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Geographic Macro and Regional Model for EU Policy Impact Analysis of Intangible Assets and Growth

Attila Varga - Péter Járosi - Tamás Sebestyén

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Attila Varga

GKK, Faculty of Business and Economics, University of Pécs
Rákóczi u. 80
Email: vargaa@ktk.pte.hu

Péter Járosi

GKK, Faculty of Business and Economics, University of Pécs
Rákóczi u. 80
Email: jarosip@ktk.pte.hu

Tamás Sebestyén

GKK, Faculty of Business and Economics, University of Pécs
Rákóczi u. 80
Email: sebestyent@ktk.pte.hu

Abstract

This paper introduces the geographic macro and regional model for NUTS-2 regions of the Euro zone. This model consists of three blocks: the TFP, the SCGE and the MACRO blocks. The model is built for impact analysis of policies targeting intangible assets in the forms of R&D, human capital and social capital. The analysis can be done both at the regional and the EU macroeconomic levels. Policy simulations illustrate the capabilities of the complex model system.

Keywords: TFP, SCGE models, DSGE models, impact analysis R&D, human capital, social capital

JEL: O31, H41, O40

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1 Introduction

The geographic macro and regional modeling (GMR) framework has been established and continuously improved to better support development policy decisions by ex-ante and ex-post scenario analyses. Policy instruments targeting the development of knowledge economies (such as R&D subsidies, human capital development, entrepreneurship policies or instruments promoting more intensive public-private collaborations in innovation) are in the focus of the GMR-approach. The framework and its roots in economics are explained in Varga (2006, 2008). The first realization of the system is the EcoRet model (Schalk and Varga 2004, Varga and Schalk 2004) which was further developed in the GMR-Hungary model (Varga 2007, Varga, Schalk, Koike, Járosi and Tavasszy 2008).

Models frequently applied in development policy analysis are neither geographic nor regional. They either follow the tradition of macroeconometric modeling (like the HERMIN model - ESRI 2002 or the QUEST II model - Veld 2007), the tradition of macro CGE modeling (like the ECOMOD model – Bayar 2007) or the most recently developed DSGE approach (QUEST III - Ratto, Roeger and Veld 2009). They also bear the common attribute of national level spatial aggregation. The novel feature of the GMR-approach is that it incorporates geographic effects (e.g., agglomeration, interregional trade, migration) while both macro and regional impacts of policies are simulated. Why does geography get such an important focus in the system? Why is the system called "regional" and "macro" at the same time?

Geography plays a critical role in development policy effectiveness for at least four major reasons. First, interventions happen at a certain point in space and the impacts might spill over to proximate locations to a considerable extent. Second, the initial impacts could significantly be amplified or reduced by short run (static) agglomeration effects. Third, cumulative long run processes resulting from labor and capital migration may further amplify or reduce the initial impacts in the region resulting in a change of the spatial structure of the economy (dynamic agglomeration effects). Forth, as a consequence of the above effects different spatial patterns of interventions might result in significantly different growth and convergence/divergence patterns.

"Regions" are spatial reference points in the GMR-approach. They are sub-national spatial units ideally at the level of geographic aggregation which is appropriate to capture proximate relations in innovation. Besides intraregional interactions the model captures interregional connections such as knowledge flows exceeding the regional border (scientific networking or spatially mediated spillovers), interregional trade connections and migration of production factors.

The "macro" level is also important when the impact of development policies is modeled: fiscal and monetary policy, national regulations or various international effects are all potentially relevant factors in this respect. As a result the model system simulates the effects of policy interventions both at the regional and the macroeconomic levels. With such an approach different scenarios can be compared on the basis of their impacts on (macro and regional) growth and interregional convergence.

The GMR-framework is rooted in different traditions of economics (Varga 2006). While modeling the spatial patterns of knowledge flows and the role of agglomeration in knowledge transfers it incorporates insights and methodologies developed in the geography of innovation field (e.g., Anselin, Varga and Acs 1997, Varga 2000). Interregional trade and migration linkages and dynamic agglomeration effects are modeled with an empirical general equilibrium model in the tradition of the new economic geography (e.g., Krugman 1991, Fujita, Krugman and Venables 1999). Specific macroeconomic theories are followed while modeling macro level impacts.

In order to simulate policy impacts at the regional and macro levels while incorporating geographical effects three model blocks are integrated in the GMR-system: a regional productivity (TFP) block, a spatial computable general equilibrium (SCGE) block and a macroeconomic (MACRO) block (Varga 2008). Novel features of the GMR-system specifically developed for the IAREG project are the followings. 1) The model focuses on the impacts of three specific regional intangible assets such as R&D, human capital and social capital. This way the system incorporates most of the intangibles of the IAREG project. 2) The TFP block is significantly further developed to model dynamic agglomeration effects of policy interventions (Varga, Pontikakis and Chorafakis 2009, Varga and Pontikakis 2009). 3) The model is extended for 144 NUTS-2 EURO zone regions and DG EcFin's QUEST III macro model is being now incorporated. 4) The SCGE model is further developed in its several parts to better adjust to the needs of IAREG.

This paper has the following structure. Section two describes the applied GMR-model in five sub-sections. Section 4 presents policy impact analyses. Appendices provide further details for readers who are interested in additional technical details.

2 Model structure

2.1 Model overview

The GMR-system integrates three sub-models which are organized in three model-blocks. The initial regional impacts of policies on total factor productivity (TFP) are modeled in the TFP block. The resulting regional level changes in quantities and prices of inputs and outputs as well as further modifications in TFP (implied by factor migration) are simulated in the spatial computable general equilibrium (SCGE) block. The SCGE model is thus responsible for estimating the effects of geography (including agglomeration forces and factor migration). However the applied SCGE model is static and as such does not account for temporal changes in labor, capital and technology in an endogenous manner. What it does is that for any given aggregate level of labor, capital and technology it calculates their equilibrium spatial distributions. As highlighted above dynamism in technology is modeled in the TFP block. Dynamic effects of interventions on labor and capital are simulated in the MACRO block. With this block QUEST III the DSGE model for the Euro zone is incorporated into the system. The three model blocks are interconnected and run subsequently until the aggregate regional impacts from the regional sub-models approach very closely the EU-level impacts estimated in the macroeconomic model.

The model system uses data from various sources. Some of them are publicly available from the EUROSTAT web-page (such as the New Cronos database for regional patents, R&D, technology employment and data for most of the macro level variables) and some of them are

developed for the European Commission (such as the regional FP5 and FP6 databases and the regional publication database). The model system includes 144 NUTS-2 regions of the Euro zone. Estimation of the equations in the TFP block is carried out in SpaceStat. The GMR-system is programmed and run in Matlab.

The following sub-sections describe the three model blocks and their integration. Sub-section 2.2 explains the TFP block, 2.3 focuses on the SCGE block, 2.4 highlights those features of the MACRO block which are relevant for the impact analyses and 2.5 discloses the manner the three sub-models are integrated.

2.2 The regional TFP block

The function of the TFP sub-model is to generate initial TFP changes as a result of policy interventions. Thus this model block (such as the whole GMR-system) is not designed for forecasting purposes but for policy impact analysis. In the followings the knowledge production equations and the TFP equation are introduced subsequently.

2.2.1 The knowledge production equations

Economically useful new technological knowledge is measured by patent counts spatially allocated according to the addresses of inventors (and distributed proportionally in case of multiple inventors). Shortcomings of patent data in measuring new technologies is well known in the innovation literature (e.g., Griliches 1990) however it has also been shown that this measure proxies innovation closely in the regional knowledge production function environment (Acs, Anselin and Varga 2002). The level of analysis (as throughout the two regional sub-models) is NUTS-2 European regions. The knowledge production equations are empirically estimated and explained in details in Varga, Pontikakis and Chorafakis (2009). Further information about the empirical analysis can be found in the regression tables shown in the Appendix.

