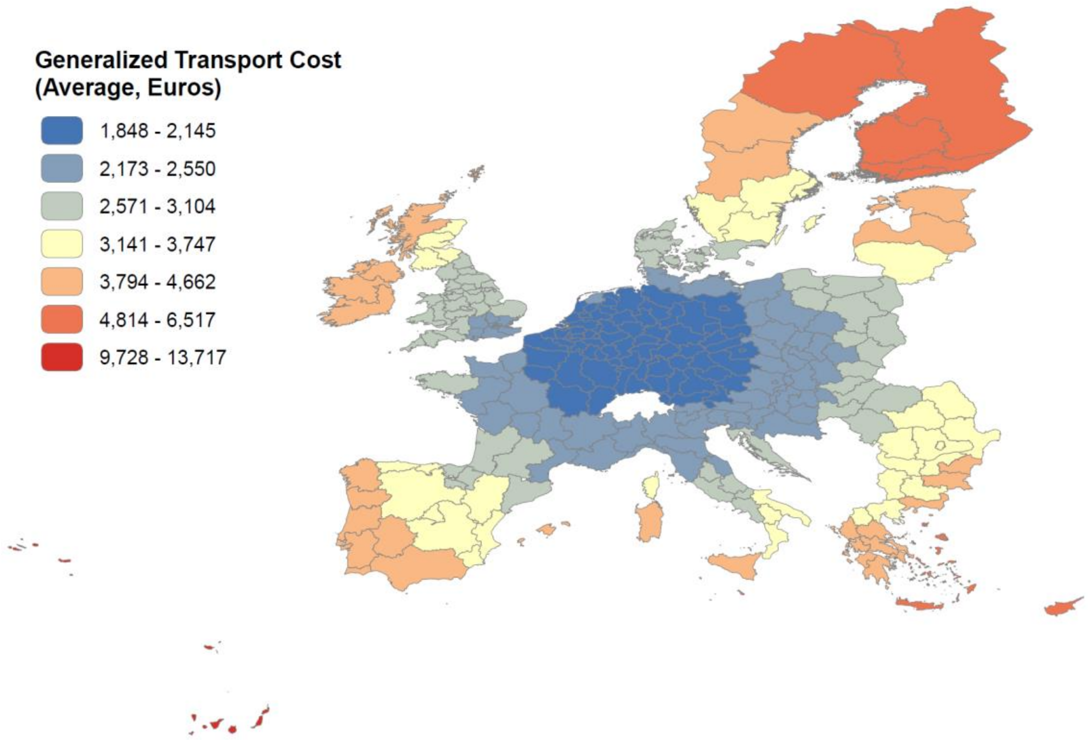


Figure 2 represents the average GTC, i.e. the transport cost (in euros), from each region to all the others. Core central regions (blue) face the lowest transport costs due to their close proximity and accessibility to other regions, which reduces their fuel consumption and time-related costs such as driver wages. By contrast, peripheral regions (red) in Southern Europe suffer from higher transport cost, whereas Nordic regions face high transport costs due to their remoteness, combined with high salaries in the transport sector.

Finally, Persyn et al., (2018) create a transport policy tool to assess the impact of transport infrastructure investment on transport costs due to upgrading roads from primary and secondary roads to highways. Roads are selected through a ranking of candidate roads for upgrading using a cost-benefit analysis, taking into account the aggregate road use, and using country-level information on construction costs, adjusted for terrain. With the upgrading, transport costs are affected, and a new set of optimal routes is calculated and a new transport-costs matrix is obtained.

The new modelling of the road network and transport costs introduces important features into RHOMOLO, because (1) it allows to capture the real geography of the EU regions; (2) it allows for transport costs shocks accounting for network effects; and (3) given the important amount of cohesion and regional funds directly invested into upgrading roads, the transport policy tool allows to transform investments in infrastructure into changes in transport costs that can be easily incorporated into RHOMOLO. Since it has been recognized that transportation costs and differences in the relative accessibility of regions drives the location of economic agents to spatially dispersed economic outcomes (Di Comite et al., 2018; Bosker and Garretsen, 2010), the new transport-costs module of RHOMOLO represents an essential tool for policy analysis.

4.3 Construction of the capital Matrix *KM*

The capital $KM_{r,i,j}$ appearing in equation (35) has been estimated by means of a Doubly Constrained Minimum Information (MI) model (Schneider and Zenios, 1990).

Let $T_r = \sum_j I^P_{r,j} = \sum_i I^P_{r,j}$ denote total Investment by regions *r*. Considering $t_{I,J}$ the model estimated probabilities that any investors in region *r*, receive from *j* and pay to *i* where *i*= *j* and some prior probabilities $\bar{t}_{r,i,j} = \frac{v_{r,i,j}}{\sum_{i,j} v_{r,i,j}}$ derived from technical coefficients as appeared in equation (15) , the model can thus be formalized as follow :

$$min \sum_i \sum_j t_{r,i,j} \left[ln\left(\frac{t_{r,i,j}}{\bar{t}_{r,i,j}}\right) - 1 \right] \quad (52)$$

subject to

$$\sum_i t_{r,i,j} = \frac{I^S_{r,i}}{T_r}; \ \sum_j t_{r,i,j} = \frac{I^P_{r,j}}{T_r}; \quad (53)$$

$$0 \leq t_{i,j} \leq 1 \quad (54)$$

where T, $\bar{t}_{r,i,j}$, $I^S_{r,i}$ and $I^P_{r,j}$ are fixed. Therefore $KM_{r,i,j} = \frac{t_{i,j}T_r}{I^P_{r,j}}$.

5. Discussion on the assumptions

RHOMOLO models the behaviour and the adjustments taking place in-and-among regions. Therefore, RHOMOLO simulations aim to capture and measure the relationships taking place between regional economies through factors mobility and trade of goods and services. As compared to country modelling, the regional dimension of the model requires an additional effort when attempting to identify the main mechanism operating in the market. Regions do not have the full range of macroeconomic policy levers typically associated with countries. For instance, monetary and fiscal policy are under the control of national Government or superior authority (EU) so that policy tools and some macroeconomic adjustment mechanisms, whose incorporation can be considered undisputed in national models, cannot regularly be applied to the case of a region.

Typically regional economies are more open than their national counterparts.[14] Furthermore, EU regions share the same market of goods, labour and capital, implying faster and easier economic adjustments. This means for instance that any price and income changes occurring in one region can be transmitted very effectively throughout the economic system, thereby inducing economic agents to adjust their market behaviour, e.g. demanding more imported goods or moving assets to other regions.

[14] By construction, the sum of the regions of a country are at least as open as the country itself (being at exactly the same level of openness only in the unlikely case of zero inter-regional trade within the country). Notice also the scale dimension of the issue: whereas every individual household is fully open (in the sense that is the imports and exports to other households the totality of its economic transactions), the world as a whole is a closed economy. Hence, there is normally a connection between the territorial scale of the analysis and the expected level of openness of the economies analysed.

Unlike national economies, it is unlikely regions will face binding balance of payments constraints.

The balance-of-payment adjustment operating in RHOMOLO is such that any current account imbalances are directly offset by changes in the capital account. We do this to reflect the high degree of openness observed in regional economic systems. Particularly in our case, regions belonging to the EU and especially those belonging to the common currency area operate in a fully integrated market and a unified banking system. This means that changes in foreign exchange reserves are not possible. This implies that, for any loss in competitiveness, price and income adjustment musts take place in order to produce the corresponding changes in capital accounts required to offset the deficits in the current account because regions cannot directly use fiscal and monetary policy to offset negative payment restrictions generated by income deflation.

We do not explicitly include money as a commodity in the model, so we do not need to explicitly impose money market equilibrium (for example allowing money supply to adjust endogenously to money demand). In these circumstances, equilibrium in commodity market (Equation (38)) is sufficient to guarantee the equilibrium also in the payments account. The lack of explicit treatment of money is a clear limitation of the model. In particular, the absence of a banking system module prevents us to capture the interaction of agents and financial intermediaries. This also means that agents could borrow or lend without facing an endogenous credit risk. However the model is able to capture any change in the market risk premium exogenously. The market risk premium parameter is calibrated in the model as the difference between the market return and the risk free rate (interest rate plus depreciation).

In RHOMOLO, investment and saving decisions are kept separated and in contrast to standard applications in our formulation savings follow the Solow-Swan assumption, keeping the rate of savings exogenous. Naturally, this does not prevent the absolute level of savings from varying over time. Investments are determined independently of savings with a separate investment function (Uzawa, 1969) to reflect the Keynesian intuition that investments varies according to profitability. The incorporation of these closures seems consistent with the adjustment that would occur in a regional economy. Regions are small open economies and it appears unlikely that regional households react passively to sustain the financial need of the regional system as in the case where households' savings is wholly determined by imposing balance of payment constraints.

The configuration of the labour market is of utmost importance for the sign and magnitude of results of the simulation. There is still no clear consensus in the economic literature on the particular form of microeconomic real wage dynamics. While Blanchflower and Oswald's estimates (1994, 1995, 2005) argue in favour of a Wage Curve specification, showing little autoregression in real wages, Blanchard and Katz (1997) provide evidence in support of a Phillips Curve, rather than a Wage Curve when United States data are used. Still for the US, Staiger, et al., (2002) and Card and Hyslop (1997) also report a high level of auto-regression in U.S. wages, suggesting support for a Phillips curve.

While the existence of a wage setting curve in United States data has been viewed as more controversial, a number of studies for the EU apparently probe the robustness for a wage curve. For instance Nijkamp and Poot (2005) in their meta-analysis on a sample of around 200 wage curve elasticities conclude that the Wage Curve is empirically robust. Moreover, for some north European countries, such as Norway, Denmark and UK, the autoregression coefficient is greater than zero but significantly lower than 1 and around 0.5 as reported in Montuenga-Gómez and Ramos-Parreño (2005). Therefore, we cannot consider this evidence strongly supporting a Phillips curve adjustment. Rather as suggested by Montuenga-Gómez and Ramos-Parreño, 2005, these estimates are favourable to a type of wage setting curve with low adjustment towards a new equilibrium.

Although the lack of clear consensus in the economic literature, it seems that empirical evidence for the EU economies argues in favour of a wage setting curve. In these circumstances we opted for a long-run wage curve, as default labour market closure operating in RHOMOLO. However, as seen in Section 3.1, alternative wage settings are incorporated in the model. We can run the model under fixed nominal or real wages to reflect wage rigidities. In addition, there is an option for running the model under a traditional Phillips curve. We believe that the flexibility to switch between labour market closures make us in the position to offer policy makers in general and our partner DGs in particular, a range of potential impacts associated to specific policies, in consideration of the uncertainty related to the real operational mechanism governing the EU labour market. Furthermore, by performing an additional set of counterfactuals based on different labour market closures one can better disentangle the main mechanisms and drivers in operation in the model.

In particular, comparisons of outcomes derived from the Wage Curve and the Phillips Curve are of extreme importance to assess two distinctive economic concepts. The wage curve reflects a non-competitive environment where unemployment not only acts as "discipline device" but also as a market clearing mechanism. In contrast, the Phillips Curve represents the necessary adjustments process of wage inflations towards a competitive equilibrium. This means that the macroeconomic impact associated with the two specifications can be dramatically different especially in the long-run. However in our baseline simulations, we attempt to embrace the two concepts parameterizing appropriately (using recent econometric evidence) the wage equation (Eq. 27) as discussed in Section 4.

As for the assumptions made on the product market structure, in the economic literature there is still no clear consensus on the realistic form of competition modellers are required to use. In the default configuration of RHOMOLO a selected number of sectors are modelled according to monopolistic competition a la Dixit-Stiglitz. The implications are such that the same selling price for a given industry applies to all destination countries since the mark-up does not dependent from the market shares. A single industry of a given region sell products to all the other regions at the same fob (first-on-board) price, even if consumers in the importing regions can observe different cif (Cost, Insurance and Freight) prices, including iceberg transport costs.

Running the model under monopolistic competition allows us to simplify the analysis and provide an easy interpretation of the results. However RHOMOLO, as seen in Section 3.3, does incorporate alternative market structures, which allow us to perform additional counterfactual analysis to measure the potential changes one will encounter assuming a different competitive frameworks. Naturally given that the market shares for individual varieties are small, the resulting quantitative effects that one can obtain from the incorporation of different market structures is expected to be negligible though technically elegant.

