European Commission

JRC TECHNICAL REPORTS

Macroeconomic Modelling of R&D and Innovation Policies

An application of RHOMOLO and QUEST

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2015

Report EUR 27084 EN

Joint Research Centre

European Commission
Joint Research Centre
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JRC Science Hub
https://ec.europa.eu/jrc

JRC89558

EUR 27084 EN

ISBN 978-92-79-45245-1 (PDF)

ISSN 1831-9424 (online)

doi:10.2791/547147

Luxembourg: Publications Office of the European Union, 2015

Abstract

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JEL codes: C68, D24, H50, O31.

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Contents

Macroeconomic Modelling of R&D and Innovation Policies: An application of RHOMOLO and QUEST[☆]

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Abstract

The paper presents a spatial computable general equilibrium (SCGE) approach to policy impact assessment which is useful for capturing knowledge spillovers and spatial interactions between regions. First, the relationship between regional productivity and R&D expenditures is estimated econometrically by applying the catching-up framework of technology diffusion of Benhabib and Spiegel (2005) to EU regions. Second, the SCGE model RHOMOLO is combined with the dynamic stochastic general equilibrium (DSGE) model QUEST to simulate and assess the impact of research and innovation funding allocated by the 2014-2020 EU Cohesion Policy. Our simulation results suggest that in the short run the benefits of R&D policies are concentrated in the less developed regions. In the long run, however, the benefits spread throughout the EU, favouring also the more developed regions. In light of the empirical results, the paper identifies strengths and limitations of the adopted approach, and the advantages of aligning a spatially and sectorally disaggregated SCGE framework with the inter-temporal dynamics of DSGE models.

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[☆]The authors gratefully acknowledge helpful comments and valuable contributions from EUROLIO conference participants in Saint-Etienne and Utrecht as well as from participants of seminars and workshops at the European Commission. The authors are solely responsible for the content of the paper. The views expressed are purely those of the author and may not in any circumstances be regarded as stating an official position of the European Commission.

1. Introduction

The European Commission's Communication on 'Research and innovation as sources of renewed growth' (European Commission, 2014b) highlights the importance of investment quality to unlock the potential of research and innovation as drivers of economic growth within the EU Members States' growth-friendly fiscal consolidation strategies. This requires far-reaching reforms of the national research and innovation systems to achieve maximum impact from constrained public budgets, at the strategy, programme and institutional level. The Communication also points to a need for a stronger evidence base in support of those structural reforms, as an essential element to allow national and European policy-makers to base their decisions on objective analyses. This requires in particular that the undisputed long-term positive impacts of research and innovation are better accounted for by macro-economic general equilibrium models used in support of EU policy-making (see Di Comite and Kancs, 2015, for an overview of the models used within the European Commission to that purpose).

This paper uses the newly developed spatial computable general equilibrium model – RHOMOLO[1] - in tandem with the Commission's dynamic stochastic general equilibrium model QUEST – to illustrate the potential of the adopted approach for impact assessment of one of the most important categories of EU-funded investments – research, technological development and innovation (RTDI). Whereas RHOMOLO introduces the key features of inter-regional linkages and spatial knowledge spillovers in a spatial computable general equilibrium framework, for example in the determination of relative prices at the regional level, the sophisticated dynamics and macro-fiscal policy coverage of QUEST allows for a fine-tuning of the dynamic results at the country level.

RHOMOLO is calibrated to Social Accounting Matrices (SAMs) for all NUTS2 regions of EU Member States in 2007 (base year). The regional data are consistent with national accounts and with international trade data for the whole EU.[2] The underlying structural parameters are either estimated econometrically or, where no sufficient data are available for econometric estimations,

[1]The acronym stand for Regional HOlistic MOdeL (Brandsma *et al.*, 2015).
[2]For the data not directly available at the regional and sectoral level, the regionalisation procedure has been explained in Thissen *et al.* (2014).

they are borrowed from the literature, and are allowed to vary with regional characteristics, such as the regional level of development and distance to the technological frontier in different sectors.

In illustrative simulations of the 2014-2020 research and innovation policies we simulate the time-location-specific impacts of the allocations to EU regions and broad categories of investment to help policy makers in understanding how cohesion policy can affect local development.

The paper is organised s follows. Section 2 outlilnes the structure of the model.[3] Section 3 describes its data and empirical implementation. Section 4 explains the details of the scenario construction. Section 5 illustrates the result of the simulation. Section 6 discusses the limitations and outlines avenues for future research. Section 7 concludes.

2. The RHOMOLO model

The domestic economy (which corresponds to the EU) consists of $R-1$ regions $r = 1, \ldots, R-1$, which are included into M countries $m = 1, \ldots, M$. The rest of the world is introduced in RHOMOLO as a particular region (indexed by R) and a particular sector (indexed by S).

The economy is composed of $s = 1, \ldots, S$ different sectors (also called industries) in which firms operate under monopolistic competition à la Dixit and Stiglitz (1977). Each firm produces a differentiated variety, which is considered as an imperfect substitute to the other varieties for households and firms. Goods are either consumed by households, government, or used by other firms as intermediate inputs or as investment goods. The number of firms in sector s and region r, denoted by $N_{s,r}$, is large enough so that strategic interactions between firms are ruled out (as in standard models of monopolistic competition). The number of firms in each region is endogenous and to a large extent determines the spatial distribution of economic activity.

Trade between and within regions is costly, implying that the shipping of goods entails transport costs which are assumed to be of the iceberg type, with $\tau_{s,r,q} > 1$ representing the quantity of sector $'s$ goods which needs to be sent from region r in order to have one unit arriving in region q (see Krugman,

[3] See Brandsma *et al.* (2015) for a formal description of the key mechanisms in the RHOMOLO model.

1991, for instance). Transport costs are specific to sectors and trading partners (region pairs), they are asymmetric (i.e. $\tau_{s,r,q}$ is allowed to differ from $\tau_{s,q,r}$) and are positive within a given region (i.e. $\tau_{s,r,r} \neq 1$). They are related to the distance separating regions r and q but also depend on other factors, such as transport infrastructure or national borders.

R&D intensity, measured as R&D expenditures over GDP, affects productivity growth. It is found in this paper that the closer a region is to the EU productivity frontier, the stronger are the returns on of R&D expenditures in terms of TFP incraeses. This means that an exogenous increase in R&D spending in the model can result in a sustained catching-up process for the least productive regions.

Each region is inhabited by H_r households, which are mobile between regions. They partly determine the distribution of economic activity across regions and size of the regional market.[4] The income of regional households consists of labour revenue (wages), capital revenue and government transfers. It is used to consume final goods, pay taxes and accumulate savings.

Finally, in each region there is a public sector, which levies taxes on consumption and on the income of local households. Regional governments use their income for public consumption, transfers and subsidies.

The detailed regional and sectoral dimensions of RHOMOLO imply that the number of (non-linear) equations to be solved simultaneously is very high (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. Two factors (physical capital and human capital) are accumulated over time and link one period to the next. Agents are assumed to save a constant fraction of their income in each period and consume the rest. The dynamics of the model is described as in a standard Solow framework, i.e. a sequence of short-run equilibria that are related to each other through the build-up of stocks.

RHOMOLO contains several endogenous agglomeration and dispersion forces affecting location choices of firms (see Brandsma *et al.*, 2015, for a formal derivation of spatial equilibrium in RHOMOLO). Three effects drive the me-

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

chanics of endogenous agglomeration and dispersion of economic agents in RHOMOLO: the *market access effect*, the *price index effect* and the *market crowding effect*. The *market access effect* captures the fact that firms in large/central regions enjoy easier access to consumers (in the sense of lower iceberg transport costs) than firms in small/peripheral regions, and hence the tendency of firms to locate their production in large/central regions and export to small/peripheral regions. The *price index effect* captures the impact of firms' location and trade costs on the cost of living of workers, and cost of intermediate inputs for producers of final demand goods. The *market crowding effect* captures the idea that because of higher competition on input and output markets, firms may prefer to locate in small/peripheral regions with fewer competitors.

RHOMOLO contains three endogenous location mechanisms that bring its agglomeration and dispersion features about: the mobility of firms, the mobility of labour, and vertical linkages (see Di Comite and Kancs, 2014, for more details).

3. Data and empirical implementation

3.1. Dimensions of RHOMOLO

RHOMOLO covers 267 NUTS2 regions in the EU27, which are disaggregated into six NACE Rev. 1.1 sectors (see Table 1 and Figure 1, respectively).[5] The regional and sectoral disaggregation implies considerable data needs. In particular, for the empirical implementation of the RHOMOLO model, data for all exogenous and endogenous variables at regional (and sectoral) level for the base year (2007) and values for all behavioural parameters are required.