Following Romer (1990) and Jones (2002) technological change is explained by the size of research and the level of already existing technological knowledge. The corresponding empirical relationship is estimated by the following regional knowledge production function.

(1) Log(PATENTS) = 1.325381*(-2.3006 + BETAPAT*Log(GRD(-2)) + 0.1804* Log(PSTCK$_N$(-2))
$\quad$ + 0.4614* PAHTCORE) + U$_1$

where GRD is gross research and development expenditures (including both private and public expenditures) PSTCK$_N$ is national level stock of patents (measuring already accumulated knowledge at the country level), PATHCORE is a dummy representing regions with high patenting activity (i.e., regions where the number of patents is two standard deviations higher than the average in the sample). Each estimated parameter is multiplied by 1.325381 which is the spatial multiplier[1].

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[1] The spatial multiplier represents the indirect knowledge inputs from spatially proximate regions. That is for example not only R&D carried out in the region effects regional knowledge production but also interactions of the region with spatially proximate regions (via formal collaborations, learning or pure knowledge spillovers) affect it indirectly. The value of the spatial multiplier is calculated based on the spatial lag coefficient in Table 1 following Anselin 1988.

BETAPAT measures regional productivity of research. It is an elasticity representing the impact of research expenditures on patents. It is assumed that regional research productivity is not constant over space but varies according to the agglomeration of knowledge necessary in innovation in the region (Varga 2000). Thus regions where considerable amount of complementary knowledge is accumulated at innovative manufacturing and service firms or public organizations are assumed to use R&D expenditures more efficiently in knowledge production than those regions where knowledge is less agglomerated.

The estimated equation of BETAPAT is:

(2) $BETAPAT = [(0.7088 + 0.1439*Log(\delta(-2))]$

where agglomeration of knowledge is measured by the following index:

(3) $\delta_i = [(EMPKI_i / EMPKI_{EU}) / (EMP_i / EMP_{EU})] / [(1 - \sum_j (EMPKI_{i,j} / EMPKI_{j,EU})][1 - (EMP_i / EMP_{EU})]$

Equation 3 is an index of relative regional specialization of knowledge intensive employment with a correction for the size of the regional economy[2].

R&D is not constant over time. It is assumed that regions with high R&D productivity attract further research activities. The following equation shows the empirical relationship between changes in regional R&D and research productivity:

(4) $(GRD-GRD(-3)) = -299.107 + 351.824*BETAPAT(-3) + 190.322*BETAPUB(-3) + 360.98*RDHCORE + U_3$

RDHCORE is a dummy variable[3]. BETAPAT has already been explained. BETAPUB is productivity of pre-competitive research in the region to produce scientific publications. The BETAPUB equation is a result of a related empirical model exhibited in Table 2 in the Appendix and has the following form:

(5) $BETAPUB = [0.4317 + 0.0003* WFP5\_Log(RD(-2))]$

where WFP5_Log(RD) is the sum of (the log of) R&D expenditures of partner regions in the 5th Framework program. While BETAPAT represents "agglomeration effects" in research productivity in patenting BETAPUB reflects the significant impact of formal interregional research collaborations on the productivity of research in producing publications. This second effect is termed "network effect" in regional research productivity.

It is also assumed that agglomeration of knowledge intensive employment partly follows the spatial distribution of R&D. The following empirical equation exhibits this relationship formally:

(6) $(EMPKI-EMPKI(-3)) = 11168.3 + [(0.0262 + 5.624E-06* GRD(-3))]* EMPKI(-3) + 21321.1*RDCORE + U_4$

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[2] EMPKI is employment in knowledge intensive economic sectors (high and medium high technology manufacturing, high technology services, knowledge intensive market services, financial services, amenity services – health, education, recreation) and EMP is total employment.

[3] RDHCORE is 1 for regions with more than two standard deviations higher than average R&D expenditures and 0 otherwise.

where EMPKI is regional knowledge intensive employment as before and RDCORE is a dummy variable[4]. Equation (6) shows that changes in the agglomeration of knowledge are to a
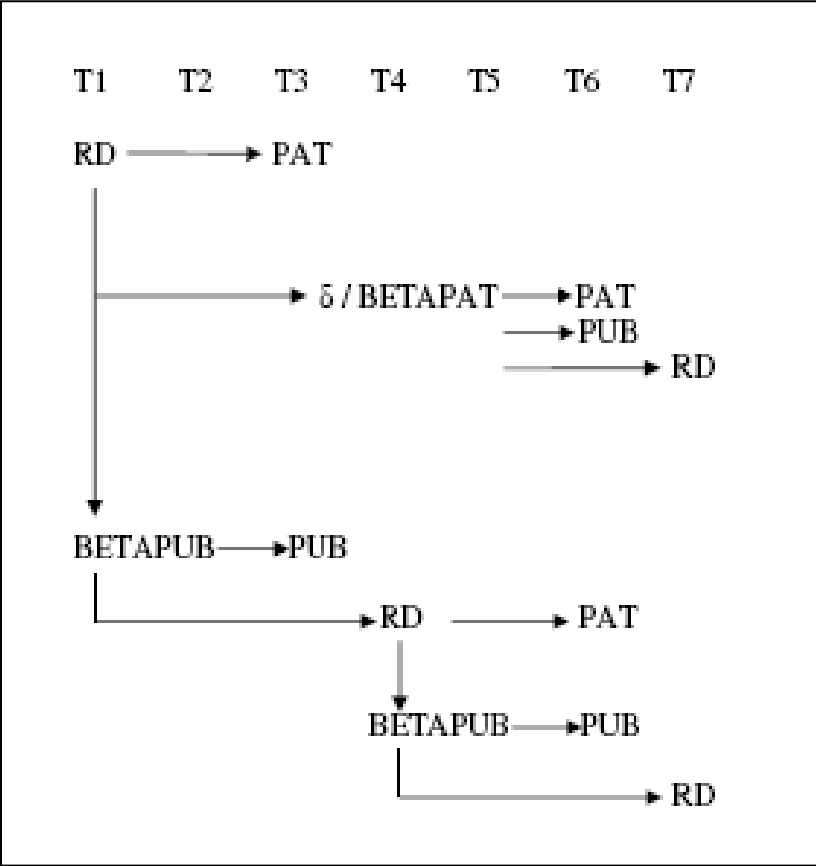

Figure 1: The dynamic impacts of R&D promotion (followed only for the first seven periods)

large extent a path dependent phenomenon. However, R&D also plays a role: attraction of knowledge intensive employment to regions with considerable R&D activities is more intensive than otherwise.

Equations 1 to 6 reflect the dynamic nature of R&D support policy impacts. In a relatively short run this support affects patenting directly while in the longer run it also strengthens concentration of research and knowledge intensive employment in the region which further impacts knowledge production indirectly (via additional R&D and increased values of the parameter BETAPAT). This dynamic feature is represented by Figure 1 where the first 7 time periods are shown (without continuing the impacts throughout additional periods).

2.2.2 The TFP equation

R&D is a very important intangible asset of a region however it is not the only one that might be critical for regional (and aggregate) growth. Dettori, Marocu and Paci (2009) draw attention to the role of human capital and social capital in this context. In the followings we introduce the estimated regional TFP equation that plays a central role in channeling policy effects into the rest of the GMR model system. Data on regional human capital, social capital and TFP is kindly provided by CRENOS. Human capital is measured by the number of people

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[4] RDCORE is 1 for regions with R&D expenditures above one standard deviation of the sample mean and 0 otherwise.