6. Experiments and analysis

6.1. Simulation strategy

We perform a simple experiment to show the main regional economic adjustments associated to a positive demand shock. Essentially, we focus on the capacity of each individual region to contribute to the overall EU economy through trade spillovers by simulating a permanent increase in final demand, namely government expenditure, of €10M in each of the 10 economic sectors, separately implemented for each of the 267 EU-NUTS2 regions incorporated in the RHOMOLO model. The experiment thus implies a total permanent monetary injection of €100M per year in each regional economy. This section provides a comparative static analysis where the initial steady-state equilibrium is compared with a post-shock long-run steady-state economy. The investigation of the long-run equilibra achieved after the process of full adjustment to the initial disturbance helps to maintain the analysis simple and it is expected to make the reader in the condition to better understand the underlying theory behind the model.To keep the analysis as simple as possible, we deliberately neglect any adverse supply-side effects that would arise from endogenous offsetting effects as we would have under a balanced budget framework. This means that we avoid binding constraints on equation (8). Yet, the nature of the government spending is such that any increase in consumption does not affect public physical assets, that is to say it will only increase demand for final goods and services, again ignoring direct supply-side implications. Furthermore, to prevent output changes to affect the effective public capital stock, we set $\xi = 0$.

Since price changes drive the sign and the magnitude of the impacts within each region and in the Rest of the EU (REU), it is interesting to differentiate and to analyse the corresponding outcomes under different labour market closures by running the same shocks for a number of alternative wage settings. Indeed, the choice of labour market assumptions may result in widely different outcomes. The wage response could be fully incorporated into commodity prices, in turn affecting competitiveness and trade patterns. We compare three labour market assumptions that correspond to the alternative labour market closures incorporated in the model: fixed real wage, wage curve and Phillips curve. The idea here is to gradually increase upward pressure on wages and measure the likely effects of alternative labour market assumptions directly on the perturbed and non-perturbed economies. We are also interested to analyse the extent to which wage pressure in the perturbed regions are passed onto other regions. That is, the degree at which, competitiveness effects in one region generate economic benefits or losses to other regions through changes in trade patterns.

Under the fixed real wage assumption, we attempt to mimic the behaviour of a fixed-price model such as a conventional Leontief model. We would expect an adjustment path that would bring prices back to their initial steady-state level.[15] This means that, in the absence of price changes, in the long-run the magnitude of the impact and the transmission of the effects from the perturbed regions to the others will solely (or mostly) depend on the initial calibrated shift and share parameters of the model.

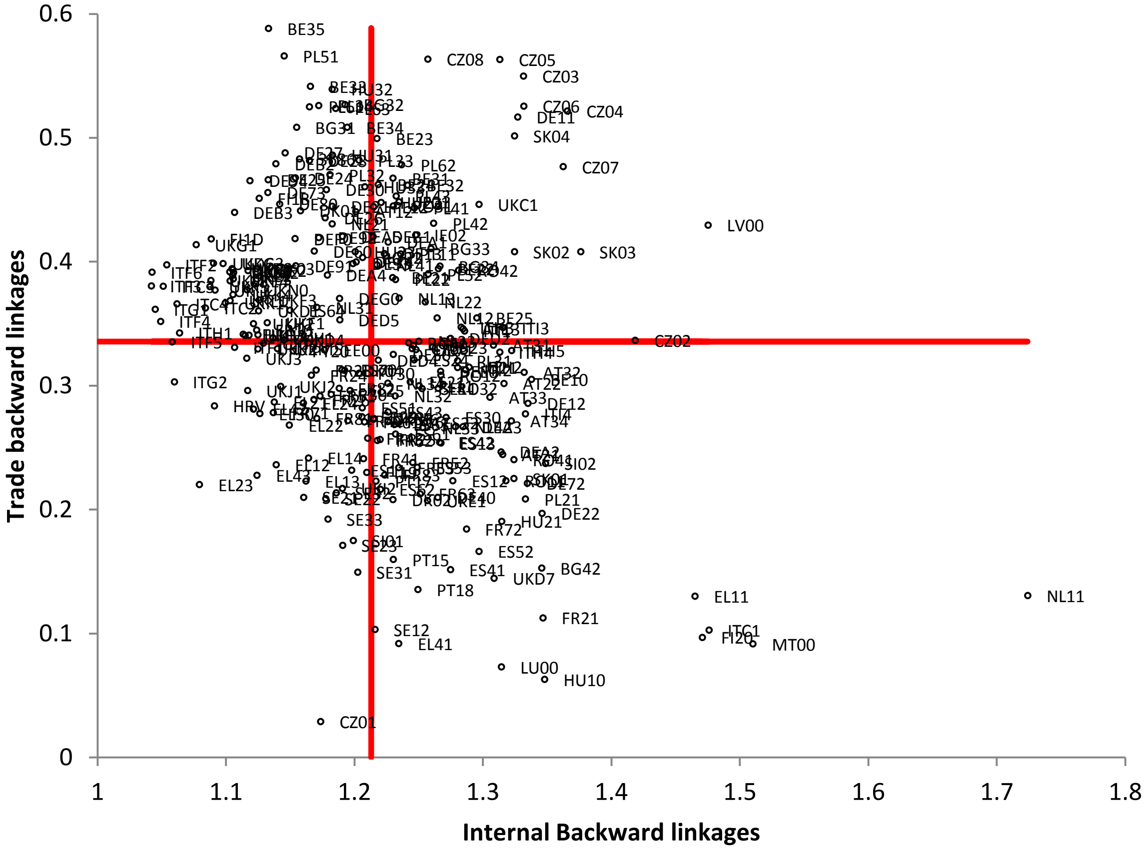
When we move to the other labour market assumptions, endogenous wage effects should generate upward pressure on prices. In the long-run, it is likely to observe higher wage pressure under Phillips curve wage behaviour because increased demand for labour resulting from a surge in demand of final goods and services has to be fully offset by a rise in wages.

Under labour market assumptions that permit upward wage pressure we would expect, following an initial disturbance, an alteration of the initial domestic and trade backward linkages. To have an idea of the backward linkages initially governing our steady-state economy, in Figure 3 we plot the domestic backward linkages (*x-axis*) and trade backward linkages (*y-axis*) derived from a Type I Leontief multiplier (Miller and Blair, 2009). The red lines identify the computed average domestic and trade backward linkages that divide the quadrant in 4. On the top right quadrant we have regions that generate greater internal multiplier and at the same time generate high spillover at the benefit of the rest of EU. On the contrary the bottom-left quadrant identifies regions that not only provide little spillover to the other regions but also generate lower multipliers in their own domestic economy. Under the wage curve and Phillips curve wage setting we expect this initial situation to be altered. However under fixed real wage, if prices remain

[15] The system behaves almost as an IO model (see e.g., Gilmartin et al., 2013). In reality prices are not exactly converging to pre-shock levels since nominal wages adjusts to offset changes in CPI.

fixed in the long-run (or close to pre-shock levels), no changes in the relative composition of the external and internal backward linkages are expected to happen.

Figure 3. Calibrated domestic and trade backward linkages



We begin by describing the long-run impact and subsequently we analyse the transitions paths for selected regional economies. In the first instance, we run the model assuming all product markets perfectly competitive. However in the proceeding of the paper we run the same set of simulations for the three alternative labour market closures incorporating imperfectly competitive markets thus comparing each of the market structure's options integrated in the RHOMOLO model: monopolistic competition, Cournout and Bertrand market structures. The purpose of using this setup is to show how a permanent demand shock alters the initial allocation of firms. A further interest is also to measure the extent to which the initial incorporated varieties in the model are influenced by alternative wage structures.

6.2. Analysis of the results under perfect competition

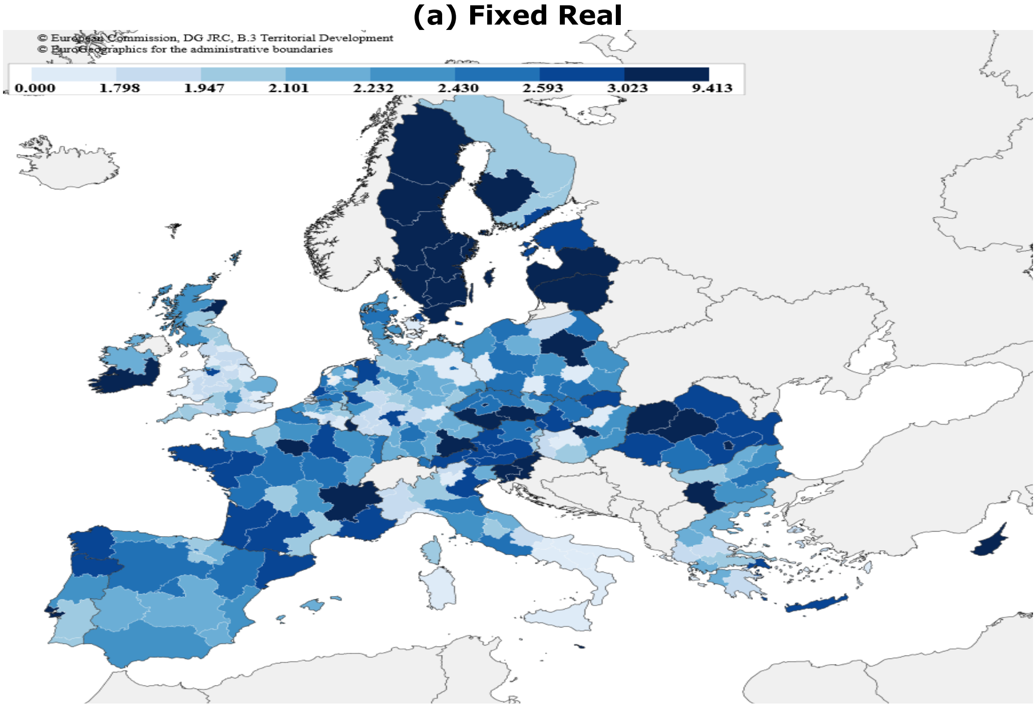
The impact on the perturbed regions

To compare the outcomes of the model obtained for each of the 267 regions under the three different wage setting structures, we map in Figure 4 the long-run regional GDP multipliers (measured as changes in GDP divided by the changes in final demand) obtained under the three labour market assumptions: fixed real wage (top panel), wage curve (central panel) and Phillips curve (bottom panel). Regions are grouped in quintiles[16] and the resulting outcome is a variegate pattern, with darker shading highlighting regions with greater GDP multiplier effects. Under fixed real wages the internal multiplier effects seem more regularly distributed compared to the other two cases. Furthermore, we observed that for all wage structures Easter European regions generate larger multiplier effects while lower multiplier effects are generally associated to central European regions. Maps' inspection also suggest that regions registering higher multiplier effects under one regional wage setting do not necessarily generate greater multiplier effects under other wage setting structures. For instance, regions in England and South of Italy report larger multiplier effects (darker shading) with a Phillips curve and a wage curve but not under fixed real wages.

It is thus noticeable that the three set of results differ not only in the magnitude of the impact experienced by each region, but also and more importantly in the geographical pattern that might change according to the labour market assumptions used in the simulations. To reinforce this finding and to test whether the outcome obtained under the three different wage structures are correlated with each other, in Figure 5 we plot absolute long-run GDP changes for each region compared across specifications of labour market modelling. The absolute changes in real GDP obtained in each of the 267 perturbed regions under the fixed real wage and the wage curve are plotted in panel (a), while panel (b) compares absolute changes in real GDP under fixed real wage and the Phillips curve, and finally in panel (c) the scatterplot illustrates the relation between regional outcomes associated with wage curve and the Phillips curve assumptions. The correlation between the results obtained under the wage curve and Phillips curve is around 0.8 whilst the correlation between the results obtained under fixed real wage and wage curve on the one hand and fixed real wage and Phillips curve on the other hand is around 0.5 in both cases.