The base year (2007) data are compiled in form of regional Social Accounting Matrices (SAMs) (see Potters *et al.*, 2013, for details). For the construction of national SAMs, data are taken from the World Input Output Database (WIOD) project and the Global Trade Analysis Project (GTAP). The WIOD database consists of International Input-Output tables, International and National Supply

[5]The simulations presented in this paper were performed with the RHOMOLO model, which was calibrated to 2007 base year data. In the next updates of the base year RHOMOLO will be extended to include also Croatia. See https://ec.europa.eu/jrc/rhomolo for the latest version of the RHOMOLO model and base year data.

Table 1: Sectoral disaggregation of the RHOMOLO model

NACE code	Sector description
AB	Agriculture, hunting and forestry
C	construction
DEF	Mining and quarrying, manufacturing, electricity and gas and construction
GHI	Wholesale and retail trade, repair of motor vehicles, motorcycles, personal and household goods, hotels and restaurants, transport and communicatio
JK	Financial intermediation, real estate and business services
LMNOP	Non-market services

Source: Authors' aggregation based on the EUROSTAT (2003) NACE Rev. 1.1 classification. R&D sector is separated out from the standard NACE group JK.

and Use tables, National Input-Output tables, and Socio-Economic and Environmental Accounts, covering all EU27 countries and the rest of the world for the period from 1995 to 2009. An attractive feature of the WIOD data is that an attempt is made to identify and take out re-exports before calculating the total value of exports. Generally, the WIOD data are available for 59 NACE Rev. 1.1 sectors, which for the purpose of the present study are aggregated into the six macro-sectors used in RHOMOLO (see Table 1). All SAMs are constructed at the national level based on the WIOD Supply and Use tables, and then regionalised by using national aggregates, such as, value added, trade, consumption, trade and employment, as constraints.

3.2. Data for inter-regional variables

Inter-regional labour migration patterns are captured by data on net changes in the regional labour force (see Brandsma *et al.*, 2014, for details). Using these data, the relocation of workers between any two regions is modelled as a function of expected income and distance. For the estimation of migration elasticities data are required on labour migration, regional GDP and unemployment. EUROSTAT's Regional Migration Statistics provides data on migration within Member States. In order to complete the regional migration matrix, national totals are brought in line with OECD data on migration in OECD countries, providing data on migration flows between countries. The Household Income and Active Population data are extracted from EUROSTAT.

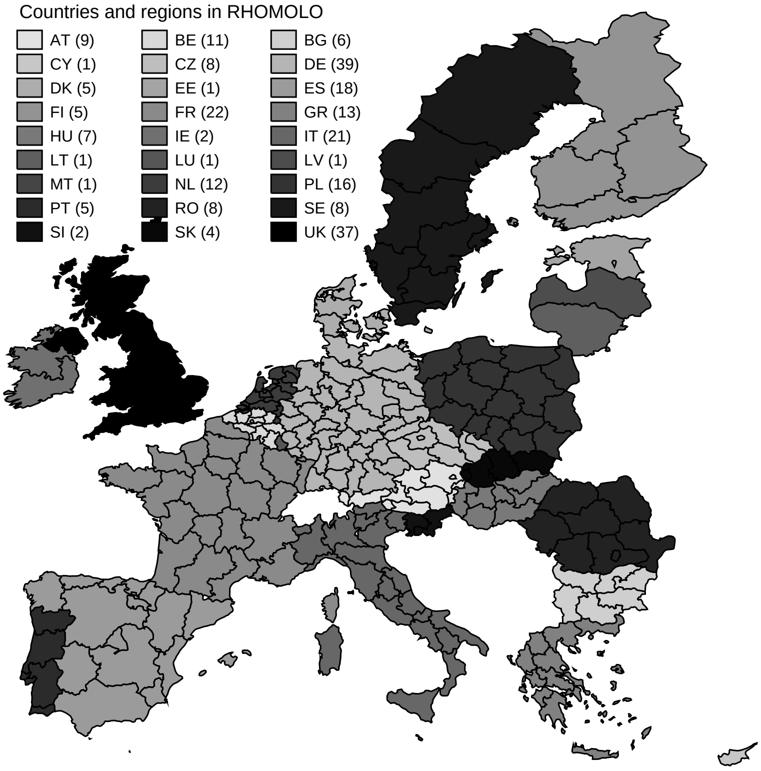

Figure 1: Spatial disaggregation of the RHOMOLO model. Notes: The number of NUTS2 regions in each country are in parentheses (in total these numbers sum up to 267).

Together with data on unemployment and wages, which are extracted from the labour force survey, the constructed data on of inter-regional migration flows provides the necessary input to the estimation, calibration and modelling of labour market and migration features in the RHOMOLO model.

Inter-regional trade flows are estimated using detailed inter-regional transport and freight data from Thissen *et al.* (2013, 2014). These data are aligned with the available macro-data: the distribution of production and consumption over the EU regions and the national SAMs to ensure consistency with the rest of the RHOMOLO database. The regionalisation of SAMs uses the regional production and consumption data from the EUROSTAT. Asymmetric region-pair-specific trade costs come from the TRANSTOOLS database, which add up to the country level trade and transportation margins calculated from the WIOD.

3.3. Data for inter-temporal variables

The regional stock of human capital is proxied in the RHOMOLO database by 3 different levels of education: low skill (isced0_2), medium-skill (isced3_4), and high skill (isced5_6). Wages are differentiated on the basis of the corresponding categories of education levels to account for the decision of households to spend their time on education. Data for this are available in the Labour Force Survey (LFS) and the EU KLEMS database.

Data on the regional stock of physical capital are constructed using the Perpetual Inventory Method (PIM). This approach starts with an estimate of the initial stock by country and industry, regionalised by the share in gross value added (GVA) in 1995 and calculates the final capital stock by region and by industry in 2007 by adding the yearly capital investments and making assumptions on depreciation. The following data can be estimated: gross fixed capital formation by sector at the NUTS2 level in current prices for the years 1995-2010; price deflators for conversion into constant prices; initial stocks for calculating the net capital stocks for each year applying the PIM from the EU KLEMS database. These data are available at the national level, which are regionalised by the GVA share; depreciation rates are calculated by weighing the average service life of each of the six types of assets for each country (according to the ESA95 classification).

3.4. Model parameters

The structural parameters of RHOMOLO are either estimated econometrically or, where not sufficient data are available for econometric estimations, borrowed from the literature (Okagawa and Ban, 2008). For example, all parameters related to the inter-regional labour migration are estimated in a panel data setting for each country separately (Brandsma *et al.*, 2014; Persyn *et al.*, 2014). Similarly, the parameters related to the elasticities of substitution both on the consumer and on the producer side are being estimated econometrically.

Finally, as usual in computable general equilibrium models, all parameters are calibrated to reproduce the base year (2007) data in the SAMs. In order to determine the sensitivity of simulation results with respect to the implemented behavioural parameters, we perform extensive sensitivity analysis and robustness checks. Among others, the sensitivity analysis allows us to establish confidence intervals (in addition to the simulated point estimates) of RHOMOLO's simulation results.

4. RTDI scenario construction

4.1. Research and innovation policy in the EU

In January 2014, the European Commission has adopted the total budget of the EU Cohesion Policy (ECP) for 2014-2020(+3). The new Cohesion Policy package is focused on the "Europe 2020" objectives and mainly targets growth and jobs. The total ECP expenditure of 341.5 billion Euro is divided into 123 categories (see Table 6 in the Appendix). In order to toggle the adequate parameters in the RHOMOLO and QUEST models, we have aggregated these categories into five broad budget lines (see Table 6 in the Appendix). European Commission (2014a) provides a detailed overview of the ECP expenditures per type of region and expenditure category. Based on the experience from the past Framework Programmes, the expenditure period for the current ECP funds spans from 2014 to 2023, taking into account the N+3 rule. The time profile of annual RTDI expenditures is reported in Table 2, whereas the time profile of cumulative RTDI expenditures is plotted Figure 2.

Table 2: Time profile of annual RTDI expenditures 2014-2020(+3)

Year	LDR, EUR	LDR, %	MDR, EUR	MDR, %	TR, EUR	TR, %
2014	1691.54	6.83	635.05	5.82	327.50	5.67
2015	2589.73	10.46	1059.79	9.72	560.44	9.71
2016	3380.52	13.65	1463.66	13.43	779.39	13.50
2017	3459.46	13.97	1518.49	13.93	804.83	13.94
2018	3494.62	14.11	1547.08	14.19	818.38	14.18
2019	3379.23	13.65	1524.24	13.98	807.07	13.98
2020	3038.15	12.27	1403.74	12.88	745.94	12.92
2021	2222.89	8.98	1042.34	9.56	554.09	9.60
2022	1265.03	5.11	593.91	5.45	314.30	5.45
2023	243.49	0.98	114.15	1.05	60.26	1.04
Total	24764.68	100.00	10902.45	100.00	5772.20	100.00
Percent	59.76		26.31		13.93	

Source: European Commission (2014). Notes: EUR = Million Euro. LDR - less developed regions, TR - transition regions, MDR - more developed regions.