Table 1. The TFP equation.
Regression Results for Log (A) for 135 Eurozone regions, 2004

Model	(1)	(2)	(3)	(4)	(5)
Estimation	OLS	OLS	OLS	OLS	IV (2SLS) Spatial Lag (INV1)
Constant	3.6425*** (0.2105)	4.0850*** (0.0460)	3.9331*** (0.0425)	3.9832*** (0.0385)	3.9309*** (0.0414)
Log(HUMCAP(-2))	0.0722*** (0.0175)				
Log(HUMCAP(-2))*SOCKAP(-2)		0.0008*** (7.9577E-5)	0.0003*** (8.7574E-05)	0.0004*** (7.5823E-5)	0.0004*** (7.4023E-5)
Log(PATSTCK(-2))			0.0623*** (0.0078)		
Log(PATSTCK(-2))*Log(DENS(-2))				0.0073*** (0.0008)	0.0054*** (0.0010)
W_Log(A)					0.0015*** (0.0005)
R^2-adj	0.11	0.41	0.60	0.63	
Sq. Corr.					0.65
Multicollinearity condition number	22	6	9	7	
White test for heteroskedasticity	8.8335**	11.1798***	10.5357*	7.7393	
LM-Err					
INV1	154.48***	57.35***	1.57	3.27*	1.38
INV2	19.56***	9.00***	0.61	0.02	
LM-Lag					
INV1	52.47***	38.11***	14.98***	7.67***	
INV2	29.31***	22.03	11.33***	3.09*	

Notes: HUMCAP is human capital, year 2002; SOCKAP is social capital, year 2002; PATSTCK is cumulated number of patents (1991-2002), year 2002; DENS is employment (in thousands) per area of the region, year 2002. Data sources: TFP, HUMCAP, SOCKAP (CRENOS), PATSTCK (EPO), DENS (EUROSTAT); Estimated standard errors are in parentheses; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; For Model 4 the Durbin-Wu-Hausman test for Log(HUMCAP)*SOCKAP and Log(PATSTCK)*Log(DENS) does not reject exogeneity; The 3-Group method was followed in instrument selection for the D-W-H test; W_Log(TFP) is the spatially lagged dependent variable where W stands for the weights matrix INV1; Instruments in Model 5 are the spatially lagged exogenous variables calculated with weights matrix INV1; The average value of regional spatial multipliers is 1.03035; *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates significance at $p < 0.1$.

that has attained at least a university degree. The proxy for social capital is the share of population over total population that has taken part at least once in the last 12 months in social activities (such as voluntary service, unions and cultural associations meetings). TFP is estimated within a regression context in Dettori, Marocu and Paci (2009). TFP is calculated for 2004 whereas the rest of the variables are collected for 2002 in order to account for a reasonable time lag between inputs and the resulting TFP level.

Table 1 provides details on the regression analysis. The idea behind the estimated model is that human capital and accumulated technological knowledge are the main inputs to regional productivity. However, the human capital effect on TFP is largely influenced by the level of social capital in the region. That is regions where substantial levels of trust, willingness to collaborate and knowledge sharing are present utilize their human capital in a more effective

way than regions with lower levels of social capital. Similarly it is assumed that regionally accumulated technological knowledge (proxied by patent stock) impacts TFP more productively in regions where industry shows a considerable concentration (measured by the density of employment). The reason behind this is that industrial concentration enhances opportunities for the application of locally accumulated knowledge as well as it provides better possibilities for formal and informal interactions.

Regression results support the hypothesized relationships described in the previous paragraph. Though both human capital (HUMCAP) and patent stock (PATSTCK) enter the equation with highly significant parameters cross products of human capital and social capital (SOCKAP) and patent stock and density (DENS) remain highly significant but result in estimated equations with better regression fits (i.e., model 1 vs. model 2 and model 3 vs. model 4). Multicollinearity is not an issue (the Multicollinearity condition number is well below the threshold value of 30) however spatial dependence remained a problem in model 4 in the form of spatial lag dependence. The weights matrix is INV1 which is an inverse distance matrix. Though the left hand side variables lag two years behind the dependent variable and as such no endogenous relationship is expected in the equation, data errors might be the source of correlation between the explanatory variables and the error term (Dettori, Marocu and Paci 2009). However the D-W-H test does not reject exogeneity for the left hand side variables. Given that error terms are not normal the appropriate regression is the spatial lag model estimated with the instrumental variables methodology (2SLS). In the final model (model 5) no remaining spatial error dependence is found.

Equation 7 is the estimated form of the TFP equation:

$$(7) \ A = 57.42*(HUMCAP(-2))^{0.0004*SOCKAP(-2)}(PATSTCK(-2))^{0.0056*\ln(DENS(-2))}$$

2.3 The regional SCGE block

To model dynamic agglomeration effects of policy interventions in the GMR-system a spatial computable general equilibrium (SCGE) model is integrated. CGE models are numerical and empirical applications of Walrasian general equilibrium models in real world circumstances (Shoven and Whalley 1992). These models build on usual assumptions in microeconomics (i.e., utility and profit maximization/cost minimization, perfect competition and most recently monopolistic competition). CGE models are especially well suited to simulate the short- and long run impacts of shocks to the system. A particularly attracting feature of these models is that they do not need as many observations and details in the data as more traditional econometric techniques do.

Spatial CGE modeling is a very recent development in empirical research. Areas of application in regional analysis range from transport modeling to environmental analysis (Donaghy 2009). A particular class of SCGE models follows the tradition of the new economic geography. A couple of such examples include the CGE Europe (Bröcker 1998), Venables and Gasiorek (1999) and the RAEM model (Oosterhaven et. al 2001, Thissen 2003, Ivanova et al 2007). These models are empirical counterparts of new economic geography systems. Resulting from the policy shock each region finds its equilibrium quantities and prices of inputs and outputs in the short run. This does not mean that the whole spatial system is in equilibrium at that stage. This happens only in the long run when inclinations for firms or households to relocate disappear as real incomes across regions equilibrate resulting from previous migrations.

The particular SCGE model integrated into our framework is the modified version of the RAEM model. This model is especially suitable in situations when regional data are only scarcely available for several variables necessary in RAEM. This section draws on the descriptions presented in Varga (2007) and Járosi, Koike, Thissen and Varga (2009).

2.3,1 Main model assumptions

a. The model considers 144 European regions of the EURO zone;

b. The model distinguishes between short run (i.e., a period of one year with the assumption that equilibrium at each region is reached at both goods and factor markets) and long run (several years through which the system is attracted towards a spatial equilibrium as a result of factor movements across regions);

c. The total number of households is assumed fixed;

d. Total housing supply is fixed or exogenously determined in each region;

e. Capital and labor are used in production;

f. Iceberg-type transportation cost (i.e., transportation cost is measured as a portion of the good needed to transport the commodity for a given distance);

g. Capital stock is owned by households (national dividend);

h. The model considers both centripetal and centrifugal forces that form the geographical structure of the economy. Centrifugal forces weaken spatial concentration while centripetal forces work towards further agglomeration. In the model the centrifugal forces are transportation costs and congestion. The level of congestion is measured by per capita housing. As indicated above housing supply is considered fixed in the model consequently increasing population decreases per-capita housing which works against agglomeration. The centripetal force in the model is a positive agglomeration economy measured by the level of Total Factor Productivity in the region in accordance with Equation 7. Increasing concentration of economic activities (measured by the level of employment in the model) increases the probability of interactions among the actors of innovation in the region that results in a higher technological level. Thus increasing concentration works towards further agglomeration. The actual balance between centripetal and centrifugal forces in the model determines the migration of labor and capital. As such the spatial distribution of production, TFP and inputs are all determined by the interplay of centrifugal and centripetal forces.