Figure 4. The regional economic impact of simulating 100 M increase in government expenditure. Simulations perform separately for each individual region under three labour market assumptions. Value in million euro

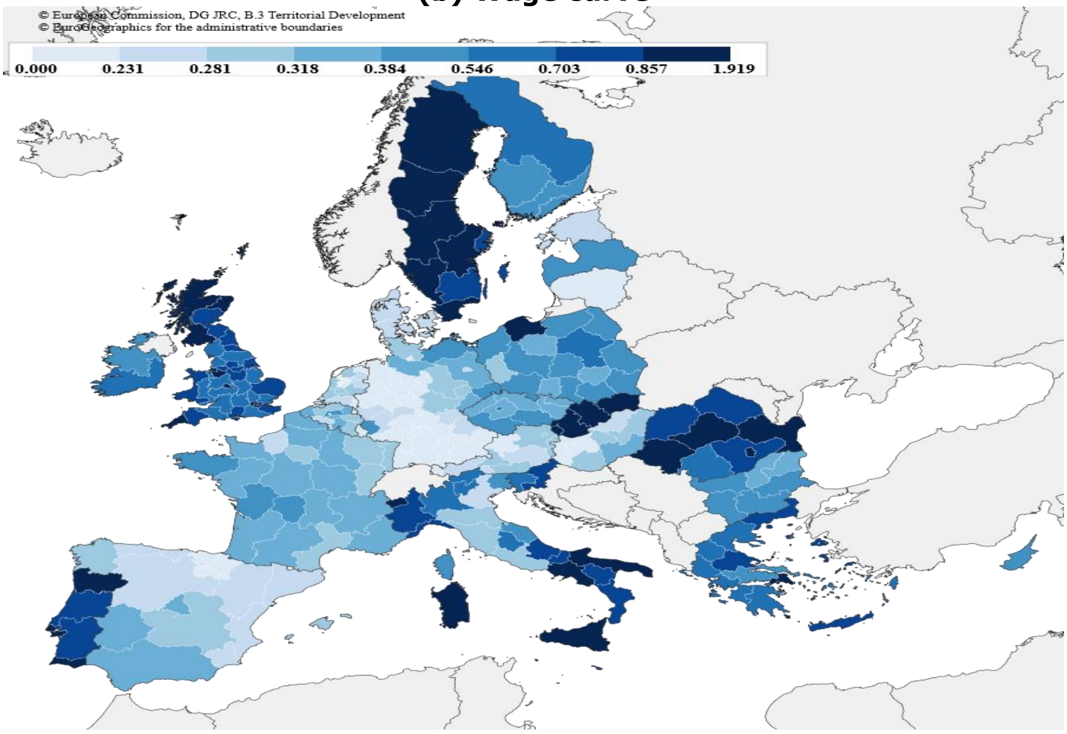
(a) Fixed Real



[16] In the maps reported in Figure 4 we are not using the same scale for each of the wage configurations. Quintile groups are thus defined on the GDP changes obtained specifically under each of the labour market closures. Application of the same quintiles for each of the three simulations would result in illegible maps given that the magnitude of the impact differs significantly among labour market closures.

Figure 4 continue

(b) Wage curve



(c) Phillips Curve

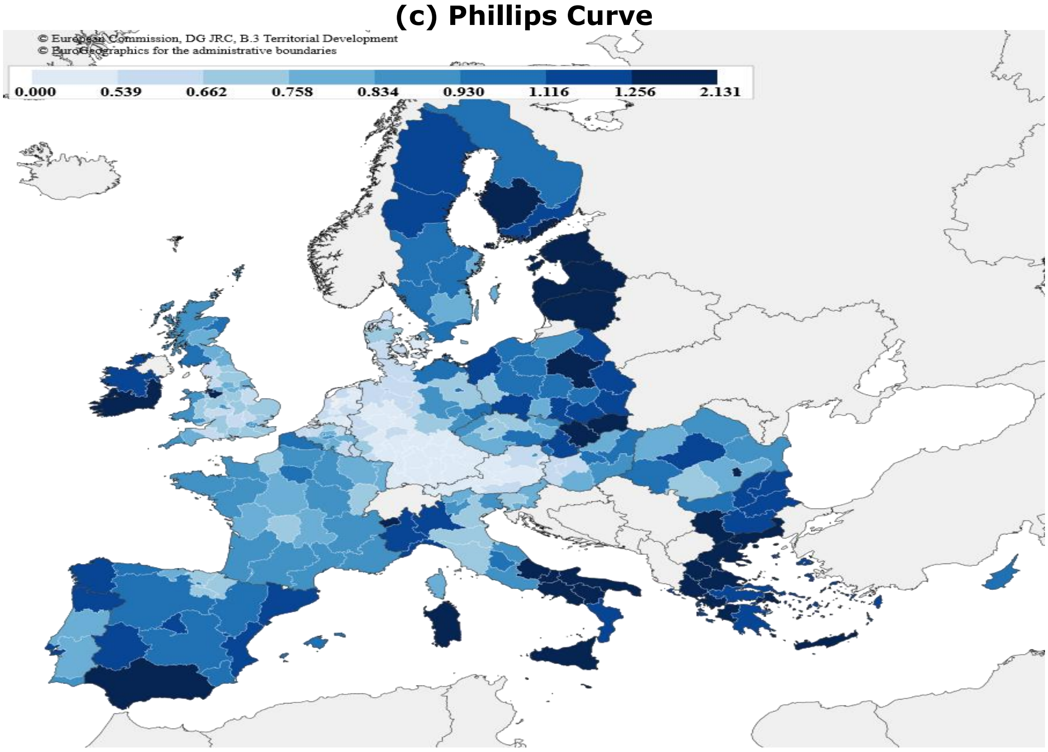
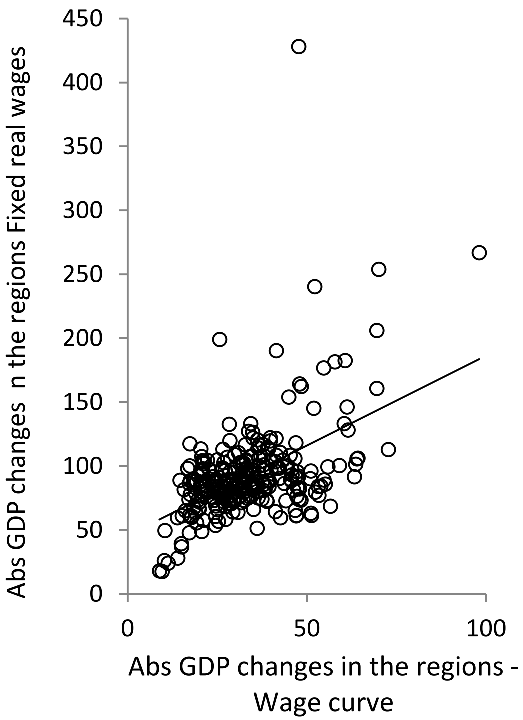
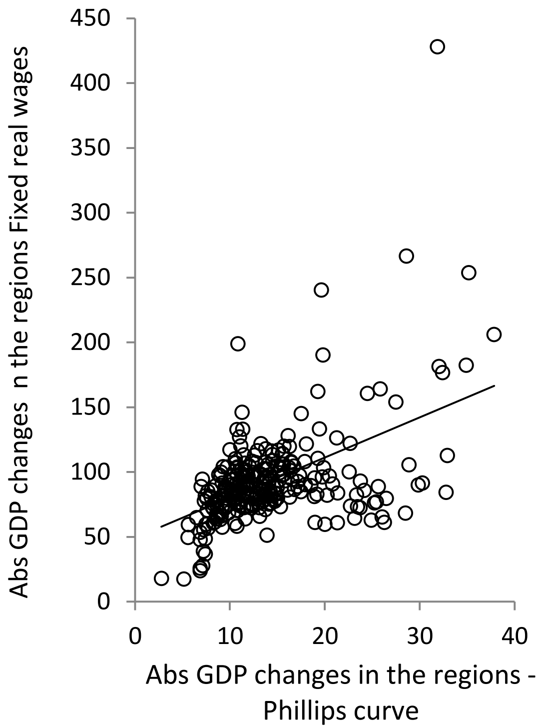


Figure 5. Co-movements between internal multiplier under three labour market assumptions

a) Fixed real wage – Wage curve **b) Fixed real wage – Phillips curve** **c) Wage curve – Phillips curve**





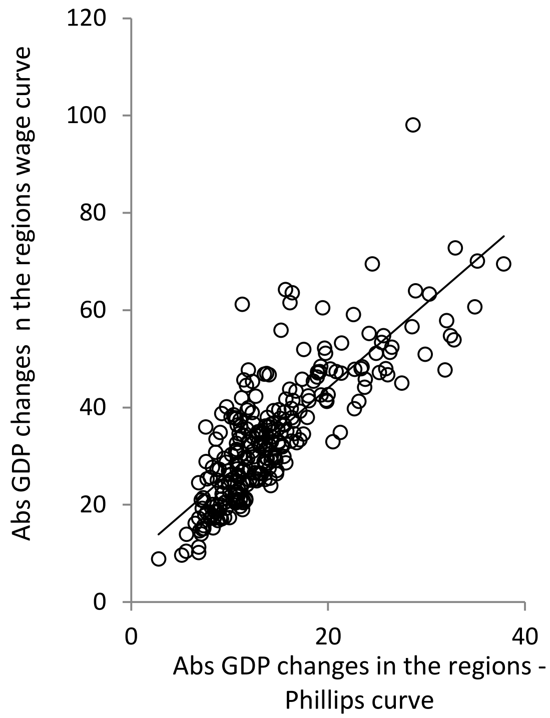
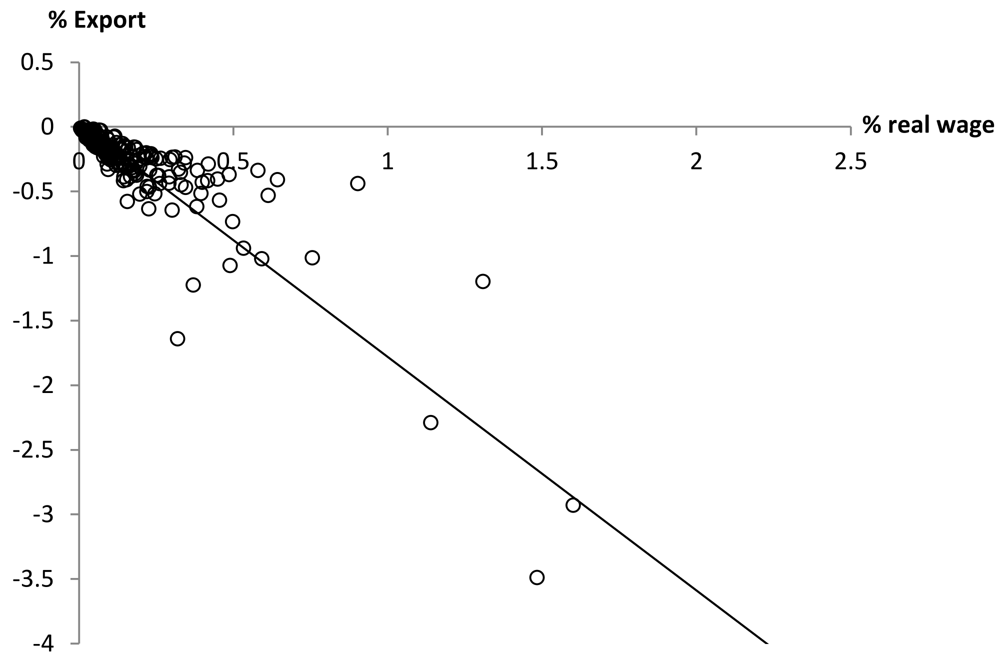
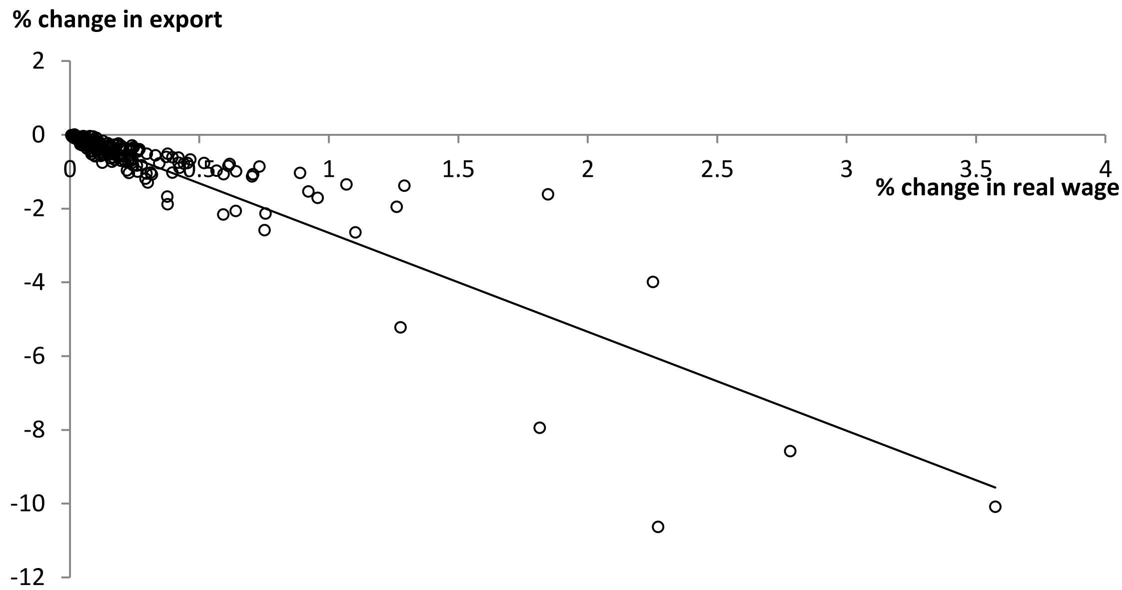