According to European Commission (2014a), the vast majority of the ECP funds will be devoted to the less developed regions. For the 2014-2020(+3) period, almost 41.9 billion euro have been allocated to lines of expenditure which can be associated with support to research, technological development and innovation (RTDI) (see row 'Total' in Table 2). This corresponds to around 12% of the total ECP expenditures. Almost 60% of the total RTDI expenditures (25 billion euro) will be allocated to the less developed regions (see bottom row in Table 2). Around 26% and 14% of the total RTDI expenditures will be allocated to the more developed regions and the transition regions, respectively. This time profile applies to all the regions and is based on the assumption that regions will improve their average absorption capacity as compared to the 2007-2013 programming period and it is assumed that more than 50% of the allocated funds will have been spent by 2018, and that figure will go up to 80% by 2020.

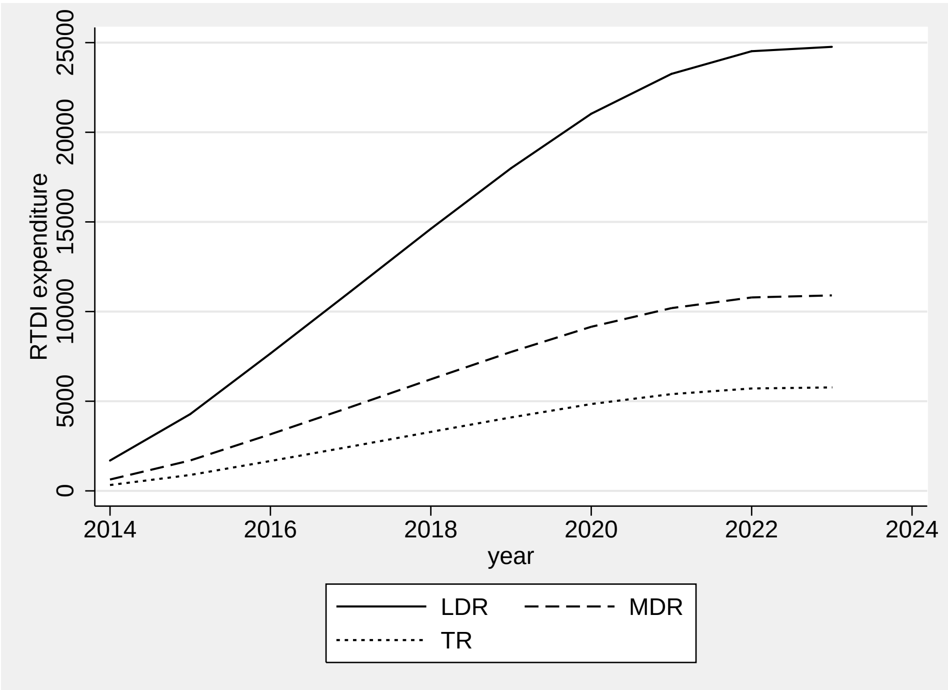

Figure 2: Time profile of cumulative RTDI expenditures 2014-2020(+3), Million Euro. Notes: LDR - less developed regions, TR - transition regions, MDR - more developed regions.

In order to construct the RTDI scenario, in a first step all relevant ECP expenditure lines have been aggregated into the total "RTDI expenditures" per region (category RTDI in Table 6). Note, however, that tracking the exact amount of resources directly and indirectly allocated to RTDI support and human capital development is a challenging task. In fact, there are also overlaps with the aid to the private sector provided under Cohesion Policy, a residual category which is as large as the RTDI part itself, and with the separate category of technical assistance. For this exercise, however, we restricted our analysis to EU funding explicitly directed towards R&D, thus providing somehow conservative estiamtes of the impact of R&D-related funding of TFP growth and GDP.

The nested production function structure of RHOMOLO allows for a differentiation of labour productivity, capital productivity, and total factor productivity effects reflecting the corresponding lines of expenditure and can handle reclassifications when needed. In the present study, however, total factor productivity (TFP) improvements are the main conduits how policy support to RTDI is modelled in RHOMOLO. In a second step, the corresponding RTDI expenditure is expressed as an increase in R&D intensity compared to the baseline in line with our estimates of the effect of R&D on total factor productivity (see section 4.2).

4.2. Estimating the elasticities of R&D and innovation policies on productivity

To measure productivity, we follow the framework of Griliches (1979), in which the parameters of a regional production function are estimated econometrically. Our starting point is the underlying RHOMOLO model, where regional value added, VA_{rt}, is modelled as a Cobb-Douglas production function of capital and labour:

$$VA_{rt} = A_{rt} L_{rt}^{\alpha_1} K_{rt}^{\alpha_2}, \tag{1}$$

where production function (1) is augmented with a Hicks neutral productivity term, A_{rt}, which captures regional TFP. In order to derive an estimable value added production function, we apply a logarithmic transformation on both sides of equation (1) and add an error term, which yields:

$$\ln VA_{rt} = c + \alpha_1 lnL_{rt} + \alpha_2 lnK_{rt} + \epsilon_{rt} \tag{2}$$

The value added function production (2) can be estimated using a simple OLS estimator, after which it is straightforward to calculate a time series of regional TFP growth using the estimates of the residual, ϵ_{rt}:

$$\frac{\Delta A_{rt}}{A_{rt-1}} = g_{rt}^{A} = \epsilon_{rt} - \epsilon_{rt-1} \tag{3}$$

In the second stage, regional TFP growth is regressed on R&D intensity, defined as the ratio of net investments in R&D over regional value added. By supplementing the model with a proxy for the region's TFP-gap and interacting it with the R&D variable, it is possible to test for the presence of technology diffusion between regions. According to Benhabib and Spiegel (2005), in an equilibrium with technology spillovers the leading region will act as an innovator and technology diffusion will allow lagging regions to catch up through imitation of technology. In the long-run, after technology convergence is reached, all regions eventually grow at the same rate. The technology gap is measured by the percentage distance to the leading region's TFP level.[6] This leads to the following empirical specification:

$$g_{rt}^{A} = c_r + c_t + \beta_1 R\&D_{rt-1} + \beta_2 TFPgap_{rt-1} + \beta_3 R\&D_{rt-1} TFPgap_{rt-1} + \eta_{rt}, \qquad (4)$$

in which $R\&D_{rt}$ is measured as year-to-year change in the regional capital stock over regional value added ($R\&D$ intensity). The explanatory variables are lagged by one year, to capture the delay between the investments and their actual return. A positive estimate of β_3 – the coefficient on the interaction term – provides evidence in favour of the technology diffusion hypothesis, as it implies that the growth rate of TFP increases with the degree a region is lagging behind the technological leader.

In order to estimate model (2), data on regional value added, the employment stock and the regional capital stock is collected. Data on regional value added and regional employment stock (full-time equivalents) can be directly extracted from the Eurostat's REGIO database. Regional labour stocks are available from 1999 to 2013. Regional capital stocks were constructed by applying the Perpetual Inventory Method (PIM) on regional Eurostat data on gross fixed capital formation, which is available from 1995 to 2011 (see section 3.3). Gross fixed capital formation and value added were corrected for price evolutions, using their respective deflators from the WIOD data base. Both price indices are made available at the national level only, but are provided in WIOD with a sectoral dimension (see section 3.1). We used this sectoral dimension to regionalise the price indices by using regional series on industry-level

[6] $TFPgap_{rt} = \frac{A_t^{max}}{A_{rt}} - 1$. The leading region is identified in each individual year.

	Mean	St.Dev.	Min	Max
g_{rt}^{A}	-0.0105	0.1104	-.270	0.4079
$R\&D_{rt-1}$	0.0017	0.0056	-.0077	0.0434
$TFPgap_{rt-1}$	0.5760	0.4110	0	4.2635

Table 3: Summary statistics of the key variables of equation 2.

	(1)
$\ln L_{rt}$	0.617***
	(0.011)
$\ln K_{rt}$	0.379***
	(0.011)
year dummies	yes
N	1671

White standard errors in parentheses; *** $p < 0.01$

Table 4: Estimation results of production function (2).

gross fixed capital formation and value added, respectively.[7]

The second stage of the estimation requires data on regional investment in R&D, which are also made available by the Eurostat at the regional level, from 1981 to 2013. Similar to the physical stock of capital, the stock of knowledge capital is calculated using the PIM. Given that R&D-specific depreciation rates are not available, the stock of knowledge capital is assumed to depreciate at the same rate as capital. R&D expenditures are expressed in monetary units and therefore should be corrected to account for price evolutions. In absence of R&D-specific price indices, prices of R&D are assumed to follow those of capital expenditures. Table 3 provides summary statistics of the key variables using to estimate the relationship between R&D and TFP growth.