2.3.2 Main model equations

Production is determined by a C-D technology:

$$(8) \qquad y_{i,t} = TFP_{i,t} \, \mathrm{L}_{i,t}^{a_i} \, \mathrm{K}_{i,t}^{1-a_i}$$

where i stands for region and t is for time, K, L and TFP representing capital, labor and total factor productivity, *a* is production elasticity of labor.

The F.O.B. prices[5] of region i

$$(9) \qquad q_{i,t} = \frac{w_{i,t}^{a_i} r^{1-a_i}}{TFP_{i,t} a_i^{a_i} (1-a_i)^{1-a_i}}$$

where w is the wage rate, r is capital rent.

The input factor demand functions:

$$(10) \qquad L_{i,t} = \frac{a_i}{w_{i,t}} q_{i,t} y_{i,t}$$

$$(11) \qquad K_{i,t} = \frac{1-a_i}{r} q_{i,t} y_{i,t}$$

where w and r are the prices of labor and capital.

The utility function of the households:

$$(12) \qquad \ln(u_{i,t}) = \alpha_H \ln\left[\frac{H_i}{L_{i,t}}\right] + \beta \ln[x_{i,t}]$$

where H is housing stock, x is final goods.

The budget constraint of the households:

$$(13) \qquad w_{i,t} \frac{L_{i,t}}{N_i} + r \frac{\sum_{i=1}^{I} K_{i,t}}{\sum_{i=1}^{I} N_i} = p_{i,t} x_{i,t}$$

where N is population p is price of goods including transportation costs (C.I.F price).

Utility maximization results in the following demand function:

$$(14) \qquad x_{i,m,t} = \frac{\beta}{1-\alpha_H} \frac{1}{p_{i,t}} \left(w_{i,t} \frac{L_{i,t}}{N_i} + r \frac{\sum_{i=1}^{I} K_{i,t}}{\sum_{i=1}^{I} N_i} \right)$$

The probability of buying goods in region i when living in region j is defined as follows:

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[5] F.O.B. = „free on board"

$$(15) \qquad s_{ij,t} = \gamma_{ji} \left[\frac{(1 + \tau_{ij})q_{i,t}}{p_{j,t}} \right]^{-\mu}$$

where τ represents the „iceberg transportation cost principle", that is the quantity of a good that accounts for transportation costs while the good is transported from i to j, μ and γ are constant parameters.

Thus interregional trade volume gets the following form:

$$(16) \qquad z_{ij,t} = N_j x_{j,t} s_{ij,t}$$

Aggregate demand in region j gets calculated as follows:

$$(17) \qquad N_j x_{j,t} = \sum_{i=1}^{I} z_{ij,t}$$

The cost of transportation is also included in the C.I.F. price:

$$(18) \qquad p_{j,t} = \sum_{i=1}^{I} s_{ij,t} q_{i,t} (1 + \tau_{ij})$$

Considering Equation (15) this always equals to the following CES form:

$$(19) \qquad p_{j,t} = \left\{ \sum_{i=1}^{I} \gamma_{ji} \left[(1 + \tau_{ij})q_{i,t} \right]^{1-\mu} \right\}^{\frac{1}{1-\mu}}$$

2.3.3 Short run market equilibrium conditions

- labor market:

$$(20) \qquad L_{i,t}^{(dem)} = L_{i,t}^{(sup)} \text{ in every region, } \forall \ i = 1..I$$

- capital market:

$$(21) \qquad r \left(\left(\sum_{i=1}^{I} K_{i,t}^{(dem)} \right) - K_{TOTAL,t}^{(sup)} \right) = 0$$

- goods market:

$$(22) \qquad y_{j,t} = \sum_{i=1}^{I} (1 + \tau_{ij}) z_{ij,t}$$

2.3.4 The long run equilibrating mechanism through migration

Utility differences across regions determine migration:

$$(23) \qquad LMIGR_{i,t} = \Phi \left(e^{\Theta \cdot (u_{i,t})} - e^{\Theta \cdot AVG(u_{i,t})} \right) L_{i,t}$$

where $L_{i,t}$ is labor of region i in year t, while Φ and Θ are parameters.

σ represents the share of savings in total output that is (1- σ) part of outputs are consumed by the households and σx is investment[6]. Thus the utility function in equation (23) has been changed to the following form:

$$(24) \quad \ln(u_{i,t}) = \alpha \ln\left[\frac{H_i}{L_{i,t}}\right] + \beta \ln\left[(1 - \sigma)x_{i,t}\right]$$

Equation (23) well exemplifies, that if value of ($u_{i,i}$) in the given region is exactly the average of the ($u_{i,t}$) values of the all regions, then there is no migration in the given region.

2.3.5 Parameter values
Some of the parameters are taken from earlier studies/experiences, some of them are estimated econometrically and some of them are calibrated. As a result variables of the system without shocks replicate the observed values of the same variables.

2.4 The MACRO block

The SCGE model accounts for the spatial dynamic effects of policy interventions. The spatial dynamics is driven by the actual balance of centrifugal (transportation costs, congestion) and centripetal (regional TFP) forces and result in the migration of production factors until the full spatial equilibrium is attained. This model is static in the temporal sense. Temporal and spatial changes in TFP resulting from policy shocks are calculated in the TFP block. Temporal changes in capital and labor caused by policy interventions are calculated by the macroeconomic model where temporal adjustments are in focus (but spatial effects are completely missing). In an ideal system spatial and temporal dynamics are integrated right at the regional level. There are already some attempts to integrate the two dimensions in regional models (Ivanova et al 2007, Bröcker and Korzhenevych 2008). However still further efforts are needed to attain a full-fledged solution for a complete theoretical and empirical integration of the temporal dynamisms of policy induced changes in technology, labor and capital in a spatial equilibrium setting.

2.4.1 DSGE models in macroeconomics

The applied macroeconomic model in the current GMR-system is Quest III a DSGE macromodel for the Euro zone. Dynamic stochastic general equilibrium models (DSGE models from here on) became the workhorse of modern macroeconomics in the last one and a half decade. These models are called dynamic, as they represent the dynamic aspects of economic activity explicitly capturing the dynamic behavior of agents: they operate with forward-looking decisions of households and firms. They are stochastic, as stochastic shocks to different structural relationships are considered. And finally, these models are general equilibrium models as they work with equilibrium conditions in all markets.

In contrast to more traditional macroeconometric models DSGE models bear the advantage of explicit microfoundations: these models are based on rational optimizing behavior of economic agents. This feature makes them theoretically very coherent on one hand, but creates some difficulties with regards to empirical fit on the other: these models do not

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[6] The actual value of σ is calculated and taken from the MACRO block.

capture the data generating process underlying the observed economic time series thus making it especially difficult to bring them to data. However, considerable efforts have been made to increase the empirical fit of DSGE models. For example Smets and Wouters (2003) show that a New Keynesian DSGE model is able to track and forecast time series as well as, if not better than, a vector autoregressive model estimated with Bayesian techniques (BVAR).