Figure 6. The relationships between exports and real wages under wage curve and Phillips curve

a) Wage curve



b) Phillips curve



The strong co-movement of the output generated under the wage curve and Phillips curve could be explained by the fact that in both cases there is an upward pressure on real wages as a consequence of an augmented aggregate demand that in turn causes an increase in labour demand. More specifically under the Phillips curve, the long-run rise in labour demand is fully counteracted by an increase in wages which is required to maintain a vertical labour supply curve at the natural rate of unemployment. By contrast, under the wage curve, the excess demand for labour is cleared through adjustments in unemployment rates that in turn act as 'discipline device' (or as a measure of bargaining power of workers). In our experiments, unemployment rates fall, placing workers in the position to claim and obtain a rise in real wages. In both cases upward pressure on wages results in an increase in commodity prices that generate a fall in competitiveness and in turn a reduction in exports particularly exports to the ROW. The strong co-movement between exports and real wages can be seen in Figure 6 where the exports-real wages relationships are plotted for the case of wage curve (top panel) and Phillips curve (bottom panel). In the perturbed economy loss in competitiveness, however, only partially offset the positive effect of an increase in demand therefore the ultimate effect in both wage configurations is an increase in real GDP. As we will discuss later in this section, by lowering the trade elasticity, the negative term of trade effects that provide adverse competitiveness effects will be moderated generating in turn bigger multiplier effects.

For the case of fixed real wages, and specifically for the example considered in this paper, where supply-side effects of an expansion in government expenditure are intentionally neglected, the long-run equilibria derived from the model attempt to emulate a conventional Input-Output model where infinite supply of factors (see e.g., McGregor et al., 1996 and Gilmartin et al., 2013) and fixed prices are applied. Essentially, with fixed real wages the upward pressure on commodity prices in the long-run is significantly reduced and of no importance. With no changes in real wages, changes in prices are constrained to be small and not enough to cause adverse competitiveness effects.[17] It is therefore likely to expect larger regional multiplier effects under fixed real wages.

Table 4. The GDP multiplier effects under three alternative labour market closures

	Regions			EU		
	PC	WC	FRW	PC	WC	FRW
Average Multiplier	0.14	0.34	0.93	-0.10	0.10	3.04
	(0.06)	(0.13)	(0.38)	(0.39)	(0.62)	(0.77)

Standard deviation in brackets. PC: Phillips curve. WC: Wage curve. FRW: Fixed real wages. Source: Author's simulations

As a results of different competitiveness effects associated to the three labour market options, the expected economic impact in the perturbed regions and the propagation of the spillovers when transmitting the shock from the perturbed regions to the non-perturbed regions vary according to the to the degree of wage pressure considered. In Table 4, we report the long-run average multiplier effects calculated over 267 simulated multipliers[18] obtained in each region perturbed and the corresponding average multiplier

[17] Under fixed real wage, the nominal wage might change in response to changes in the regional consumer price index (CPI). Furthermore, all the excess demand of labour is absorbed raising labour market participation.
[18] The multiplier effect is calculated in each region dividing the absolute changes in GDP obtained in the perturbed region to the changes in government expenditures. The EU multiplier is calculated dividing the absolute GDP changes for the whole EU obtained by simulating each region divided by the change in government expenditure.

obtained for the overall EU economy as a result of a single regional perturbation. Results for the three labour market modelling assumptions are also reported.

As expected at the individual regional level, larger upward pressure on wages reduces the economic impact on the perturbed regions. We observe the highest impact under fixed real wages (0.93) while the lowest impact is recorded under the Phillips curve (0.14). Greater regional variation is observed under fixed real wages where the standard deviation for the regional multiplier effects is higher (0.38). The lowest standard deviation is recorded under the Phillips curve wage assumption (0.06) suggesting that under this labour market closure each single regional economy is by and large generating a similar internal multiplier effect (or at least close to the average).

For each of the wage configurations it is helpful to investigate the role played by the calibrated shares parameters. Intuitively we would expect that the capacity to generate higher multiplier effects within a region is contingent upon its import intensity. If a region satisfies the increased demand for goods and services through higher imports, the resulting impact is likely to be lower than the case in which excess demand are met through internal production. In Figure 7, we evaluate the model's ability to match these facts by showing the correlation between the simulated absolute GDP changes and the log of the share of import/GDP ratio as in the initial steady-state for each of the wage structures: fixed real wage (panel a), wage curve (panel b), Phillips Curve (panel c). There is a strong negative correlation under fixed real wage whilst for the remaining wage setting alternatives the correlation is lower, though still negative as expected. Under fixed real wages, the steady-state economy does not suffer from significant price pressure and therefore the economic impact mainly depends on the initial (pre-shock) ability to meet augmented demand using internal production. In other words, the initial backward linkages play a great role in determining the economic impact associated to an external disturbance. As said above under fixed real wage assumption the RHOMOLO model operates as an extended standard I-O-based demand-driven model where all the elements of final demands (e.g., investment and consumption) are endogenous (see e.g., Lecca et al., 2015 and Swales 2005). However, for the case of wage curve and Phillips curve, the change in price alters the initial economic structure making the regional economy less dependent from the calibrated share parameters. In these circumstances the indirect supply-side effects achieved through change in prices contrary to the case of the fixed real wage are able to modify the existing pre-shock backward linkages.

Interregional spillover

By and large, the spillovers generated by each region differ dramatically and so the capacity of a single regional economy to transmit the shock to the rest of non-perturbed regions is also subject to an extensive variation. Inspecting Table 4, we observe that the wage setting structure will also impact significantly the REU economies. In this table we report the multiplier effects for the all EU, however given that the shock performed in each region is the same, the average spillover (that is the impact on the REU economy as whole) can be easily calculated from the difference between the EU multiplier and the regional multipliers.

Under fixed real wages and a wage curve we register a positive impact for the EU as a whole (the multipliers being 3.04 and 0.10 respectively) while the overall EU impact obtained under the Phillips curve is in average negative (-0.10). Only under the fixed real wage, the EU multiplier is significantly higher than the internal average multiplier observed in the regions (0.93) meaning that the impact on the REU is positive. Whilst for the remaining two labour market assumptions the resulting spillovers generate, on average, negative impact on economic activities for the REU. The reported standard deviation suggests that not all regions generate negative spillover for the REU. In general, we have observed that a single region perturbation generates positive spillovers within the country they belong to, but ultimately the impact in the other REU regions is negative. Typically distance matter for backward spillovers but country boundaries seem more important in this cases[19].

The perverse effects in operation under upward wage pressure on the REU economy need to be analysed further. When a single region is perturbed, the demand for intermediate and final goods from the REU economies increases. Therefore, the overall REU economy will enjoy an increase in exports towards the perturbed regions and possibly towards the other remaining EU regions. However, the increase in demand for goods and services in the REU economy generates also an increase in wages that in turn cause commodity prices to rise and therefore generate negative terms of trade effects. Ultimately, loss in competitiveness especially with respect to the ROW will come into play. While loss in competitiveness in the perturbed regions are fully counteracted by the increase in internal production, in the REU economies (the non-perturbed regions) the fall in the exports to the ROW could fully offset the positive benefit of an increase in interregional exports. In addition, the rise in domestic prices makes the import of goods and services more expensive. This is what is happening for the wage curve and Phillips curve cases as shown in Table 4. The upward wage pressure registered under these two labour market closures is able to make in average the REU economy worst off. Under these two wage setting options an important role in determining the effectiveness of the channels of interregional spillover transmission is played by trade elasticities; lower values being associated with bigger multipliers within the region due to a higher resistance of regional consumers to trade-off locally produced goods for imported goods when the prices of the former rise.

In order to test how sensitive our results can be to variations in trade elasticities, in Table 5, we report the EU average multipliers obtained lowering the substitution possibilities with the REU and the ROW. The default elasticity is set to 4 in both cases. We now implement the same simulations recalibrating the model with an elasticity of substitution of 2 in EU interregional trade while for the international trade (trade with the ROW) the elasticity is now set to 0.5. The GDP impact in the perturbed regions has increased significantly compared to the case where default elasticities apply. Furthermore the overall impact on the EU and the REU is now positive for all three wage structures considered. As anticipated above this is the result of lower substitution possibilities in trade that reduce the adverse competitiveness effects previously occurring in the REU economy.

Table 5. The multiplier effect under three alternative labour market closures obtained with lower trade elasticity

	Regions			EU		
	PC	WC	FRW	PC	WC	FRW
Average GDP Multiplier	0.35	0.56	0.93	2.49	2.26	3.04
	(0.4)	(0.25)	(0.38)	(2.09)	(0.88)	(0.77)

Standard deviation in brackets. PC: Phillips curve. WC: Wage curve. FRW: Fixed real wages. Source: Author's simulations

With lower trade elasticities the perturbed regions are faced with lower adverse competitiveness effects of an increase in wages resulting in a higher GDP impact. Similarly in the REU economies, the fall in exports to the ROW is now not able to

[19] It is part of our future agenda to undertake further research to analysis the extent to which trade spillover are affected by distance.

counteract the benefit of an increase in demand of goods and services coming from the perturbed regions and the rest of other REU regions. Hence impact on GDP is positive for most of the non-perturbed regions.

It is worth noticing that trade elasticity however plays no role under fixed real wage. For this wage configuration the results reported on Table 5 are the same reported in Table 4. In this case the change in prices expected in the long-run are negligible making changes in elasticity of substitutions of no importance. Hence with fixed prices the propagation of the shock towards the other EU regions will exclusively depends from the capacity to generate bigger internal output multipliers and from the initial propensity to import from the REU economies.

In summary, there are two sets of stylized facts that deserve to be highlighted in the simulations. First, the propagation of the shock to other regions crucially depends on the wage regime adopted in the model. Clearly the labour market closure adopted in the model has to be as close as possible to that empirically observed in the region under scrutiny. In our analysis we show that under fixed real wage the magnitude of the spillovers is higher than in the alternative modelling options for two main reasons. The first, is that the internal multiplier generated in the perturbed regions is significantly greater than in the other wage specifications because the absence of upward wage pressure prevents the loss of competitiveness. The perturbed regions thus faces higher demand for goods and services from the REU. The second reason is that the spillovers are transmitted to the other regions without altering the initial geographical trade pattern because the initial import intensity is not affected significantly due to the long-run return of prices to their initial steady-state level.

The second stylized fact is related to the importance of the choice of trade elasticity that in combination with the labour market channels could results in a widely different outcome. The real GDP changes for the non-perturbed regions under a wage curve and a Phillips Curve could be negative if the trade elasticity is high enough to cause adverse competitiveness effects. However, under fixed real wage the non-perturbed regions always benefit from an increase in demand occurring in another region. The extent of the trade spillover, that is the impact on the REU economies, in this case will necessary be influenced by the share of imports of goods and services from the REU by the perturbed region. This can be for example be seen in Figure 8, where for each of the wage structures assumed we plot the absolute GDP changes in the REU on the x-axis and the log of import from REU of each region as a share of GDP. Scatterplots suggests that only under fixed real wage we can envisage positive correlation between the two variables. However some sort of correlation is hard to be identified in the other two cases.