Table 4 reports production function estimates that will serve as the basis for calculating the regional TFP growth. The coefficient estimates of capital and labour indicate that regions produce with a constant returns to scale technology. In a final step, regional TFP growth is computed using the estimates of table 4.

We estimate four different specifications of equation (4), the results of which are displayed in Table 5. In specifications (1), (3) and (4) the regional TFP

[7] The depreciation rates were regionalised using a similar procedure.

growth is regressed on lagged R&D intensity. Generally, the estimation results suggest that investments in R&D boost TFP growth. The results from the first specification (column (1) in Table 5) suggest that increasing R&D intensity, defined as the ratio of R&D expenditures over value added, by 10 percentage points leads to a rise in TFP growth by 8.8 percentage points. This might seem overly optimistic but, evaluated at the standard deviation of the R&D intensity variable (0.0056), the effect becomes much less pronounced, as it reduces to a 0.49 percentage point growth. The second column isolates the effect of the TFP gap and confirms the catching-up hypothesis of Benhabib and Spiegel (2005): regions whose productivity is lagging behind tend to grow faster and at a higher rate. Thus, ceteris paribus, technological and hence productivity convergence can be achieved in the long run. Specification (3), containing both the R&D intensity and the TFP gap, does not qualitatively alter the results.

The fourth specification is the most interesting in light of the adopted catching-up framework of technology diffusion of Benhabib and Spiegel (2005), it estimates the relationship as portrayed in equation (4). The coefficient of the interaction between R&D intensity and TFP gap is negative. This implies that regions lagging behind in terms of productivity actually experience lower R&D returns compared to technological leaders with high R&D intensity. These results could be explained by the missing necessary absorptive capacity in the less developed regions, which invest very little in R&D and are far from the technological frontier (Brandsma *et al.*, 2013). These results are consistent with findings of Geroski (1998) and Gonzalez and Jaumandreu (1998), who find that a certain critical mass of R&D capacity is required, before significant productivity growth can be achieved from new technology diffusion. In the absence of a sufficiently productive environment, firms are not capable to absorb and use the new knowledge effectively, and hence are not able to benefit from internal and external R&D investment (Cohen and Levinthal, 1989; Griffith *et al.*, 2004; Fabrizio, 2009).

Based on these estimation results, we may conclude that regional investments in R&D have a significantly positive effect on local productivity. The empirical estimates confirm that the intensity of regional R&D expenditures are indeed a crucial factor affecting the speed of catching up. The estimates of specification (4) will be used to simulate the R&D impact on regional productiv-

	(1)	(2)	(3)	(4)
$R\&D_{rt-1}$	0.879^{**}		1.396^{**}	2.733^{***}
	(0.401)		(0.575)	(0.875)
$TFPgap_{rt-1}$		0.19^{**}	0.193^{**}	0.203^{***}
		(0.082)	(0.082)	(0.076)
$R\&D_{rt-1}$ X $TFPgap_{rt-1}$				-2.735^{*}
				(1.631)
year dummies	*yes*	*yes*	*yes*	*yes*
N	833	833	833	833

White standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Estimation results of the production function (4).

ity. The constructed RTDI scenario, which will be simulated in the RHOMOLO and QUEST models and the results will be described in section 5, is summarised in the Appendix, Table 7.

5. Simulation results

5.1. Main results

First, we present simulation results with the technology catching-up mechanism of Benhabib and Spiegel (2005). In these simulations the TFP equation includes spillover and catch-up effects, which are captured by the interaction term, $R\&D \cdot \triangle TFP$, implying that the closer the region is to the technology frontier, the greater will be the effect on the TFP due to the increase in RTDI, given the same starting level of R&D intensity (Benhabib and Spiegel, 2005).

As explained in Section 2, given the high dimensionality of the RHOMOLO model, it cannot be solved by including the same appealing features as in the QUEST model, such as household heterogeneity (in their level of financial constraints) or inter-temporal optimising behaviour with forward-looking expectations. Therefore, at the national level, the output of QUEST is considered as more reliable and the regional outcomes obtained through RHOMOLO are aligned such that at the aggregate level (i.e. country level) they are consistent with QUEST simulations. Hence, the results presented in this section are consistent with those of QUEST, as growth parameters in the RHOMOLO model have been harmonised to the GDP impact of QUEST at the national level.

The results of the RTDI input modelled as TFP shocks in RHOMOLO show positive effects in all regions, with few exceptions in the first years. Czech, Hungarian, Polish and Portuguese regions benefit the most; with impacts on regional GDP of 1% above the baseline in 2030. The impact on GDP in the less developed regions (LDR) is considerably higher than in the transition regions (TR) and the more developed regions (MDR). According to the simulation results mapped in Figure 3, the more developed regions show an impact, which is higher than the RTDI funding they receive, although, for some regions the cost advantages of neighbouring regions receiving the support seem to divert the trade away, leading to insignificant or even to slightly negative effects on output (see Figure 3). This is most visible for regions in the Member States around the North Sea, which receive little RTDI support under cohesion policy and, for instance, in Romania, which absorbs less RTDI support than Bulgaria and other neighbouring countries. These results are consistent with those of Brandsma and Kancs (2015).

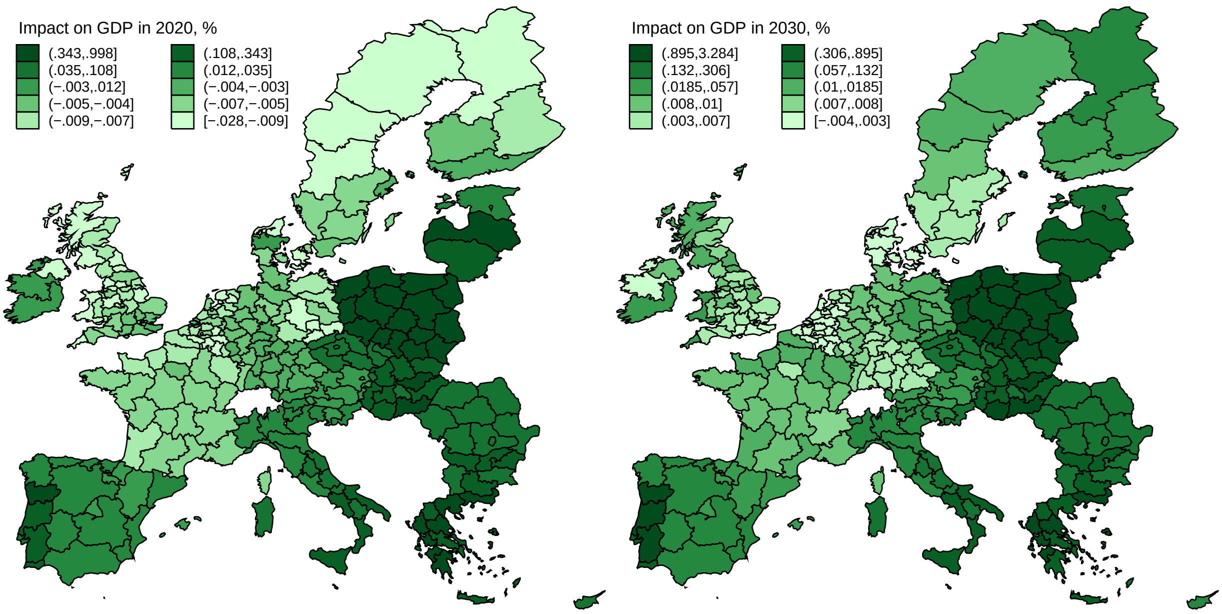

Figure 3: Simulated RTDI impact on real GDP, % changes in 2020 (left panel) and 2030 (right panel).

5.2. Decomposition analysis

The underlying conceptual framework contains multiple endogenous channels of adjustment, as a result of which the net effects are non-linear in the size of policy shocks. In general equilibrium models, such as RHOMOLO and QUEST, a policy shock – here an increase in productivity or productive public capital – may trigger changes in the relative prices/costs. For example, the output price in one sector may change relative to the output price of another sector; the input price of one factor (e.g. labour), may change relative to the price of another factor (e.g. capital); the output or input price in one region may change relative to the output or input price in another region. Depending on which prices/costs change, relative to the prices/costs of competitors, the adjustments take place through different channels, involving sectors, factor supply, factor demand and technology.