It is important to note that DSGE modeling is a tool in the hand of macroeconomists which can be filled up with different contents. Contemporary DSGE models are based on two paradigms: the real business cycle and the New Keynesian literatures. However, elements from the latter one are dominant in these models. These result in the fact that these models are mainly aimed at explaining short term economic fluctuations and as a consequence, they incorporate nominal and real rigidities and imperfect competition as well. However, the DSGE toolbox can also be used to accommodate more long-term focused models as well.

In spite of the considerable achievements in developing DSGE models lots of challenges are still present in this field of macroeconomics. One of the most important weaknesses of current DSGE models is the absence of appropriately modeling financial markets, especially frictions on these markets though there are some attempts to overcome this problem (e.g., Bernanke et al. 1999, Engel and Matsumoto 2005, Schmidt-Grohé and Uribe, 2003). The role of fiscal policy in DSGE models is also under-emphasized as most of these models work under the assumption of Ricardian equivalence. The model used in this paper is a considerable exception by assuming that part of the households are liquidity constrained, i.e. 'non-Ricardian' (Ratto et al., 2009). On the other hand, the use of overlapping generations modeling is also possible to rule out Ricardian equivalence.

Although DSGE models are mostly theory-driven descriptions of economic activities, considerable efforts have been made in order to bring them as close to data as possible. Two basic methods are used to carry out this work. Previously DSGE models were mostly calibrated in order to match observed data, but with the continuous development of estimation techniques it is now common to estimate these models in order to verify their explanatory power and to use them as policy tools. However, there is a tension between theoretical coherence and the empirical fit of models which is clearly visible in the case of DSGE models. These models are designed to gain insights into economic relationships and not to capture the data generation process, which makes it especially difficult to bring them to the data. On the challenges of the estimation of DSGE models see for example Tovar (2008).

2.4.2 The QUEST III model

In this paper we use the QUEST III model as the macro part of our integrated system. The QUEST III model was developed by the economists of the European Commission' Directorate General Economy and Finance for the Euro zone. This model reflects all basic features of contemporary DSGE models highlighted in the previous section. In what follows, we present some of the most important elements of this model. We only place some cornerstones as it would be overwhelming to introduce the whole model. For a detailed discussion of the QUEST model and relevant analysis, please consult the paper of Ratto et al. (2009).

The QUEST III model is a New Keynesian open-economy DSGE model with active fiscal and monetary policy, forward-looking households and firms, real and nominal rigidities. The model also works with several numbers of exogenous shocks both at the demand and at the

supply sides. The model is estimated using Bayesian techniques in order to fit to Euro area data and then used for the evaluation of policy interventions and different kinds of external shocks.

2.4.2.1 Households

Households in the model are divided into two subgroups: liquidity constrained and non-liquidity constrained ones. This division represents the aim of ruling out Ricardian equivalence from the model as mentioned earlier. Non-liquidity constrained households have access to capital markets, i.e. they can save and accumulate wealth. On the other hand, liquidity constrained households do not save: they simply consume their labor income. The share of the two subgroups is exogenously given in the model by parameter *slc*. Both types of households derive utility from consumption and leisure, the utility function specified as a CES-type utility function as below:

$$(25) \quad U(C_t^i, 1 - L_t^i) = \frac{\exp(\varepsilon_t^C)\left[(C_t^i - h^C C_{t-1})(1 - \exp(\varepsilon_t^L)\omega(L_t^i - h^L L_{t-1})^\kappa\right]^{1-\rho} - 1}{1 - \rho}$$

In this utility function C_t^i represents the consumption of household i at time t, L_t^i is the labor supply of the same household (available labor is normalized to 1). h^C and h^L stand for habit formation in consumption and leisure, respectively. ε_t^C and ε_t^L are exogenous shocks in consumption and leisure, ω, κ and ρ are constant parameters ($(\rho - 1)/\rho$ being the elasticity of substitution between consumption and leisure).

Households maximize future discounted utility considering appropriate budget constraints. Non-liquidity constrained households receive income from labor, nominal bonds and rental income from lending capital to firms plus profit income. These incomes are taxed by the government. On the other hand, liquidity constrained households only consume what they earn from labor supply and pay taxes according to labor and consumption.

From the forward looking optimization of households the model gains the main behavioral equations describing consumption, labor supply and wealth accumulation over time. These equations resemble those used in more simple models: the Euler equation of inter-temporal optimization and the labor-supply rule of intra-temporal optimization.

2.4.2.2 Firms

The QUEST model operates with two sectors: a final good producing sector and an investment good producing sector. The former is characterized by monopolistic competition and the latter one by perfect competition. Investment good producers combine domestic and foreign (imported) final goods in order to produce investment goods which in turn, are used by final good producers in their production.

The production of the final good producing sector is described by a standard Cobb-Douglas technology with the exception that a slight increasing return to scale is incorporated:

$$(26) \quad Y_t = A_t^\alpha K_t^{1-\alpha} L_t^\alpha (K_t^G)^{\alpha_G}$$

In this equation K_t is the stock of private capital, K_t^G is the stock of public capital. α and α_G are the respective elasticities. As $0 < \alpha_G < 1$ holds, the production function shows increasing returns to scale. The TFP is represented by A_t which is also effected by the production elasticity of labor.

The most important part in our integrated model is the TFP in the production function, as this is the point where the QUEST model interacts with other parts of the model. In the original QUEST model A_t follows a random walk with drift:

$$(27) \quad \ln A_t = g^A + \ln A_{t-1} + \varepsilon_t^A$$

That is, g^A is the (log) trend of TFP growth and ε_t^A is a random technology shock. In our model these random shocks are not taken as random, but received from the regional model as a result of regional TFP shocks[7].

Firms maximize future discounted profits with a usual profit function and the technology above as a constraint. The resulting equations describe firms' behavior regarding labor and capital demand, capital utilization and price setting. These equations resemble those given in more simple models by equating marginal products to factor costs and so on.

The investment good producing sector is described by a very simple linear technology:

$$(28) \quad I_t = A_t^I I_t^{inp}$$

where I_t^{inp} is the input (foreign and domestic final goods) used in production and A_t^I is the respective technology. Technology in this sector as well as that in the final good producing sector follows a random walk with drift:

$$(29) \quad \ln A_t^I = g^{AI} + \ln A_{t-1}^I + \varepsilon_t^{AI}$$

2.4.2.3 Wage setting
The basic model works with different types of labor thus allowing for price setting power for households in the labor market. In the QUEST model this is implemented by establishing an implicit trade union which sets wages in order to maximize utility of households. The wage rule is quite simple: it equates the marginal utility of leisure to marginal utility of consumption times the real wage, adjusted for a wage mark-up.[8]

2.4.2.4 Frictions
Both the decisions of households and firms are bounded by different market frictions which manifest in adjustment costs in the model. Without describing these costs in detail we just mention that households face labor market frictions (through trade unions) as there is a wage-adjustment cost, and non-liquidity constrained households face capital-adjustment costs as well. On the other hand, firms face labor-, capital and price adjustment costs which are explicitly considered in the profit function. These frictions are the main drivers of the

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[7] In order to clearly focus on TFP-shock impacts all the remaining shocks in the QUEST III are set to zero in policy simulations
[8] In all respects, the weighted average of the two household types are considered.

dynamic adjustment in the time series generated by the model, however they make behavioral equations more complicated.

2.4.2.5 Foreign trade

As was mentioned earlier, the QUEST model is an open economy model. International trade and financial relationships are captured as well. Exports are defined as part of the world demand,[9] dependent on relative price levels (including the exchange rate). Imports are similarly defined as a portion of domestic demand, dependent on relative price levels. Domestic agents can buy foreign bonds which pay a risk premium which is a positive function of the economy wide level of indebtedness. Exchange rate dynamics are captured by interest parity and purchasing power parity.