Figure 7. The relationships between the change in real GDP and the import intensity under the three labour market assumptions

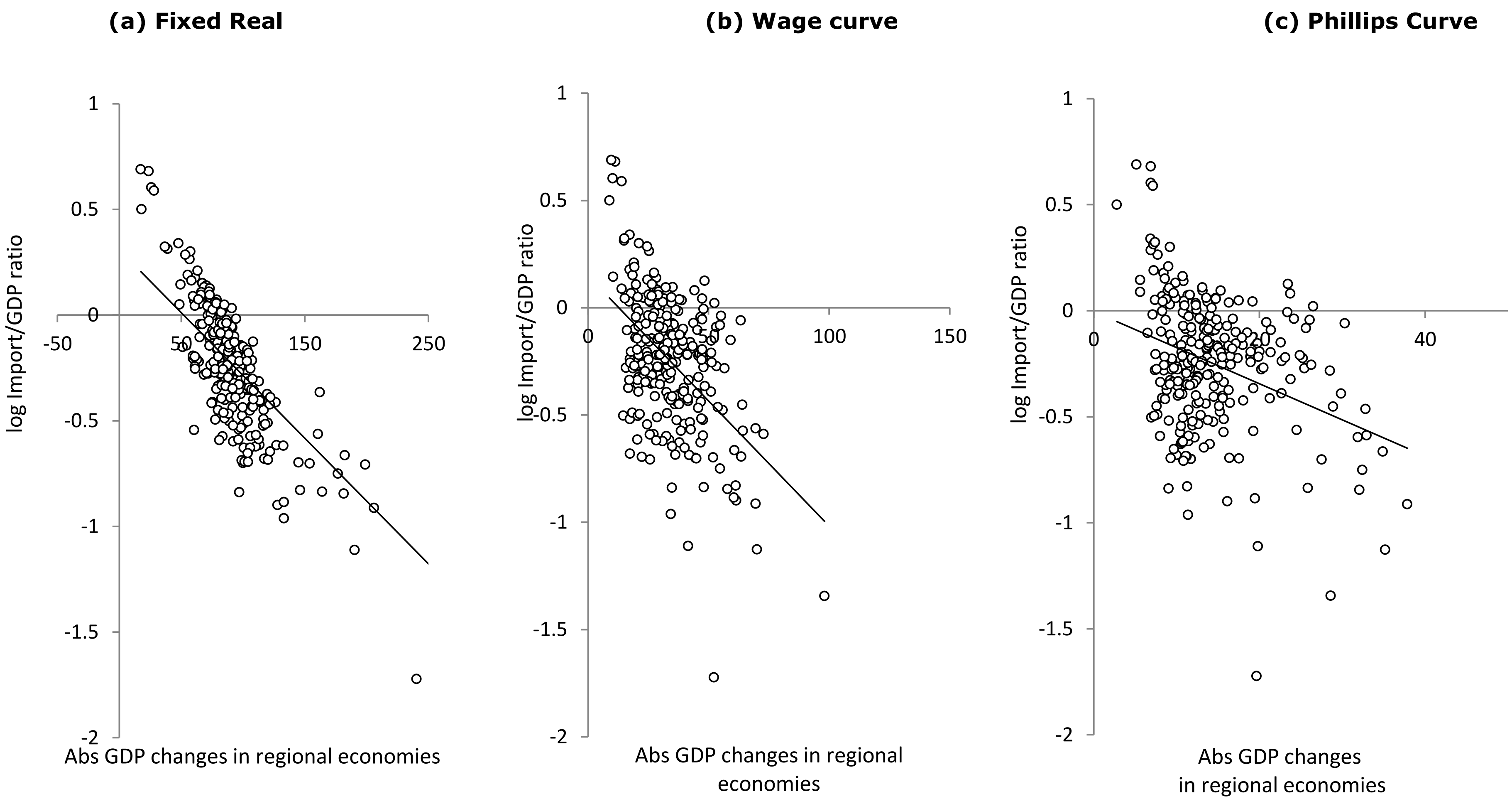


Figure 8. The relationships between the absolute change in real GDP in the aggregate REU economy and the regional import intensity from REU under the three labour market assumptions

6.3. Transition path

Until this point, the analysis of the simulations has been focussed on the long-run equilibrium. In this section we discuss the transition path toward the new steady state as a result of the shock. We are primarily interested to present the differences in the qualitative adjustments observed under the three types of labour market structures. To facilitate the understanding of the model mechanisms at the regional level in Figure 9 we plot the percentage deviations from initial steady-state in real GDP, employment, investment, household consumption and CPI for one representative region – Île-de-France (FR10, NUTS2), distinguishing between the results obtained under fixed real wages (top panel), wage curve (middle panel) and Phillips curve (bottom panel).

As expected, for the entire transition path changes in real GDP are larger in the case of fixed real wages and lower when using the Phillips curve. The reader will notice that in the first period the simulated outcomes obtained under the Phillips curve and the Wage curve coincide. This is the result of myopic agents' expectations. However, as the economy adjusts, the results generated under these two distinctive labour market closures start to diverge. Under the Phillips curve the economy is required to return to a competitive equilibrium according to which the employment bounces back to its pre-shock steady-state values in the long-run. This reflects the fact that in steady-state the unemployment rate is constrained to return to its initial steady-state level. A different mechanism is observed under the wage curve, where employment keeps raising until reaching a level of 0.004% above the baseline level.

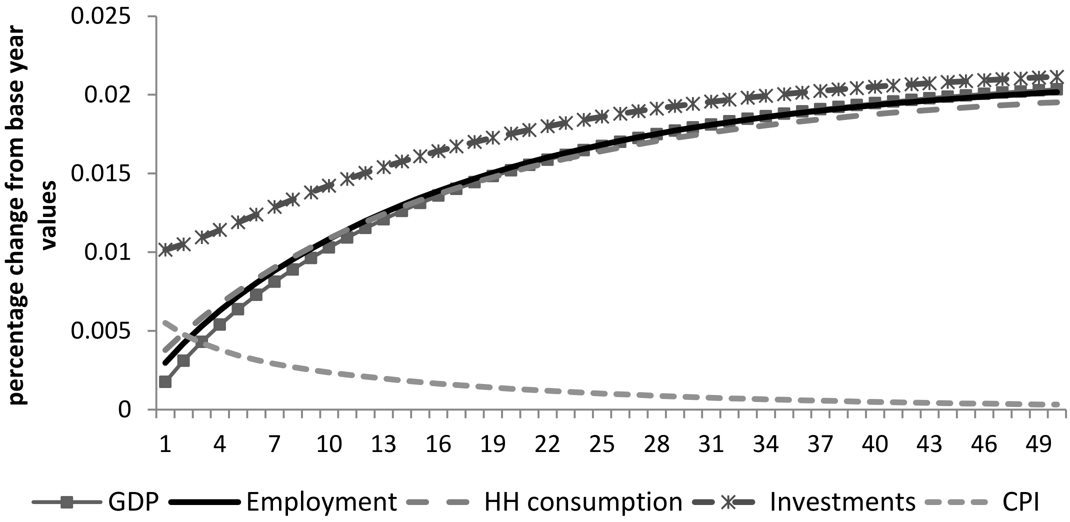
In all three cases, our simulations suggests that in the short-run employment is affected proportionally more than real GDP. This is substantially due to the supply-side constraints imposed in the first period, where capital stock is fixed to its base year value. However, in the long-run we observe a rather different situation. Under fixed real wages the change in employment and GDP equalized, meaning that capital is increasing at the same rate in this time frame. This is what we would expect under fixed real wages where prices will adjusts so as to go back to pre-shock level making therefore the capital-labour substitution effects in the long-run solely dominated by the initial values of calibrated shares. For the other two labour market assumptions, capital-labour substitution is sensitive to price changes and typically we observe that soon after the first period the changes in GDP is above the change in employment. Hence capital is increasing more than employment proportionally. Under a wage curve assumption, the economic expansion associated with the perturbation, increase labour demand making workers in the position to bargain for higher wages, hence encouraging substitution away from labour. Similarly under the Phillips curve substitution in favour of capital is more pronounced. Upward pressure on wages continues until the employment rate goes back to its original equilibrium generating expansion in economic activities gradually determined only by capital expansion.

One final interesting observation is that under the wage curve and the Phillips curve labour market assumptions, the proportionate changes in consumption and investments are in the long-run higher than the changes in GDP. Since economic activities are increasing, there should be some offsetting effects preventing the GDP to rise more than its actual level.

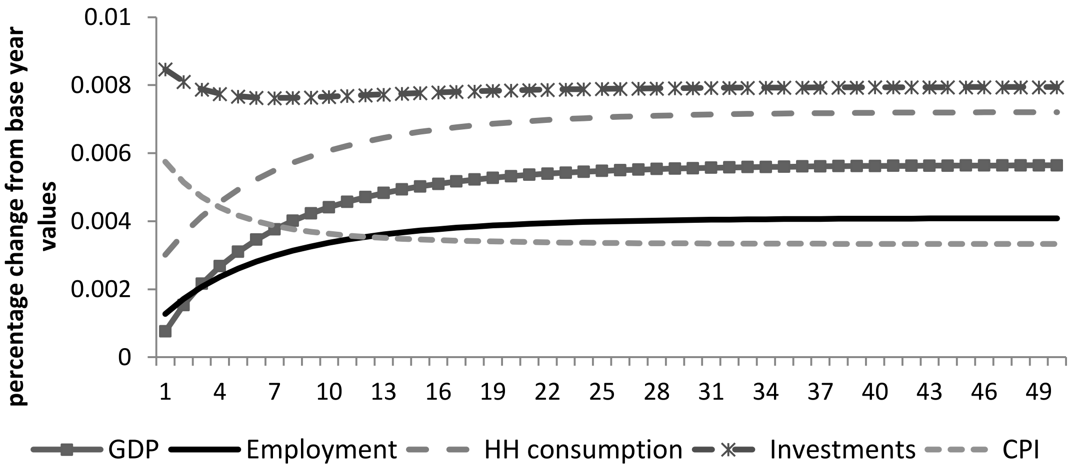
While negative competitiveness effects occur in all three cases, the larger loss in competitiveness is registered in the case of Phillips curve and the Wage-curve where prices are well above the base year values (this can be seen observing the CPI changes in Figure 9). Essentially a greater increase in internal demand is indeed required to offset the fall in net-exports, so as to sustain growth in these cases. Hence household consumption and investment have to increase more than the GDP in the long-run.

Figure 9. Impact of €100M increase in Government expenditures on selected economic variables in the – Île-de-France Region (FR10 NUTS2)