In order to identify and better understand the different sources of the generally positive effects of the total factor productivity improvements set in motion by R&D and innovation policies, it is helpful to decompose the aggregated effects on real GDP generated by productivity changes (higher production) on the one hand, and those generated by the reduction in the relative prices due to the increase in production efficiency (lower unit costs) on the other hand.[8] Note that, in reality, productivity gains are distributed over all production factors and may be partly shifted to higher wages, depending on the negotiation powers of employers and employees. This is modelled in more detail by switching on a more elaborated labour market module of RHOMOLO (Persyn *et al.*, 2014).

On the output side, a positive productivity shock is associated with an increase in firm output (right bottom panel in Figure 4). In RHOMOLO, increasing firm productivity makes goods less expensive. A lower price of goods allows households (and firms) to buy more goods, which implies higher demand, higher output and hence higher profits for firms. The right bottom panel in Figure 4 confirms that firm output is increasing in all regions, particularly in the less developed regions. Higher growth in firm output in the less developed regions explains part of the higher GDP growth in these regions.

[8]Note that for the decomposition analysis presented in this section RHOMOLO has not been calibrated to QUEST, implying that there may be differences in the levels and dynamics compared to the main simulations results reported in section 5.1.

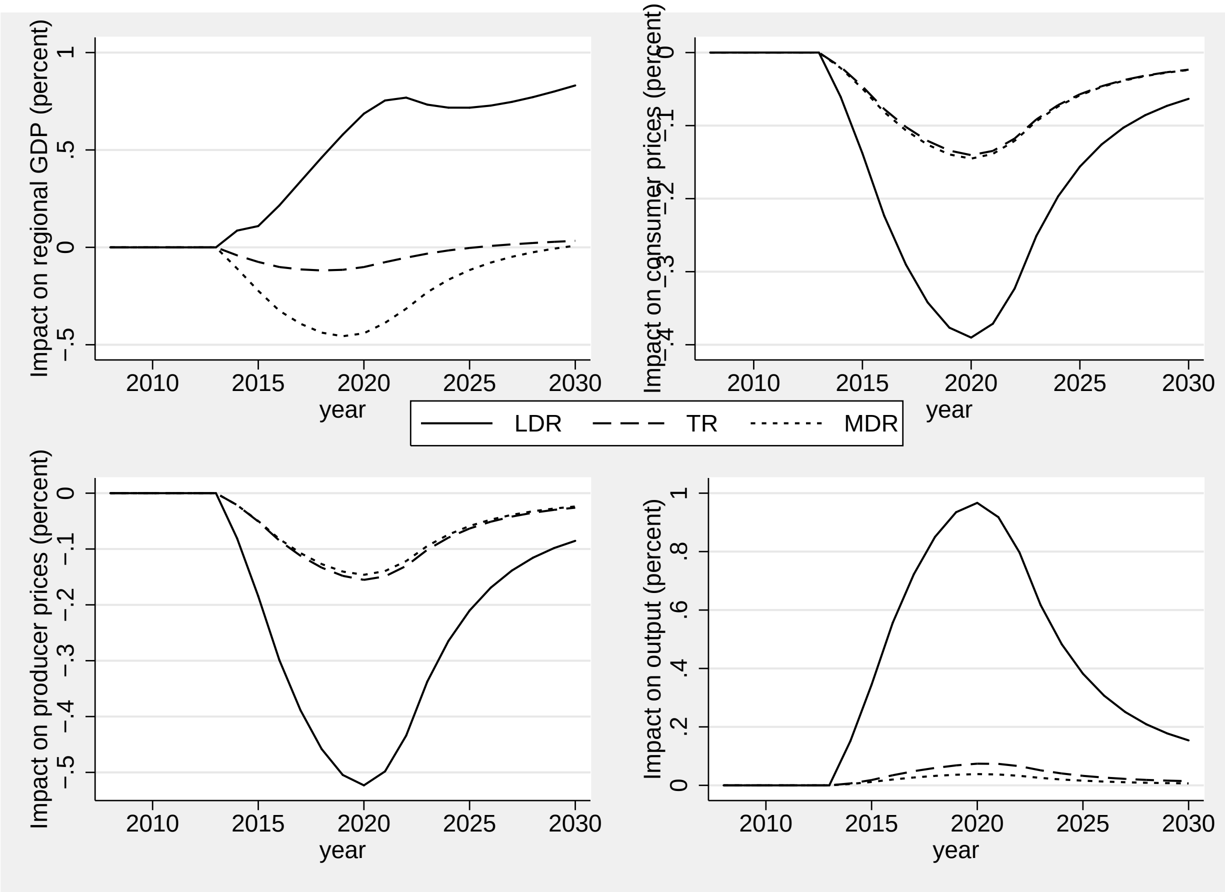

Figure 4: Simulated RTDI impact on GDP, consumer price index, producer prices and output. Notes: LDR - less developed regions, TR - transition regions, MDR - more developed regions.

Figure 4 suggests that a reduction in producer prices (prices of intermediate inputs) contributes more to the real GDP effect than an increase in output due to improvements in the total factor productivity in transition and more developed regions. The left bottom panel in Figure 4 confirms that the price index of intermediate inputs for producers of final demand goods decreases. Larger decrease in the cost of intermediate goods in the less developed regions explains part of the higher GDP growth in these regions.

Next, consider productivity-induced changes in the cost of living (right top panel in Figure 4). In RHOMOLO higher firm productivity reduces the price of consumer goods, which implies that goods are sold at a lower price. The right top panel in Figure 4 confirms that the consumer price index decreases in all regions, particularly in the less developed regions. Larger decreases in the cost of living in the less developed regions explain part of the higher GDP growth in these regions.

The triptych of effects on the consumer price index, the producer price and output shows a reduction in producer prices in the less developed regions by 0.5%, allowing for a decrease in consumer prices and an increase in the demand for goods and services produced in the region (see left bottom panel in Figure 4). The more developed and transition regions benefit from price reductions as well, but the effect on their output is considerably smaller. In fact, while the output of transition and more developed regions increases and the prices of their final and intermediate goods decrease, we can see that their GDP decreases in the short run as compared to the baseline. This result is driven by an increase in imports from poorer regions due to their increased productivity, but consumers are expected to be better off in both rich and poor regions in the short term because of the increased production levels and lower prices. However, in the long term also GDP levels of richer regions converge and surpass their baseline level without cohesion Policy.

Notice also that the impact on poorer regions' GDP in Figure 4 is strong not only in the short term, when the investments are made, but also in the long term, due to the reduction in distance from the leading region in terms of TFP, which makes investments in R&D become more productive and sustain the convergence of productivity levels, as compared to the baseline scenario without Cohesion Policy investments.

Next, we calculate the relative efficiency of RTDI policies across EU regions. Figure 5 maps the GDP results in terms of fiscal multipliers: per one Euro invested and per one percent in productivity improvement. As shown in Figure 5, on average the less developed regions benefit more per one Euro of ECP investment than the transition and the more developed regions. Note, however, that in Figure 5 the results have been normalised, implying that they represent the relative values of multiplier effects across regions. In order to derive absolute values of fiscal multipliers of RTDI interventions, other elements of policies need to be modelled explicitly, e.g. collecting tax revenue to finance the policies, as it is done in the QUEST model (Varga and in 't Veld, 2011). Therefore, for policy simulations, the RHOMOLO model is aligned with the QUEST model.

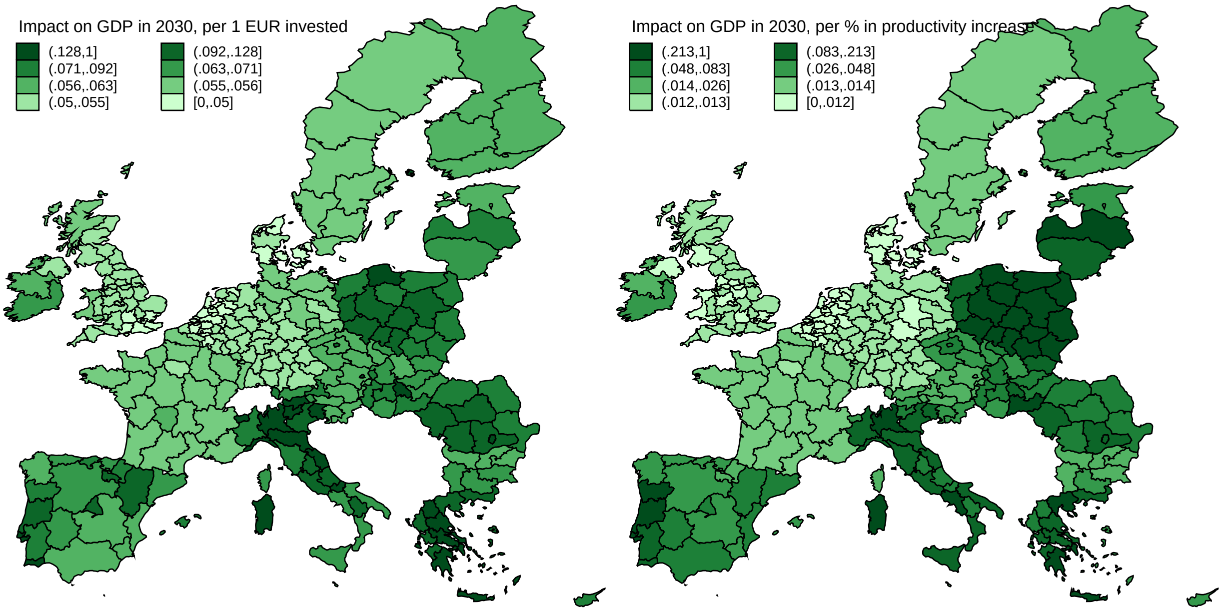

Figure 5: Simulated RTDI impact on GDP per 1 Euro investment and 1% of productivity improvement.