2.5 Model integration

Figure 1 describes the way the different sub-models are interrelated in the complex system. Following this figure the current section explains the model structure in details. Without interventions TFP in both the macro model and in the regional models grow with a constant rate. This growth rate (0.974 percent each year) is estimated in the Quest III model.
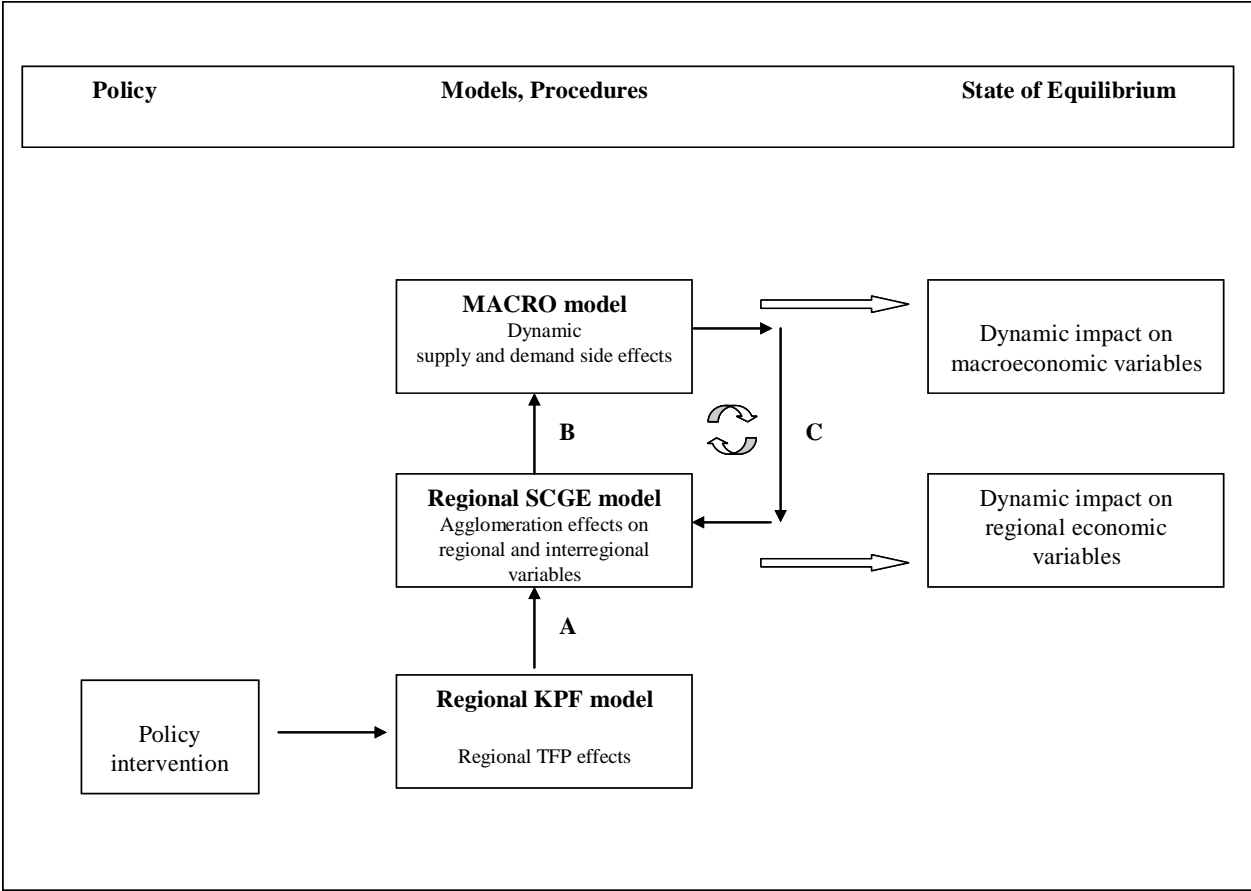

Figure 1. The mechanism of the effects of TFP-related policy interventions

<u>Step 1</u> When a TFP-related policy shock happens (in the forms of R&D support resulting in an increase in patent stock or human capital and social capital development) it induces

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[9] The prefix world meaning rest of the world relative to the Euro area.

changes in the value of A in Equation 7. The baseline value of TFP ($\text{TFP}_{i,t=0}(1+\text{TFPGROWTH})^t$) is then multiplied by the ratio of the value of $A_{i,t}$ with interventions ($A_{i,t}^{SH}$) and without interventions ($A_{i,t}^0$). Equations 7a – 31 below show this in details.

$$(7.a) \quad A_{i,t}^{SH} = \omega_i \, e^{SPATMULT_i \alpha_0} \, HUMCAP_i^{SPATMULT_i \alpha_1 SOCKAP_i} \, PATSTCK_{i,t}^{SPATMULT_i \alpha_2 \ln\left(L_{i,t}/AREA_i\right)}$$

$$(30) \quad \text{TFP}_{i,t=0} = A_{i,t=0}^0$$

$$(31) \quad TFP_{i,t} = TFP_{i,t=0}(1+TFPGROWTH)^t \, (A_{i,t}^{SH} / A_{i,t}^0) \qquad \text{if } t > 0$$

<u>Step 2</u> In the next step $\text{TFP}_{i,t}$ enter the SCGE model where equilibrium values of capital, labor, output, consumption, wages, capital rents and final good prices are calculated for each region and for each year. Differences in utility levels induce factor migration. As a result of this process the equilibrium value of $A_{i,t}^{SH}$ might not remain the same: changing spatial distribution of labor induces changes in labor density in the power of PATSTCK (Equation 7.a) altering the value of $A_{i,t}^{SH}$ in the region.

<u>Step 3</u> In the following step regional TFP values are weighted averaged[10] for each year to get the macro level aggregate in TFP. These annual values enter the MACRO model as a shock in Equation (27) where equilibrium macroeconomic values are estimated for several variables.

<u>Step 4</u> Equilibrium aggregate values of investment and change in labor calculated in the MACRO model are distributed across regions following the patterns of policy induced changes in TFP:

$$(32) \quad \frac{\Delta L_i}{L'_{i,t}} = E_{t+1/t} \frac{\Delta TFP_i}{TFP_{i,t}}$$

where

$$(33) \quad L'_{i,t} = L_{i,t} + LMIGR_{i,t} \,^{11}$$

and

$$(34) \quad E_{t+1/t} = \frac{\Delta L_{TOTAL}}{L_{TOTAL,t}} : \frac{\Delta TFP_{AVG}}{TFP_{AVG,t}}$$

with

$$\sum_i L_{i,t} = L_{TOTAL,t} \,; \Delta L_{TOTAL} = L_{TOTAL,t+1} - L_{TOTAL,t} \,; \Delta L_i = L_{i,t+1} - L'_{i,t} \,;$$

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[10] With the following weights: $L_{i,t}^{a_i} K_{i,t}^{1-a_i}$

[11] LMIGR is explained in Equation 23.

and

$$\Delta TFP_{AVG} = TFP_{AVG,t+1} - TFP_{AVG,t} \quad \text{and} \quad \Delta TFP_i = TFP_{i,t+1} - TFP_{i,t}$$

The resulting change in regional labor is calculated as follows:

$$(35) \qquad L_{i,t+1} = L'_{i,t} + E_{t+1/t} \frac{TFP_{i,t+1} - TFP_{i,t}}{TFP_{i,t}} L'_{i,t}$$

Investment increases total capital:

$$(36) \qquad K_{TOTAL,t+1} = (1-\delta)K_{TOTAL,t} + INV_{TOTAL,t}$$

Where δ is the average depreciation rate according to the corresponding value in the MACRO model. Investment shares in output for each year in the MACRO model is taken to the SCGE model as σ in Equation 24.