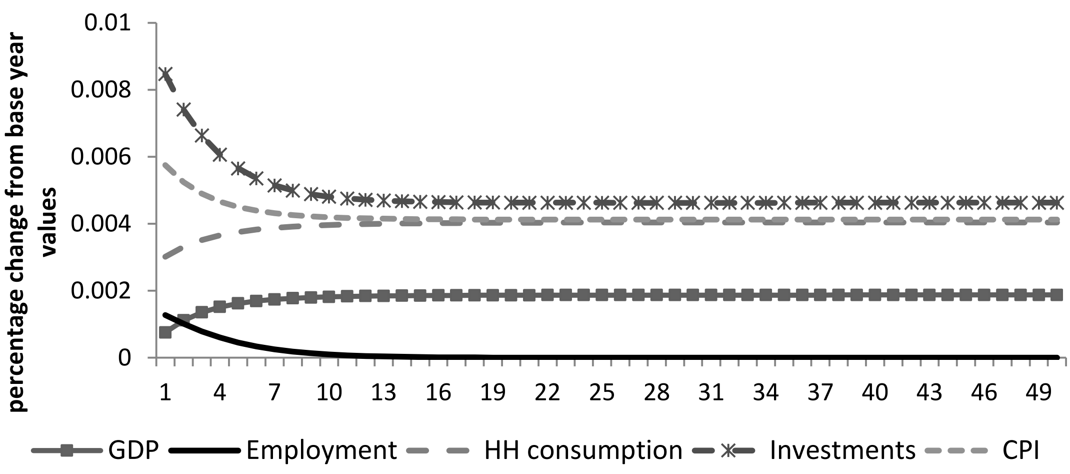
b) Fixed real wage



b) Wage curve

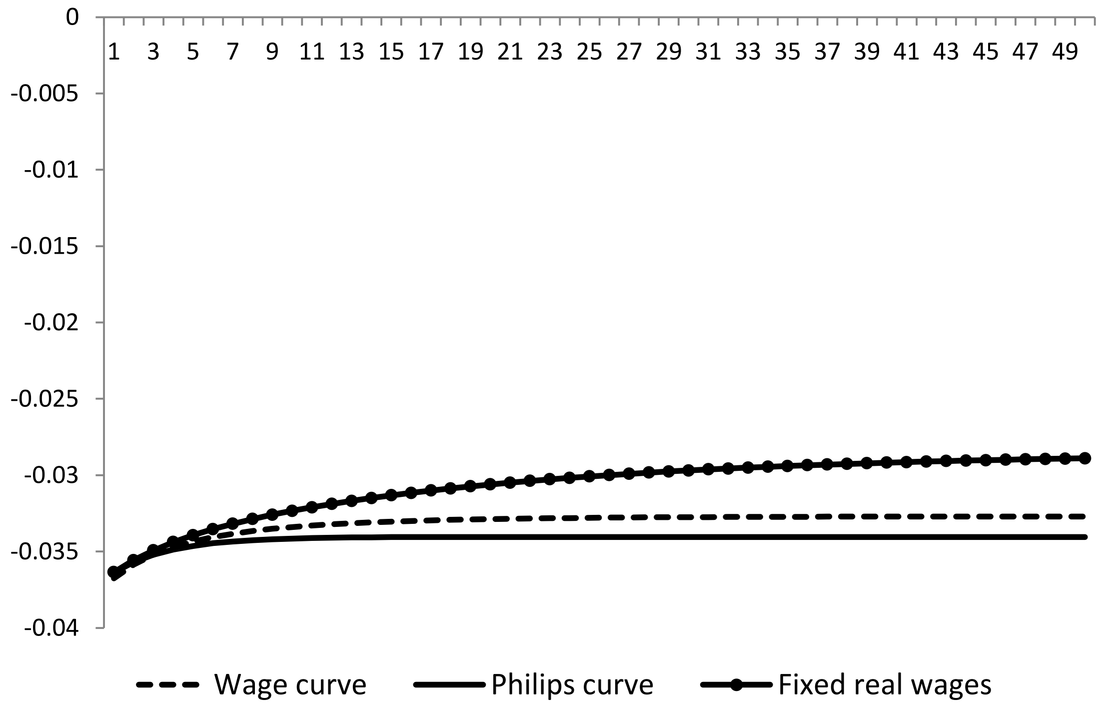


c) Phillips curve



To reinforce our findings, Figure 10 displays changes in net exports for the three labour market structures under examination. We observe that the fall in next export is similar across labour market closures in the short-run however the differences tend to expand as the economy grows. Since greater pressure on wages takes place under Phillips curve labour market it is in this wage setting that we observe a greater reduction in net export.

Figure 10. Impact of 100M increase in Government expenditures on Net-Export in the – Île-de-France region (FR10 NUTS2)



6.4. Analysis of the results under alternative product-market structures
Until now the analysis has been performed assuming perfect competitive commodity markets. To gain further insights and to have comprehensive understanding of the regional economic consequences of a demand shock, we take advantage of the flexibility of our modelling framework by simulating, as in the previous experiment, a €100 M per year permanent increases in current government expenditures equally distributed in each of the 10 economic sectors using alternative formulations of imperfectly competitive commodity markets. In Section 4, we have seen that RHOMOLO is equipped to deal with three configurations of imperfectly competitive markets: monopolistic competition and oligopolistic competition à la Bertrand and à la Cournot. The main difference between the three types of market structures rests on the determination of the mark-up. Under standard monopolistic competition firms do not internalise their impact on the market-wide price index and so the mark-up is fixed for all firms and depends only on trade elasticities. Given that trade elasticity is the same for each region-pair, the selling price set by firms is the same for the same variety sold in all the regions. By contrast, in the other two cases the mark-up not only depends on trade elasticity but also from the market shares of varieties of region r in region r'. The implications is that while under the simple case of monopolistic competition we assume integrated markets, under Cournot and Bertrand markets are segmented and prices differ across regions for the same variety of goods.

In all three cases considered, the demand functions for an individual firm-specific variety produced in region r take the form of equation (21). Therefore the pure love-for-variety incorporated in the model take the form of a simplified Armington–Dixit–Stiglitz model, where the demand nesting function collapses towards a single nest structure with a single constant elasticity of substitution between goods of all geographic origins, with the only difference with respect to the standard monopolistic competition case being the prices of the different varieties.

A comparison of simulation results under the three different models is reported in Table 6. For the sake of comparability we also report the results shown in the previous section, obtained under perfectly competitive product markets. Similarly to the analysis carried out in Section 6.2 we compute the average multiplier obtained in the perturbed regions under the three labour market assumptions. These results are reported on the left-side of Table 6. We also show the magnitude of the spillovers obtained shocking a single region by reporting the associated average multipliers for the EU as whole on the right-hand side of the same table.

Our modelling experiment suggests that for a simple demand shock the magnitude of the macroeconomic effects generated in the perturbed regions under the three alternative imperfectly competitive market structures are similar. Under Phillips curve wage behaviour, the multiplier is around 0.13, under wage curve equates to 0.31, while under fixed real wage the multiplier is around 0.93-0.94. So the main stylized fact emerging from this analysis is that regardless of the pattern of adjustments that might occur under alternative mark-up specifications, in the long-run a demand shock does not generate dramatic differences among alternative configurations of market structures. This is due to the fact that we are adopting a basic Armington-Dixit-Stiglitz nesting structure that results in an application of a simple model of pricing and mark-ups where selling prices do not change radically to variation of the structure of imperfectly competitive models, even when Bertrand and Cournot types of competition are assumed. As observed for the perfectly competitive case, we obtain higher average multiplier under fixed real wages for the perturbed and the non-perturbed regions. The EU average multipliers under fixed real wages equate to 3.04, 3.08 and 3.24 for the monopolistic competition, Bertrand and Cournot market structures respectively.

When comparing perfectly and imperfectly competitive markets we observe that the sign of the impact is qualitatively the same in all market structures considered. The size of the effects differs, but not substantially. Further inspecting Table 6 we can see that under imperfectly competitive market, the size of the multiplier for the whole EU tend to be larger under imperfectly competitive models, when the fixed real wage is used in the model.

Table 6. The multiplier effects, under three alternative labour market closures and different assumptions on market structures

	Regions			EU		
	PC	WC	FRW	PC	WC	FRW
Perfect competition	0.14	0.34	0.93	-0.10	0.10	3.04
	0.06	*0.13*	*0.38*	*0.39*	*0.62*	*0.77*
Monopolistic competition	0.13	0.31	0.93	-0.14	-0.03	3.04
	0.06	*0.13*	*0.38*	*0.40*	*0.68*	*0.77*
Bertrand	0.13	0.31	0.93	-0.14	-0.03	3.08
	0.06	*0.13*	*0.38*	*0.40*	*0.68*	*0.80*
Cournout	0.13	0.31	0.94	-0.14	-0.03	3.24
	0.06	*0.13*	*0.41*	*0.40*	*0.68*	*1.31*

Standard deviation in brackets. PC: Phillips curve. WC: Wage curve. FRW: Fixed real wages. Source: Author's simulations

In order to see how the geographical shapes of the internal multiplier effects change by gradually reducing wage pressure in the system, in Figure 11 we plot the z-scores calculated on the multipliers computed in all the 267 perturbed regions: the fixed real wage case on the left-hand panel, wage curve on the central panel and the Phillips curve on the right-hand panel. Z-scores show us how many standard deviations a single region multiplier is above or below the average multipliers. Red colours in the figures represent negative standard scores, meaning that multiplier effects are below average, while blue colours denote multipliers above average. Given that the results are qualitatively similar, independently of the imperfectly competitive model used, in Figure 11 we only plot the scores obtained under monopolistic competition.

Generally we observe a quite significant group of regions that maintain multipliers above average regardless the labour market closures assumed. However, other regions, such as those belongs to the UK, Spain, Finland or Denmark register below average multipliers under some labour market closures and above average multipliers under other labour market closures. For instance, several regions in Denmark register below average multipliers under Phillips curve, less marked but still below average multipliers under a wage curve and finally above average multipliers when real wage rates are fixed.

One of the peculiarities of using imperfectly competitive market structures as those operating in RHOMOLO is the possibility to account for changes in firms' entry/exit. Firms' entry (exit) means that the system will enjoy larger (fewer) varieties and therefore an increase (reduction) in production. Strictly speaking. creation of new varieties is positively correlated with positive changes in output. In Table 7 we report the average percentage change deviation from base year values registered in the perturbed regions for all three labour market closures. Not surprisingly for all three market structures assumed greater changes in number of firms are recorded under fixed real wage behaviour. Under this closure, pressure on commodity prices disappears and therefore negative competitiveness effects are absent linking firm entry/exit simply to changes in regional output. On the contrary under upward wage pressure negative competitiveness effect limit firm's expansion and thus regional output.

Table 7. Percentage changes in the number of firms

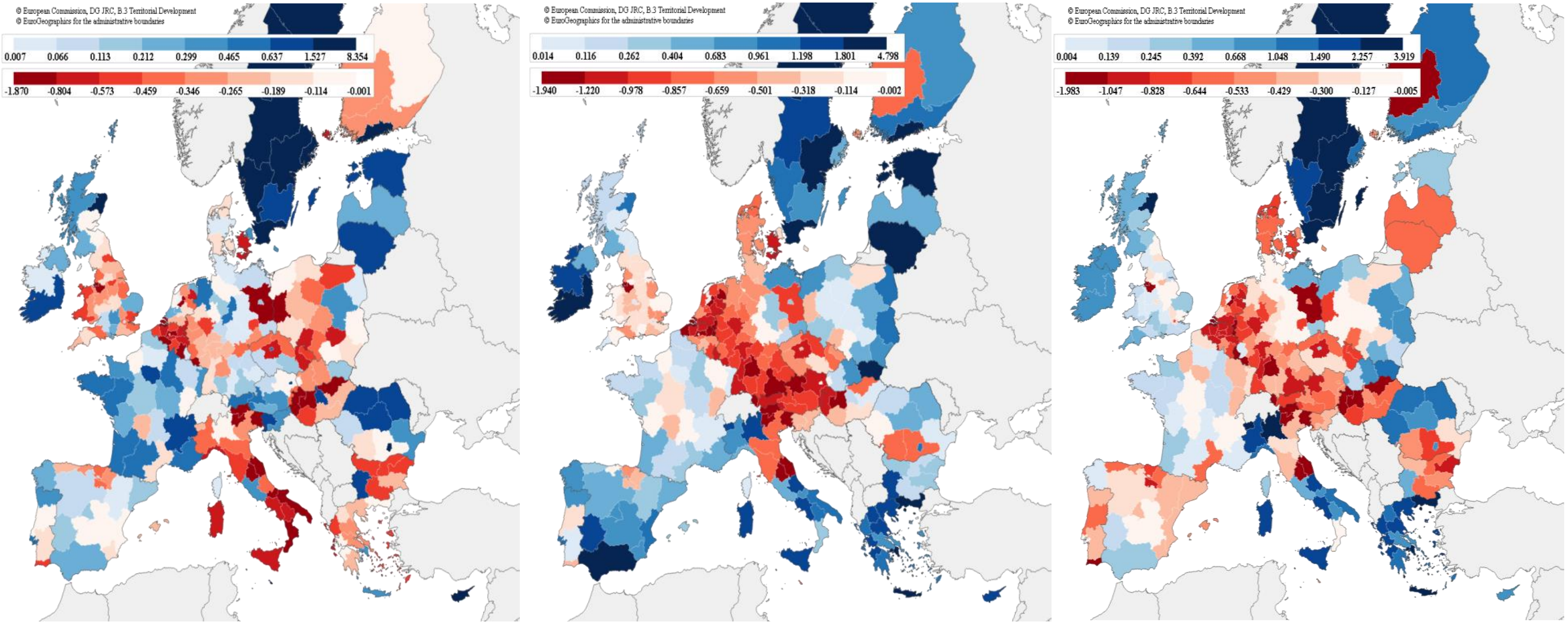
	Regions		
	PC	WC	FRW
Monopolistic competition	0.12	0.24	0.56
Bertrand	0.12	0.24	0.56
Cournout	0.12	0.24	0.57

PC: Phillips curve. WC: Wage curve. FRW: Fixed real wages.
Source: Author's simulations

Summing up, our analysis on imperfectly competitive markets highlights that specific market structure assumptions seem to play a relatively low role in shaping the results after a demand shock. We find that perfectly competitive models generate lower multiplier effects only if upward wage pressures are in operation in the model. By contrast, fixed real wages tend to provide larger multiplier effects in imperfectly competitive models. In terms of spillovers we have observed that perturbed regions affect positively the non-perturbed regions only under fixed real wages independently of the competitive structure assumed. Again, as for the case of perfectly competitive markets, the impact on the REU strictly depends on trade elasticities. Lowering substitution possibilities with the ROW will result in positive EU multipliers.