5.3. Sensitivity analysis

As a fist exercise of robustness checks, we fix some of the endogenous variables in RHOMOLO simulations at their baseline values. The results are plotted in Figures 6-7. When the price level is fixed at the baseline level, Figure 6 shows that the increase in GDP is lower than the increase in output. In Figure 6, it is shown how the output-increasing productivity effects would lead to an increase in imports from the less developed regions, partly mitigating the effect on their real GDP and improving the impact on richer regions.

Finally, as part of the sensitivity analysis, we perform simulations without the catch-up term, $R\&D \cdot \triangle TFP$ (specification (3) in Table 5). The simulation results reported in Figure 7 suggest that the absence of knowledge spillovers reduces the positive impact of RTDI policies on regional growth considerably, whereas in percentage terms the reduction is more sizeable for the less developed regions. In particular, notice that less developed regions do not benefit from the long-term improvement in returns on R&D investments under this scenario and so tend to slowly converge to their baseline GDP values in the very long term.

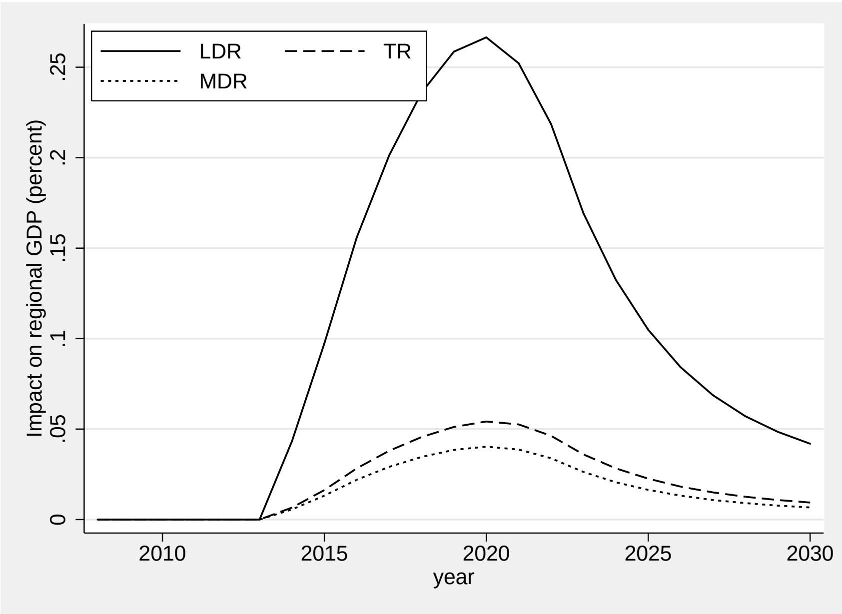

Figure 6: Simulated RTDI impact on GDP with fixed prices. Notes: LDR - less developed regions, TR - transition regions, MDR - more developed regions.

By comparing Figure 7 with Figure 4 one can see that the pattern of the impact of R&D and innovation policies remains largely the same for prices and output, but it is significantly different for regional GDP, which in Figure 7 closely follows output. As expected, the impact on less productive regions is weaker when the catching up effect is not taken into account and there is no increase in the speed of convergence due to the reduced distance from the TFP frontier.

6. Limitations and avenues for future research

For the purpose of the ECP simulations, we have made several important assumptions, which need to be taken into account when interpreting the presented simulation results. First, in our simulations all ECP policies are implemented according to the ex-ante time profile foreseen by the European Commission (2015). In reality, however, there are significant delays in policy implementation, and these delays vary significantly across EU countries and regions. Insufficient absorptive capacity and lacking funds for co-financing the ECP are among two most important reasons for delays in the implementation of the ECP funds (Brandsma *et al.*, 2013). The implications of this assumption on RHOMOLO simulation results is that in reality the medium- and long-run

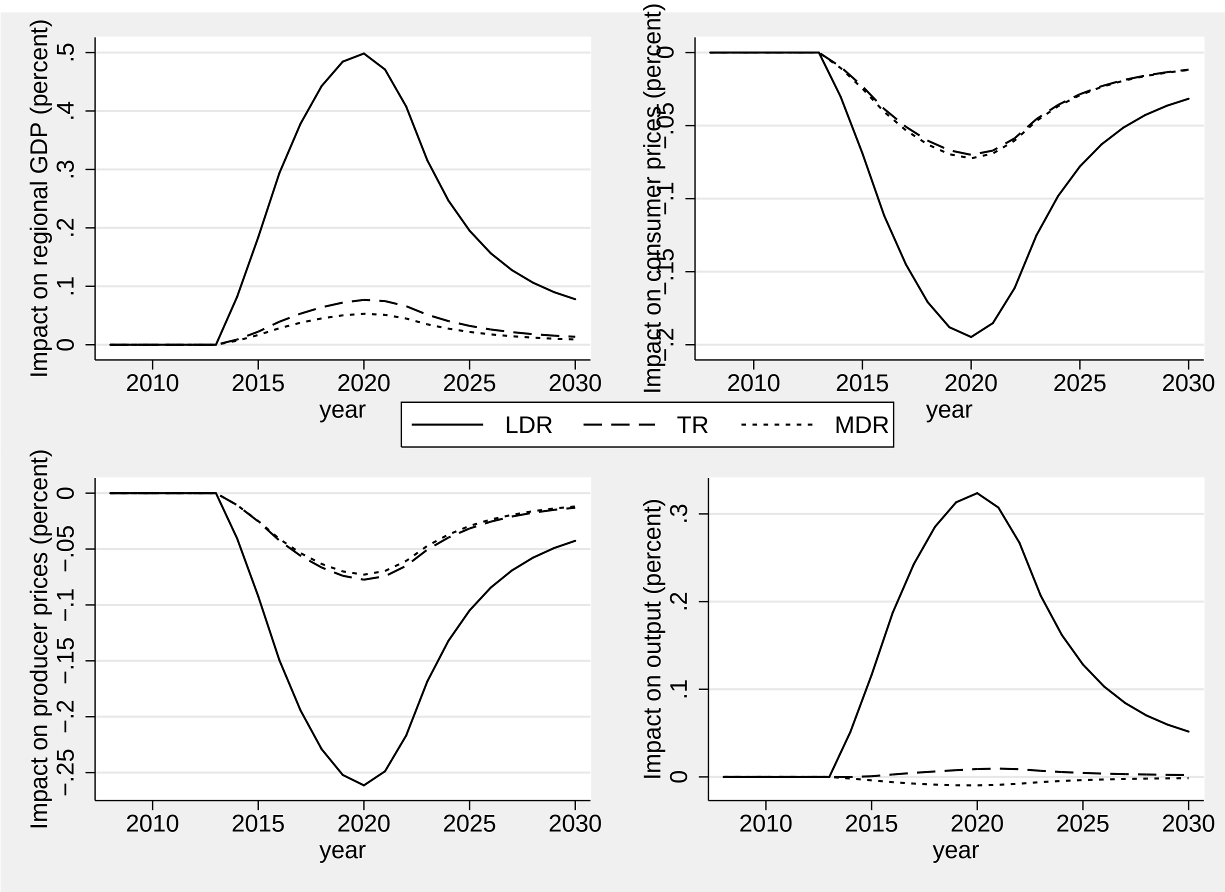

Figure 7: Simulated RTDI impact on GDP, consumer price index, producer prices and output. Notes: LDR - less developed regions, TR - transition regions, MDR - more developed regions.

results may be delayed, in reality, compared to our simulations. In future simulations the issue of absorptive capacity will be addressed based on the past policy expenditure data.

Second, the RHOMOLO model focuses solely on the supply-side impacts of the ECP investments, even though the ECP investments have also important demand-side effects. These are taken into account by calibrating RHOMOLO results at the national level to macro-dynamic results of the QUEST model, which is able to capture the demand side effects through inter-temporal optimisation framework of economic agents, when responding to policy shocks.