Step 5 In the next step the SCGE model is run again to calculate the equilibrium quantities and prices for each region. At this stage the calculations will result in the regional distribution of quantities and prices that bear the impacts of both spatial and temporal dynamisms.

Step 6 In most of the cases the aggregate values of regional output, capital, labor and consumption closely correspond to the respective values in the MACRO model. However, if this close correspondence is not attained Steps 2 to 5 are re-run until this happens.

4. Policy impact analysis

4.1 Regional and macro-level impacts of EU FP6 research contributions

EU Framework programs are designed with the aims of serving the purposes of both scientific progress and technological development. Impact analysis of the FP programs have usually been based on surveys of participants (e.g., Polt, Vonortas, Fischer et al. 2008) which can provide good information at the level of participating institutions or firms, but not at the level of regions where participants located not to mention the level of the European Union. With the help of the complex geographic macro and regional model described in this paper the impacts of EU R&D contributions within the 6th Framework program can be estimated. Main results of the impact analysis are presented in this section.

The Institute for Prospective Technological Studies of the European Commission collected data on FP6 EU R&D contributions and provided the regional and temporal distribution of them for the period of 2003-2007. The monetary values correspond to the information on the projects in the Fall of 2008. Figure 2 exhibits the spatial distribution of funds for the whole period in the Euro zone.

Euro zone regions are classified according to their level of agglomeration given by the values of the agglomeration index (Equation 3). Regions with values of the index of more than one
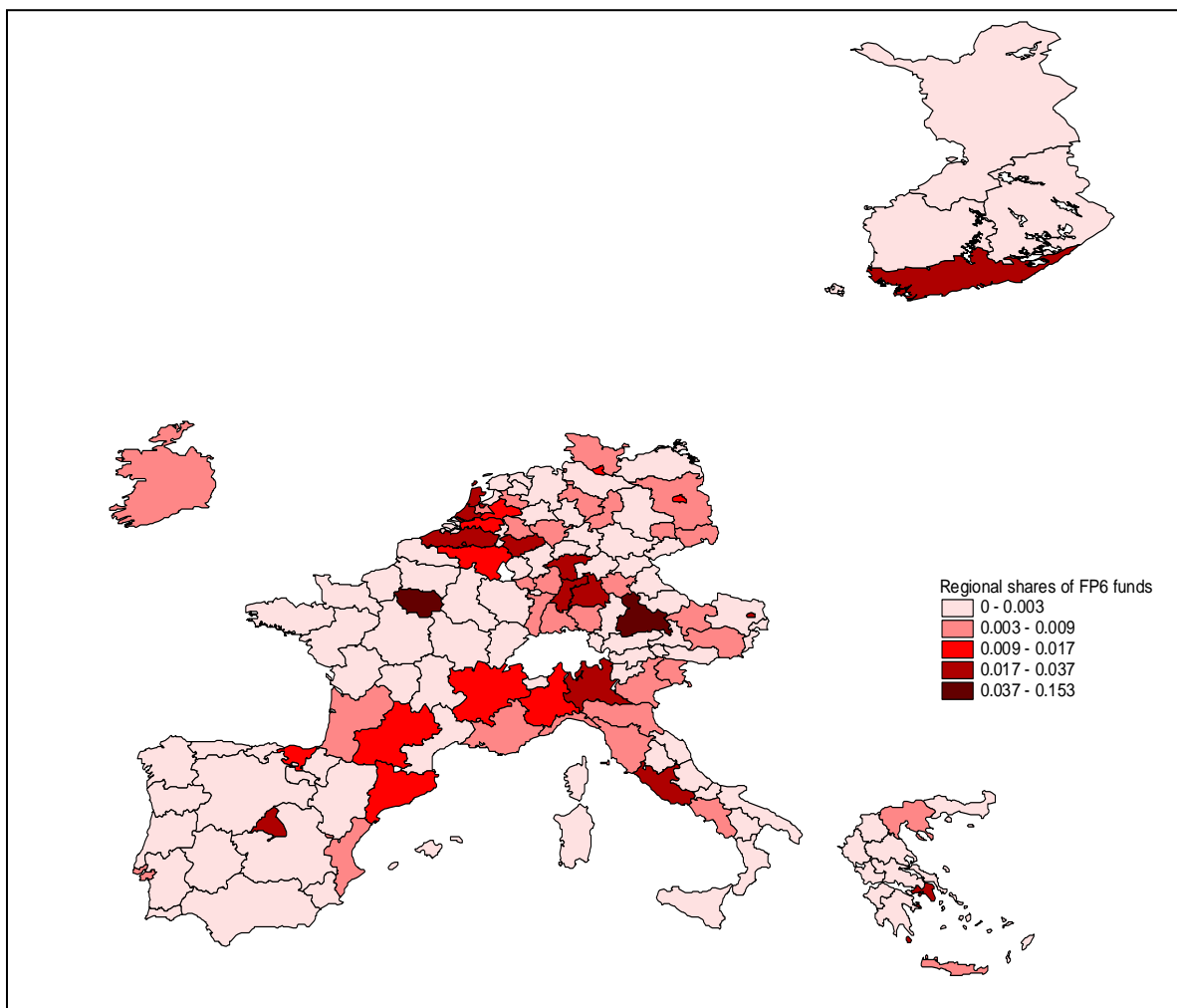
Figure 2. Regional distribution of FP6 funds in the Euro-zone, 2003-2007
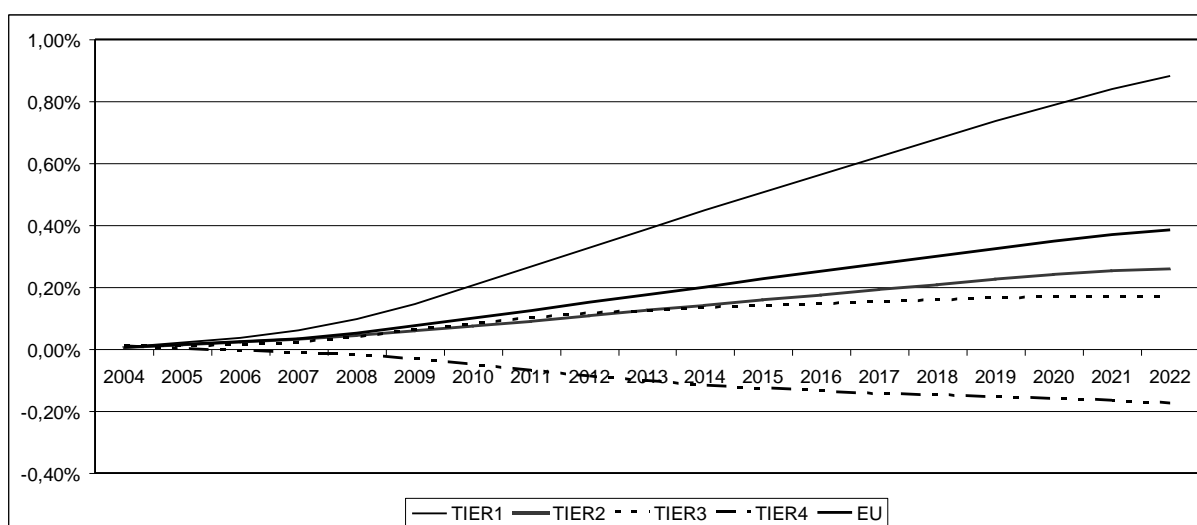

Figure 3.   Average FP6 impacts on GDP in regions belonging to different agglomeration tiers: percentage differences between scenario and baseline values

standard deviation above the mean belong to the first tier. Second tier regions exhibit agglomeration values between the mean and the mean plus one standard deviation. Third tier regions are half standard deviation value below the mean whereas the rest of the regions belong to the fourth tier. Average impacts on GDP in regions belonging to these four tiers are shown in Figure 3.