Figure 11. z-scores under three alternative labour market closures obtained using Monopolistic competition

a) Fixed real wages **b) Wage curve** **c) Phillips curve**



7. Conclusions

An exhaustive theoretical background and analytical framework of the RHOMOLO model have been documented along with the discussion of the output derived from some stylized and illustrative simulations with the aim to make the reader familiar with the economic adjustment mechanisms incorporated into the model.

The RHOMOLO model share some similarities with other macroeconomic models currently adopted for policy analysis and policy evaluations existing in the economic literatures. However the high spatial dimension and the flexibility of switching among the model's closures reveal the peculiarity of the RHOMOLO modelling framework. There is a trade-off between mathematical complexity when modelling agents' decisions and geographical dimension and between the number of behavioural parameters and uncertainty. In the future however we will make an additional effort in order to moderate a number of simplified assumptions currently present in the model. For instance, currently under construction is a model that is able to accommodate perfect foresights agents and incorporate heterogeneous agents to better understand the transmission of the economic policies. Furthermore, a specific R&D module consistent with the spatial dimension of the RHOMOLO model is presently under construction. Furthermore, in order to reduce the uncertainty associated to the parametrization of the model we plan to estimates a number of key elasticity parameters that are specific to the regions modelled in RHOMOLO.

This Technical Report aims to provide the reader and the potential model users with an intuition of the transmission channels and adjustment mechanisms existing in RHOMOLO. As already mentioned in the introductory section, the analysis is kept simple to facilitate a better understanding of the model's findings. We have simulated a demand shock, implemented separately for each of the 267 regions contained in the model, and discussed the results. We repeated the same simulations under three alternative labour market closures and with three different imperfectly competitive product market structures. We have tested the extent to which a gradual increase in the upward pressure on wages generated by a domestic increase in demand can affect the magnitude of the economic impacts in the long-run and the degree to which this could results in changes in trade patterns.

Our modelling exercise yields three key results. First, it demonstrates that the upward wage pressure resulting from an internal increase in demand generates losses in competitiveness that partially offset the impacts on economic activities. Second, it illustrates the potential significance of wage settings in generating regional spillovers, finding that their intensity and magnitude are magnified by the introduction of real wage rigidities in the model. Finally, the inter-regional trade structure of the economy is subject to a larger degree of alteration when upward pressure on prices is higher. This last result draws attention to the importance of the labour market institutions when assessing trade spillovers. Furthermore we have shown that under fixed real wages the system operates in a manner which is rather similar to a Leontief-type model according to which spillovers strictly depends on the calibrated shift and share parameters.

A second set of results are related to the changes in the market structures. Our modelling experiment reveals that for an increase in internal demand that abstracts from supply-side effects, there are differences between the results obtained in perfectly and imperfectly competitive market settings, but these are almost negligible. Assuming labour market closures that allow upward pressure on wages result in a higher loss of competitiveness, thus restraining the expansion in the number of varieties and in turn reducing the system-wide economic impact. This is a crucial results stemming from our experiment, highlighting how any loss in competitiveness maps into a lower number of varieties in the perturbed region.

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Annex

Annex I List of variables and parameters

Variables

C_r	Aggregate consumption in r
YC_r	Household disposable income
$L_{r,e}$	Labour supply/working age population
$K_{r,i}^P$	Private capital stock
P_r^c	Consumer price index
$W_{r,e}$	Nominal wage rate
$u_{r,e}$	Unemployment rate
TR_r	Net transfer to Households from Government
$rk_{r,i}$	Rate of return to capital
$N_{r,i}$	Number of firms
$c_{r,i}$	Household consumption in goods and services for sector *i*
$P_{r,i}$	Armington price index
S_r	Nominal savings
B_r	Government deficit/savings
$G_{j,r}$	Government current consumption
I_r^g	Government capital consumption
$Z_{r',j}$	Sectoral output
$I_{r,i}^{gS}$	Government capital consumption by sectors
$Y_{r,j}$	Value Added
$V_{r,j}$	Aggregate intermediate inputs
$Py_{r,j}$	Value added price
$Pz_{r,j}$	Output price
$Pin_{r,j}$	Intermediate inputs price
$K_{(g)}^d$	Public capital services available to firms
$KD_{r,j}$	Private capital demand
$LD_{r,j}$	Labour demand
$v_{r,i,j}$	Intermediate inputs sold by *i* and purchase by *j*
$FC_{r,j}$	Fixed costs
$ld_{r,j,e}$	Labour demand by sectors and skills
$x_{r,r',j}$	Commodity *j* sold by region *r* to region *r*'
$p_{r,r',j}$	Commodity price applied by sector r for selling in region r'
$\varepsilon_{r,r',j}$	Perceived elasticity in markup price
P_r	Aggregate Armington price index
$P_{r,j}^*$	Marginal cost
$rw_{r,e,t}$	Real wage
$I_{i,r}^P$	Private capital investments
K_r^P	Private capital stock
uck_r	User cost of capital
$K_{j,r}^*$	Desired level of capital
p_{EU}^I	Price index of investments
$X_{r',j}$	Armington aggregate
$I_{i,r}^S$	Investments by sector of origin
$K_{(g),r}^S$	Public capital stock
$m_{r,e}$	Net migration rate
$s_{r,r',e}$	Probability of workers moving from r to r'

Fixed Variables

$FC_{r,j}$	Fixed costs
τ_r^w	Labour income tax rate

τ_r^{π}	Capital Income tax rate
τ_r^{p}	Net production tax rate
$\tau_{r,r',j}$	Iceberg transport costs
s_r	Saving rate
r	Interest rate

Calibrated shifts and shares parameters

ψ_r	Share of capital income paid directly to households
$\vartheta_{r,i}$	Share of Households expenditure parameter
$z_{r,i}$	Share of public investments
$Ax_{r,j}$	Scale parameter in output production function
$\delta_{r,j}^{x}$	Calibrated share of intermediate inputs in total production
$Ay_{r,j}$	Scale parameter in value added production function
$\delta_{r,j}^{Y}$	Share of capital in Value added
$b_{r,i,j}$	Intermediate inputs shares
$Al_{r,j,e}$	Scale parameter in labour function
$\delta_{r,j,e}$	Share of labour skills in total employment
$d_{r,r',i,}$	Calibrated expenditure shares in Armington function
$a_{r,j}^{y}$	Leontief coefficient for value added
$a_{r,j}^{Int}$	Leontief coefficient for intermediates
$KM_{i,j,r}$	Capital matrix

Elasticity of substitutions and other behavioural parameters

ρ^{c}	Parameter for the elasticity of substitution between consumption goods
σ^{c}	Elasticity of substitution between consumption goods
ρ_j^{x}	Parameter for the elasticity of substitution between value added and intermediate
σ^{x}	Elasticity of substitution between between value added and intermediate
ξ	Public capital elasticity
ρ_j^{y}	Parameter for the elasticity of substitution between capital and labour
σ^{y}	Elasticity of substitution between capital and labour
ρ^{v}	Parameter for the elasticity of substitution between intermediate inputs
σ^{v}	Elasticity of substitution between intermediate inputs
ρ_j^{l}	Parameter for the elasticity of substitution between labour skills
σ_j^{l}	Elasticity of substitution between labour skills
σ_j	Armington trade elasticity
α	Elasticity for lag real wage in real wage equations
ζ	Elasticity for unemployment rate in real wage equation
ς	Elasticity for changes output price rate in real wage equations
θ	Elasticity for changes in unemployment rate in real wage equations
v	Elasticity of the cost of capital/accelerator elasticity
γ	Parameter in the congestion specification
η	Congestion effects

Annex II Selected calibrated share parameters

Figure A 1. Relationship between number of firms and GDP for each of the imperfectly competitive sectors