Third, the empirical estimates of the impact of R&D investments and spillovers should be better differentiated across sectors, the source of investment funding (private or public) and the efficiency in spending, which will be addressed in the future versions of RHOMOLO.

Another limitation of the R&D modelling approach taken in RHOMOLO is that it does not explicitly distinguish between private and public R&D investments. In addition, the underlying conceptual approaches assume that there is only one type of endogenous innovation, which can be interpreted as product or process innovation, but marketing and organisational innovations are exogenous. Similarly, the current versions of RHOMOLO and QUEST cannot account for reforms in the R&D system that support higher quality investments, even if the quality aspect of R&D investment is at least as important as the amount of R&D expenditure invested in innovation and will be accounted for in the future.

Finally, the inter-temporal dynamics is captured in a rather simple way in RHOMOLO. As usual for high-dimensionality CGE models, all minimisation/maximisation problems of objective functions of economic agents are inherently static to allow us to model different types of interaction within the same model.

7. Concluding remarks

This paper presents and exploits RHOMOLO – a newly developed spatial computable general equilibrium model – implemented at the NUTS2 regional level for the whole EU, to illustrate the mechanisms through which research and innovation policies can have a structural impact on regional economies to foster growth and technological convergence. In order to capture dynamic and macro-fiscal issues, RHOMOLO is used in combination with the Commission's dynamic stochastic general equilibrium model QUEST.

Both the RHOMOLO and QUEST models provide a theoretically consistent micro-founded approach for modelling the innovative activities of firms, as well as the impact of innovation policies. In both models all behavioural equations are derived from maximisation/minimisation of objective functions of the respective agents, implying that no ad hoc specifications of behavioural responses are present in the model. RHOMOLO and QUEST are general equilibrium models, implying that in the model every transaction triggers a relocation of resources, which enter the national accounts with the opposite signs: one negative (demander) and one positive (supplier). This implies that no resources can disappear from the economy without benefiting someone, as no agent

/ production factor can enjoy free manna from heaven. This is particularly important for comparing alternative R&D policy options and/or for calculating fiscal multipliers. In the QUEST model, in order to boost innovation through subsidies, additional tax income must be collect through higher tax rates. Higher tax rates in turn affect production, consumption and saving behaviour of economic agents, which in turn would affect the innovation activity itself. On the other hand, an important strength of RHOMOLO is that it allows to model spatial knowledge spillovers and complex interactions between different levels of policy (EU, national and regional). Given that R&D activities are highly concentrated in geographical space, and knowledge spillovers are significant only locally (Jaffe *et al.*, 1993), the detailed spatial dimension of RHOMOLO can be used to address questions related to geographic concentration of innovative activities and spatial knowledge spillovers.

In order to simulate R&D and innovation policies, first, we econometrically estimate the productivity elasticities with respect to R&D investment. Following Benhabib and Spiegel (2005), we adopt a simple but robust catch-up mechanism to the econometrically estimated effect of investments in research, technological development and innovation. Our estimates suggest that regional investments in R&D have a significantly positive effect on local productivity.

In a second step, we apply the RHOMOLO model in combination with the QUEST model to simulate selected R&D and innovation policies. Our simulation results suggest that the benefits of RTDI policy would spread spatially from the least developed regions to the rest of Europe, also as a result of knowledge spillovers. The simulation shows that cohesion policy support to this type of investment is justified by the lower returns associated with being further away firm the technological frontier, which may trap technologically lagging regions into a low-returns-to-R&D vicious circle. Cohesion policy can thus put the least developed regions on a virtuous path of closing the technology gap with more advanced regions and help them achieve a level of productivity that allows them to self-sustain further investments and growth.

Based on these results we may conclude that the spatial computable general equilibrium approach, such as the one taken in RHOMOLO, is essential for capturing spatial effects of R&D and innovation policies, although it has its limitations. For example, one issue of large-dimension spatial computable general equilibrium models is the technical difficulty to approximate rational intertemporal behaviour and thus agents have to be treated as myopic (Broecker and Korzhenevych, 2013). In fact, the recursive dynamics of the model imply that the dynamics of RHOMOLO depend merely on the continuous accumulation of human, knowledge and physical capital, which extend past accumulation rules to the future. In order to address these issues, in the present paper RHOMOLO is combined with the QUEST model by calibrating the former to be consistent at the country level with the latter, whose dynamics rely on fully fledged inter-temporal optimisation behaviour of economic agents.

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Table 6: Scenario construction: Aggregation scheme of the 2014-2020 ECP expenditure categories.

No	Group	Priority theme
1	RTDI	R&TD activities in research centres
2	RTDI	R&TD infrastructure
3	RTDI	Technology transfer and improvement of SMEs cooperation
4	RTDI	Assistance to R&TD, particularly in SMEs
5	SER	Advanced support services for firms and groups of firms
6	IND	Environmentally-friendly products and processes in SMEs
7	RTDI	Investment in firms directly linked to research and innovation
8	IND	Other investment in firms
9	RTDI	Research and innovation and entrepreneurship in SMEs
10	INF	Telephone infrastructures
11	INF	Information and communication technologies
12	INF	Information and communication technologies
13	SER	Services and applications for the citizen
14	SER	Services and applications for SMEs
15	SER	Access to and efficient use of ICT by SMEs
16	INF	Railways
17	INF	Railways
18	INF	Mobile rail assets
19	INF	Mobile rail assets
20	INF	Motorways
21	INF	Motorways
22	INF	National roads
23	INF	Regional/local roads
24	INF	Cycle tracks
25	INF	Urban transport
26	INF	Multi-modal transport
27	INF	Multi-modal transport
28	INF	Intelligent transport systems
29	INF	Airports
30	INF	Ports
31	INF	Inland waterways
32	INF	Inland waterways
33	IND	Electricity
34	INF	Electricity
35	IND	Natural gas
36	INF	Natural gas
37	IND	Petroleum products
38	INF	Petroleum products
39	IND	Renewable energy: wind
40	IND	Renewable energy: solar
41	IND	Renewable energy: biomass
42	IND	Renewable energy: hydroelectric, geothermal and other
43	IND	Energy efficiency, co-generation, energy management
44	INF	Management of household and industrial waste
45	INF	Management and distribution of water
46	INF	Water treatment
47	INF	Air quality
48	INF	Integrated prevention and pollution control
49	INF	Mitigation and adaptation to climate change
50	INF	Rehabilitation of industrial sites and contaminated land
51	INF	Promotion of bio-diversity and nature protection
52	INF	Promotion of clean urban transport
53	INF	Risk prevention
54	INF	Preservation of environment and risk prevention
55	SER	Promotion of natural assets
56	INF	Protection and development of natural heritage
57	SER	Other assistance to improve tourist services
58	INF	Protection and preservation of the cultural heritage
59	INF	Development of cultural infrastructure
60	SER	Other assistance to improve cultural services
61	INF	Integrated projects for urban and rural regeneration
62	HC	Development of life-long learning systems and strategies in firms
63	HC	Innovative and more productive ways of organising work
64	HC	Services for employment, training and support
65	HC	Modernisation and strengthening labour market institutions
66	HC	Active and preventive measures on the labour market
67	HC	Active ageing and prolonging working lives
68	HC	Self-employment and business start-up
69	HC	Employment and sustainable participation of women
70	HC	Migrants' participation in employment
71	HC	Integration, re-entry into employment for disadvantaged people
72	HC	Reforms in education and training systems
73	HC	Participation in education and training throughout the life-cycle
74	HC	Human potential in research and innovation
75	INF	Education infrastructure
76	INF	Health infrastructure
77	INF	Child care infrastructure
78	INF	Housing infrastructure
79	INF	Other social infrastructure
80	HC	Partnerships, pacts and initiatives through the networking
81	HC	Good policy and programme design, monitoring and evaluation
82	SER	Compensation of accessibility deficit and territorial fragmentation
83	SER	Compensation of size market factors
84	IND	Compensation of climate conditions and relief difficulties
85	A	Preparation, implementation, monitoring and inspection
86	A	Evaluation and studies

Source: European Commission, DG Regio (2014). Notes: INF: Infrastructure; HC: Human Capital; RTDI: Research, Technological Development and Innovation, IND: Industry; SER: Services; A: Technical Assistance.

Table 7: RTDI scenario construction: ECP expenditure on RTDI in 2014-2020 (Million Euro) and the estimated impact in regions' productivity (percent).

Region	EUR	TFP	Region	EUR	TFP	Region	EUR	TFP	Region	EUR	TFP
AT11	23.2	0.118	DEC0	50.2	0.120	GR25	50.5	0.180	PT11*	1486.7	2.219
AT12	69.0	0.050	DED1	269.6	0.626	GR30	199.4	0.118	PT15	52.4	0.528
AT13	6.5	0.004	DED2	294.0	0.775	GR41	15.6	1.450	PT16*	977.2	1.113
AT21	51.7	0.150	DED3	156.4	0.496	GR42	3.6	0.094	PT17	134.2	0.144
AT22	94.7	0.108	DEE0	373.5	0.403	GR43	49.1	0.152	PT18*	234.6	1.941
AT31	63.4	0.053	DEF0	83.2	0.107	HU10	86.3	0.099	PT20*	24.2	1.345
AT32	6.5	0.014	DEG0	268.9	0.036	HU21*	182.4	0.979	PT30	23.6	0.122
AT33	14.3	0.036	DK01	34.9	0.013	HU22*	115.0	0.817	RO11*	82.5	0.189
AT34	9.1	0.010	DK02	22.2	0.033	HU23*	199.6	2.833	RO12*	69.7	0.144
BE10	16.4	0.015	DK03	30.3	0.019	HU31*	276.4	2.658	RO21*	121.9	0.316
BE21	24.5	0.021	DK04	27.9	0.018	HU32*	240.5	2.287	RO22*	84.6	0.206
BE22	33.1	0.083	DK05	13.3	0.009	HU33*	316.4	0.864	RO31*	97.0	0.131
BE23	13.4	0.017	EE00*	600.6	1.981	IE01	46.3	0.025	RO32	31.8	0.023
BE24	11.2	0.016	ES11	550.9	1.085	IE02	152.2	0.024	RO41*	68.8	0.186
BE25	20.2	0.041	ES12	78.5	0.304	ITC1	193.8	0.282	RO42*	54.5	0.086
BE31	9.9	0.033	ES13	85.5	0.287	ITC2	5.8	0.080	SE11	7.0	0.002
BE32	95.8	0.287	ES21	155.6	0.173	ITC3	89.4	0.065	SE12	46.3	0.053
BE33	40.6	0.166	ES22	23.3	0.103	ITC4	138.4	0.031	SE21	26.6	0.048
BE34	12.0	0.211	ES23	13.5	0.081	ITD1	7.0	0.038	SE22	8.1	0.008
BE35	18.2	0.017	ES24	56.6	0.043	ITD2	3.9	0.006	SE23	29.2	0.026
BG31*	50.0	1.798	ES30	99.7	0.022	ITD3	134.6	0.050	SE31	119.6	0.330
BG32*	49.7	2.001	ES41	178.8	0.251	ITD4	51.8	0.064	SE32	117.8	0.736
BG33*	50.8	1.923	ES42	356.2	0.849	ITD5	64.8	0.024	SE33	177.5	0.190
BG34*	57.6	0.929	ES43*	225.2	0.484	ITE1	164.7	0.131	SI01*	329.0	0.842
BG41*	66.3	0.557	ES51	348.7	0.110	ITE2	75.0	0.220	SI02	241.9	0.468
BG42*	84.4	0.938	ES52	494.2	0.400	ITE3	74.5	0.076	SK01	142.9	0.322
CY00	54.2	0.178	ES53	30.2	0.049	ITE4	180.0	0.108	SK02*	331.2	0.850
CZ01	30.5	0.043	ES61	1078.4	0.847	ITF1	49.6	0.301	SK03*	309.0	1.925
CZ02*	297.3	0.711	ES62	173.0	2.374	ITF2	19.5	0.140	SK04*	410.6	1.608
CZ03*	314.3	1.734	ES63	3.9	0.000	ITF3*	1681.2	1.640	UKC1	95.9	0.219
CZ04*	325.3	2.168	ES64	6.7	0.000	ITF4*	835.6	2.651	UKC2	122.9	0.536
CZ05*	447.5	1.854	ES70	319.8	0.354	ITF5*	37.8	0.409	UKD1	16.9	0.069
CZ06*	424.5	1.683	FI13	109.3	0.258	ITF6*	519.8	1.896	UKD2	23.8	0.022
CZ07*	371.0	2.281	FI18	52.9	0.035	ITG1*	1068.9	1.963	UKD3	136.4	0.114
CZ08*	339.8	0.766	FI19	70.4	0.156	ITG2	62.1	0.025	UKD4	71.6	0.095
DE11	14.6	0.005	FI1A	120.4	0.501	LT00*	882.8	1.491	UKD5	88.8	0.245
DE12	10.5	0.006	FI20	1.2	0.010	LU00	16.6	0.018	UKE1	31.2	0.075
DE13	8.7	0.008	FR10	29.9	0.004	LV00*	632.0	1.476	UKE2	11.8	0.026
DE14	7.0	0.004	FR21	80.9	0.146	MT00	39.2	0.395	UKE3	50.0	0.057
DE21	33.1	0.015	FR22	112.7	0.149	NL11	22.7	0.046	UKE4	91.7	0.067
DE22	15.2	0.027	FR23	115.4	0.124	NL12	31.6	0.118	UKF1	63.2	0.045
DE23	11.6	0.019	FR24	82.5	0.095	NL13	23.6	0.096	UKF2	59.7	0.079
DE24	13.1	0.020	FR25	85.3	0.183	NL21	20.2	0.029	UKF3	42.8	0.107
DE25	21.2	0.021	FR26	58.3	0.071	NL22	28.8	0.033	UKG1	29.0	0.040
DE26	15.3	0.018	FR30	268.0	0.225	NL23	11.1	0.043	UKG2	67.9	0.063
DE27	25.0	0.020	FR41	120.0	0.187	NL31	7.9	0.005	UKG3	161.5	0.092
DE30	269.7	0.339	FR42	31.8	0.064	NL32	15.0	0.007	UKH1	19.8	0.015
DE41	149.0	0.667	FR43	51.6	0.087	NL33	24.3	0.012	UKH2	11.5	0.008
DE42	38.8	0.126	FR51	150.5	0.116	NL34	1.9	0.005	UKH3	17.4	0.005
DE50	40.2	0.065	FR52	100.3	0.121	NL41	25.4	0.014	UKI1	14.6	0.004
DE60	4.6	0.002	FR53	64.6	0.095	NL42	16.6	0.008	UKI2	19.6	0.006
DE71	32.1	0.014	FR61	207.9	0.226	PL11*	612.7	1.009	UKJ1	1.3	0.001
DE72	9.0	0.016	FR62	147.7	0.302	PL12	749.7	0.688	UKJ2	2.6	0.002
DE73	12.2	0.018	FR63	31.4	0.037	PL21*	915.1	2.211	UKJ3	2.2	0.002
DE80	212.5	0.789	FR71	117.2	0.075	PL22*	1076.1	1.432	UKJ4	2.5	0.002
DE91	80.1	0.097	FR72	55.2	0.110	PL31*	638.9	4.276	UKK1	17.4	0.013
DE92	98.9	0.117	FR81	141.0	0.184	PL32*	662.4	4.970	UKK2	10.4	0.037
DE93	56.6	0.101	FR82	166.9	0.368	PL33*	399.8	3.263	UKK3*	83.4	0.642
DE94	80.7	0.067	FR83	20.0	0.006	PL34*	378.1	3.292	UKK4	18.9	0.059
DEA1	130.5	0.038	GR11*	89.7	1.066	PL41*	746.0	1.350	UKL1*	380.9	0.716
DEA2	67.2	0.031	GR12*	167.5	0.590	PL42*	390.3	2.850	UKL2	53.4	0.077
DEA3	46.6	0.040	GR13	11.2	0.180	PL43*	237.9	1.802	UKM2	81.0	0.116
DEA4	31.1	0.026	GR14*	107.6	0.877	PL51*	562.3	1.460	UKM3	210.0	0.376
DEA5	103.0	0.058	GR21*	63.5	1.879	PL52*	311.1	1.922	UKM5	14.8	0.209
DEB1	34.1	0.071	GR22	23.1	0.921	PL61*	516.3	2.168	UKM6	37.9	0.477
DEB2	7.7	0.027	GR23*	92.9	0.922	PL62*	387.0	3.042	UKN0	98.5	0.016
DEB3	39.5	0.042	GR24	20.7	0.135	PL63*	570.9	0.762			

Source: Authors' estimates based on the European Commission (2014) data. Notes: Aggregate Cohesion Policy expenditure on RTDI for the entire 2014-2020 period in Million EUR, TFP: estimated increase in total factor productivity in percent. * indicates Less Developed Regions.

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European Commission
EUR 27084 EN – Joint Research Centre – Institute for Prospective Technological Studies

Title: **Macroeconomic Modelling of R&D and Innovation Policies: An application of RHOMOLO and QUEST**
Author(s): Francesco Di Comite, D'Artis Kancs, Wouter Torfs

Luxembourg: Publications Office of the European Union

2015 – 33 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-45245-1 (PDF)

doi:10.2791/547147

LF-NA-27084-EN-N

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doi:10.2791/547147

ISBN 978-92-79-45245-1

Publications Office