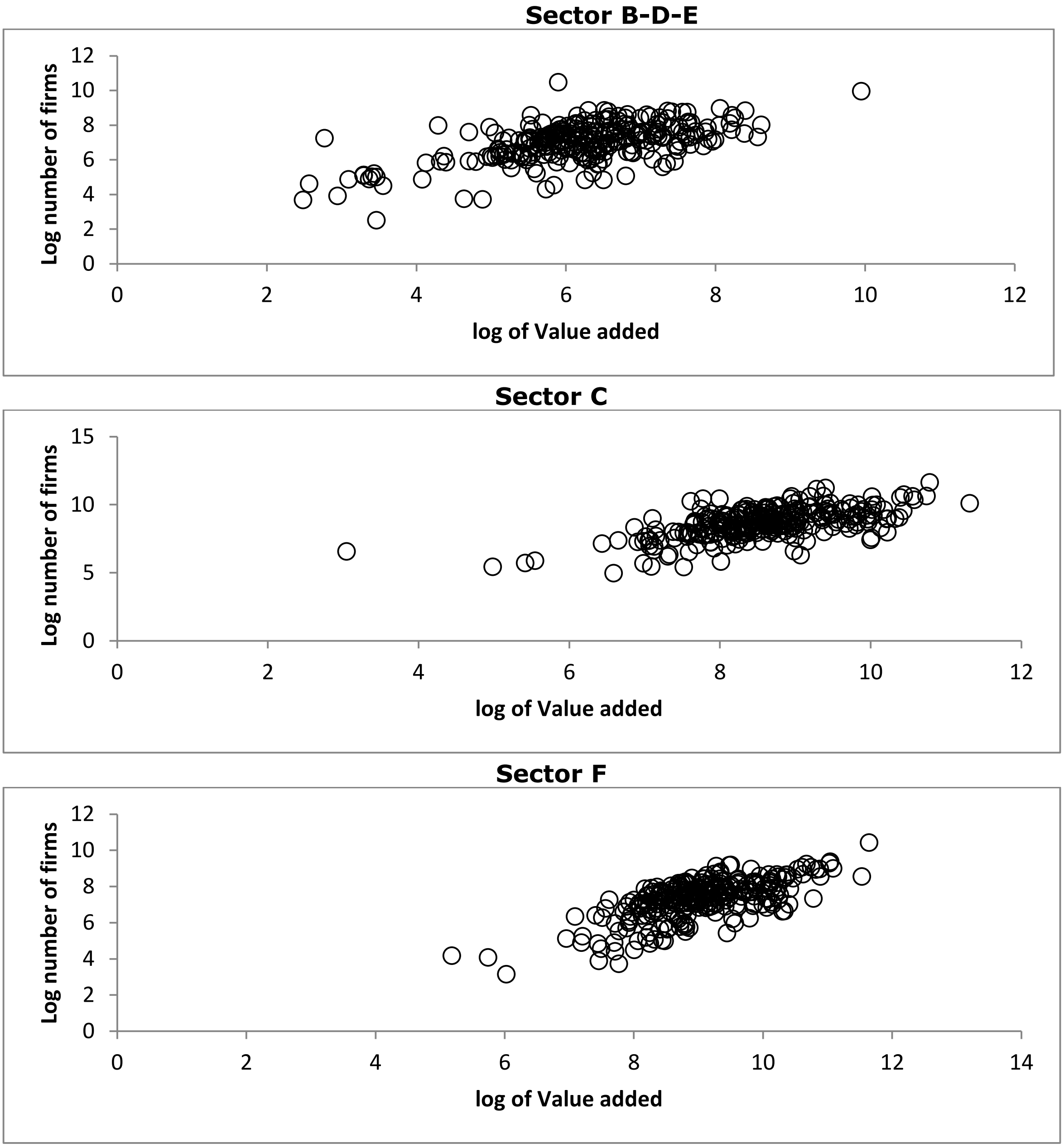
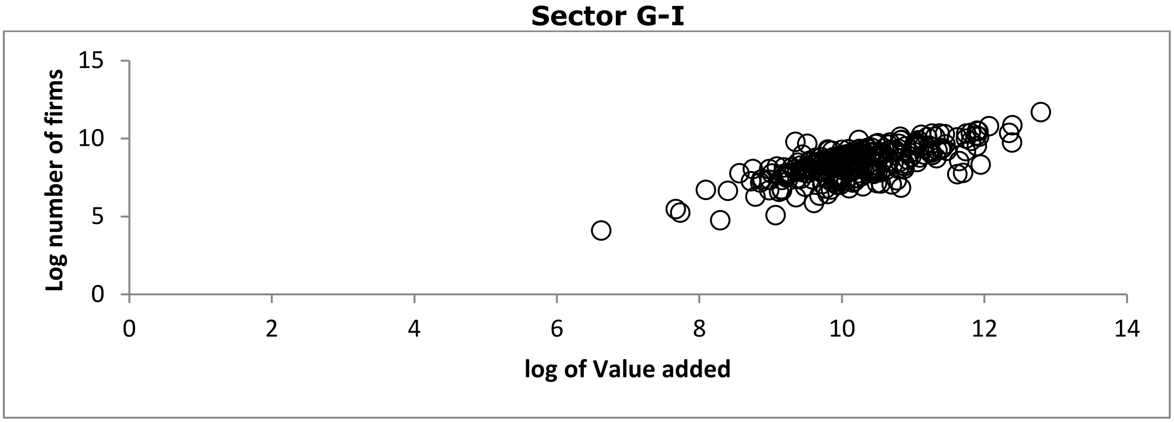
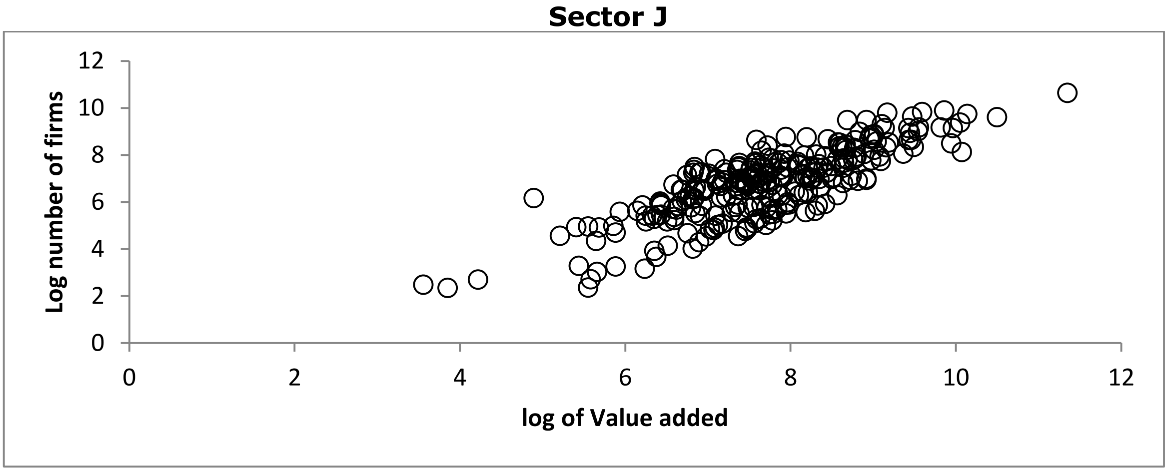
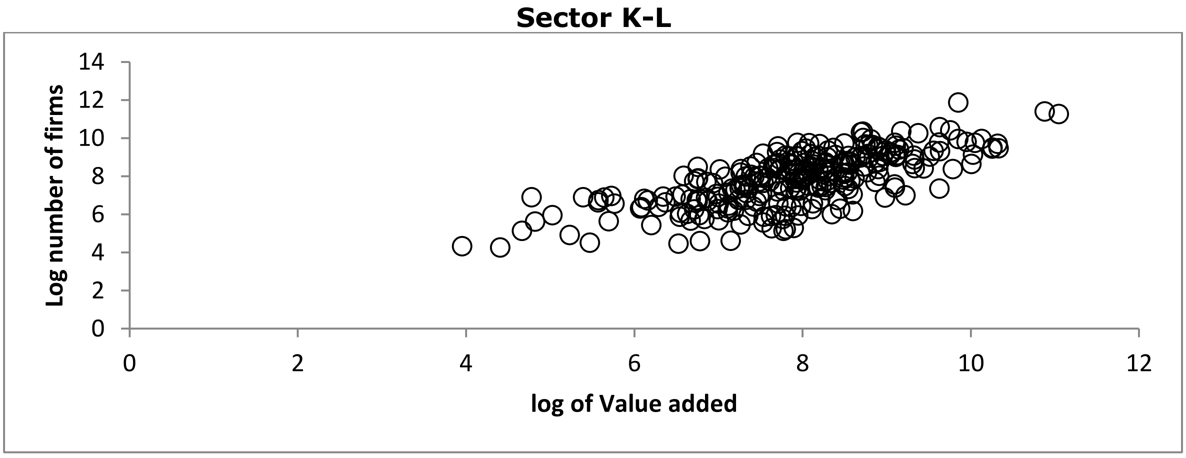


Figure A1 (continue)







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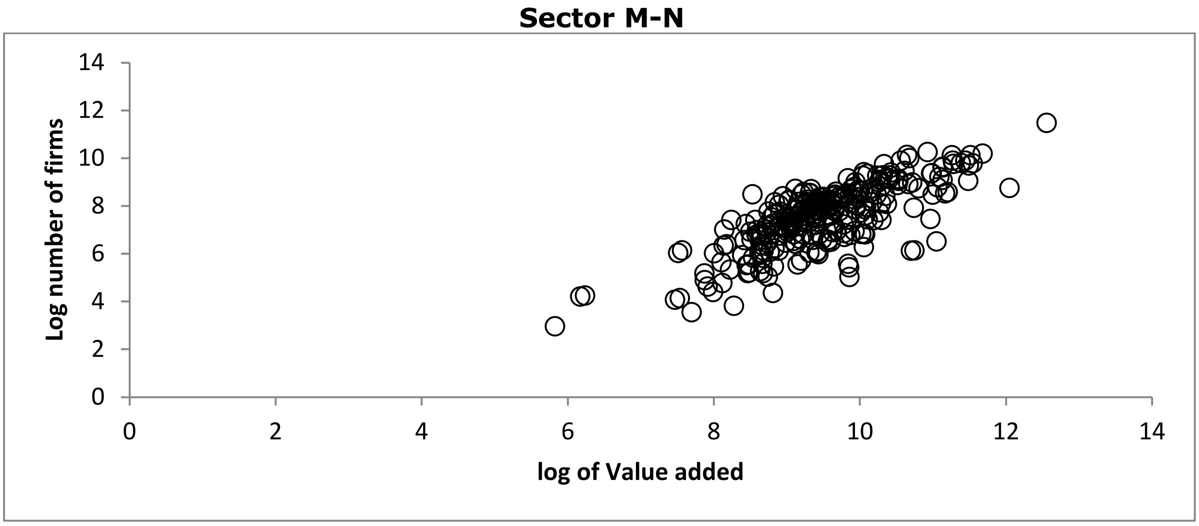


Figure A 2. The share of total imports (horizontal line) vs the share of total export (vertical line)

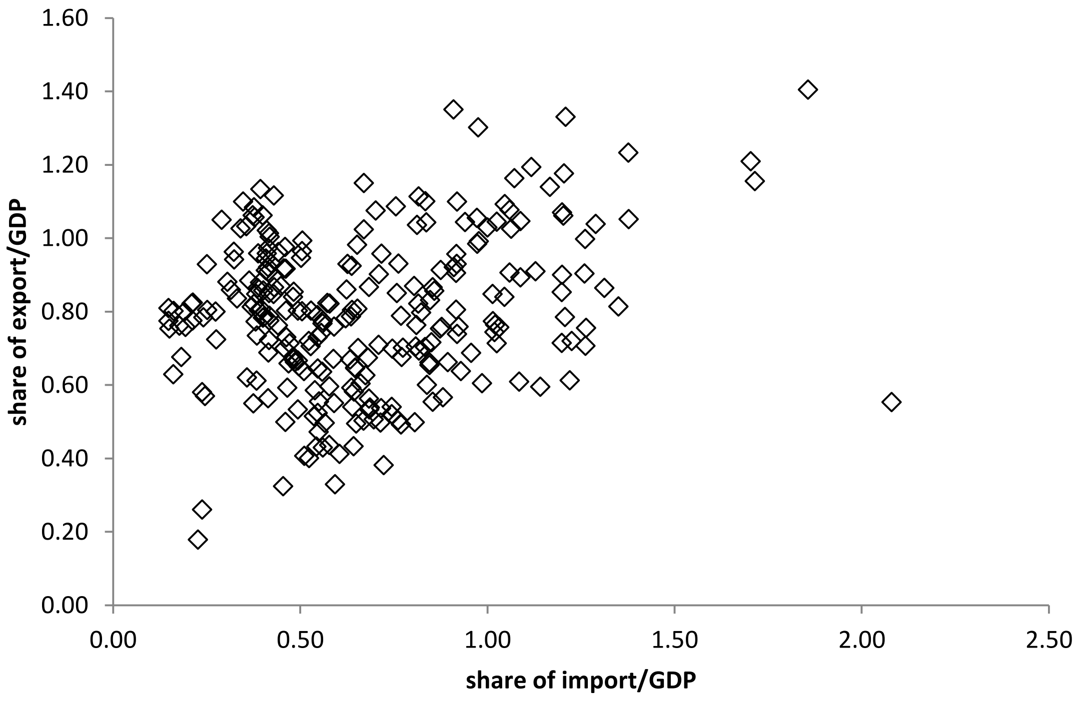
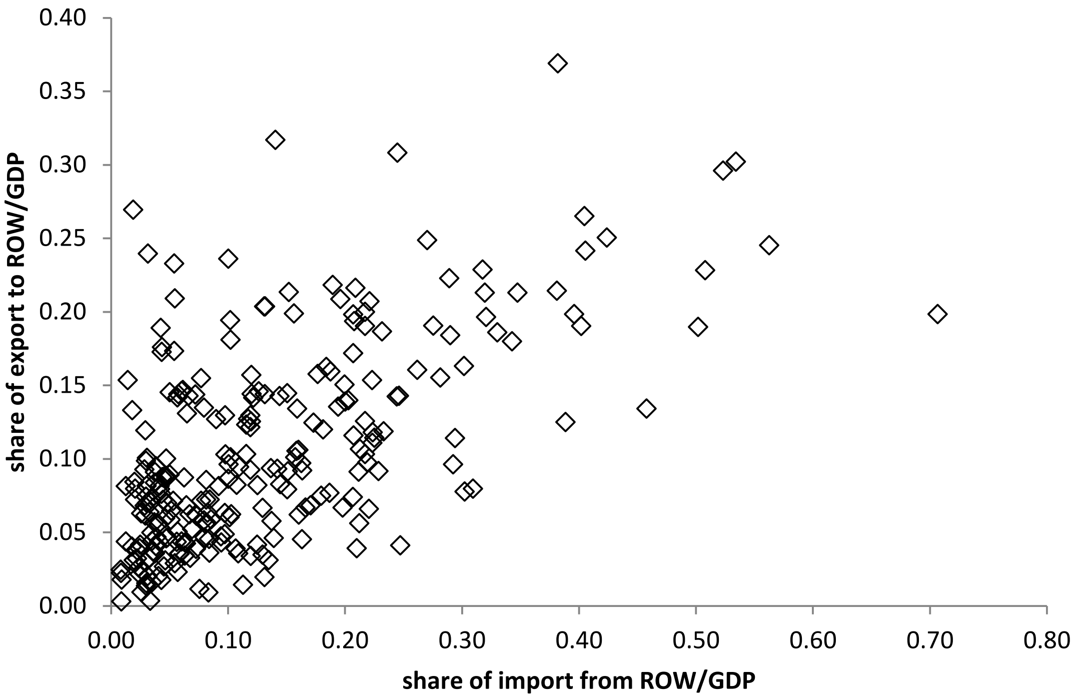


Figure A 3. The share of non-EU imports (horizontal line) vs the share of non-EU export (vertical line)



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