As it is clear from the figure the estimated impacts are not dramatic. However one cannot expect large impacts from EU R&D contributions accounting for about 4 percent of regional R&D expenditures on average. More than 60 percent of the funds are won by regions belonging to the first tier. Thus it would not be a surprise if the largest impacts are found in these regions. According to the expectations the relative impacts are highest in first tier regions (by the end of the examination period GDP exceeds its no intervention level by about 0.88 percent) whereas market loss and negative net migration result in a slight decline in average GDP in fourth tier regions. (These regions won less than about 4.5 percent of all the FP6 funds during the period of the program.) Figure 4 gives more details as to the regional impacts on GDP by the end of the study period (2022).
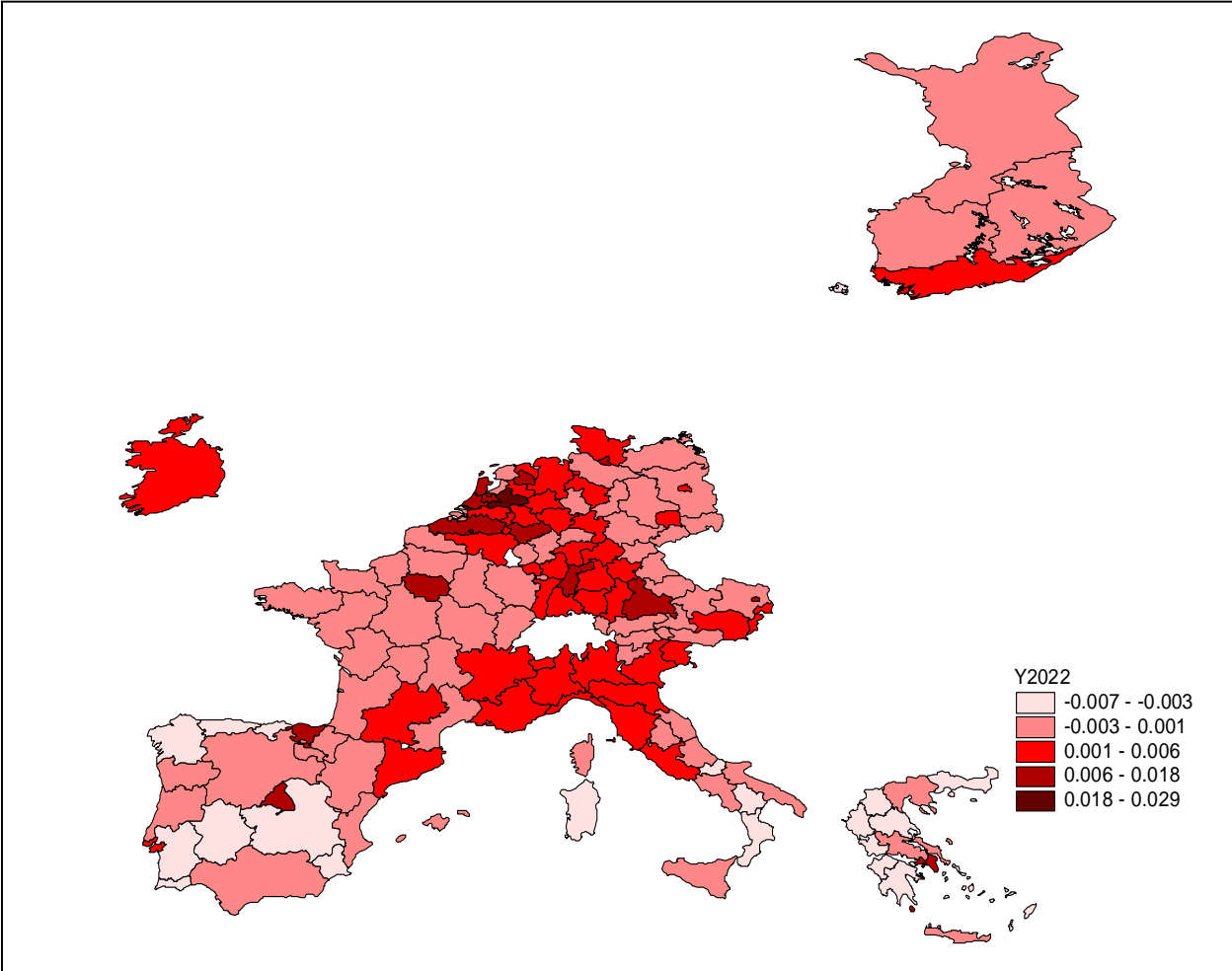

Figure 4. Regional impacts of FP6 funds on GDP of Euro-zone regions, year 2022: percentage differences between scenario and baseline values
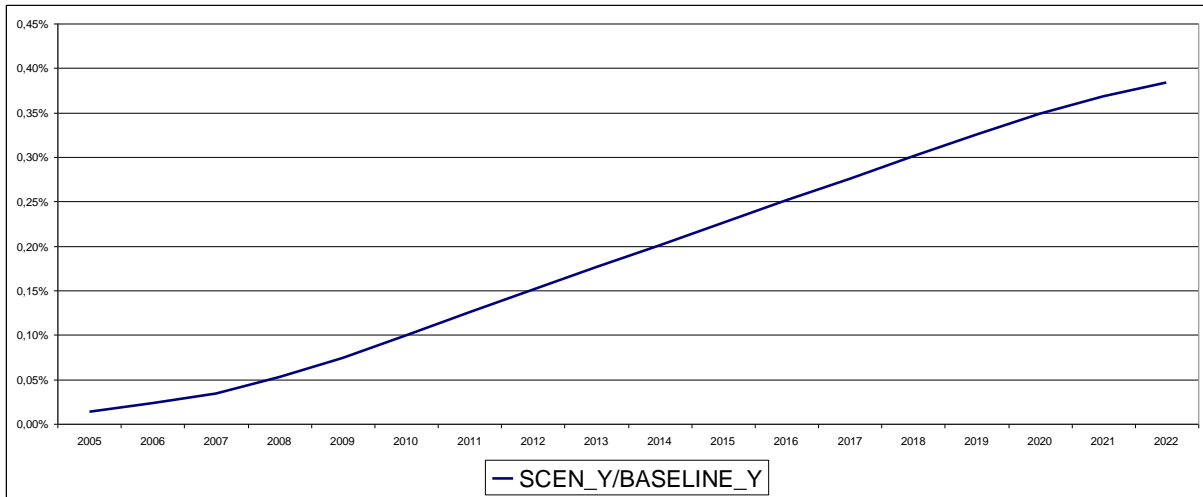
Figure 5. Impacts of FP6 funds on EU GDP, Euro-zone, period 2003-2022: percentage differences between scenario and baseline values

In Figure 5 the estimated impacts on GDP at the Euro zone level are provided. After a slow increase of the initial impacts from 2008 changes in the differences between the non-intervention (baseline) GDP and the GDP of the FP6 impact start to increase from 2007 (which is caused by the lagged temporal effects as well as the induced agglomeration effects
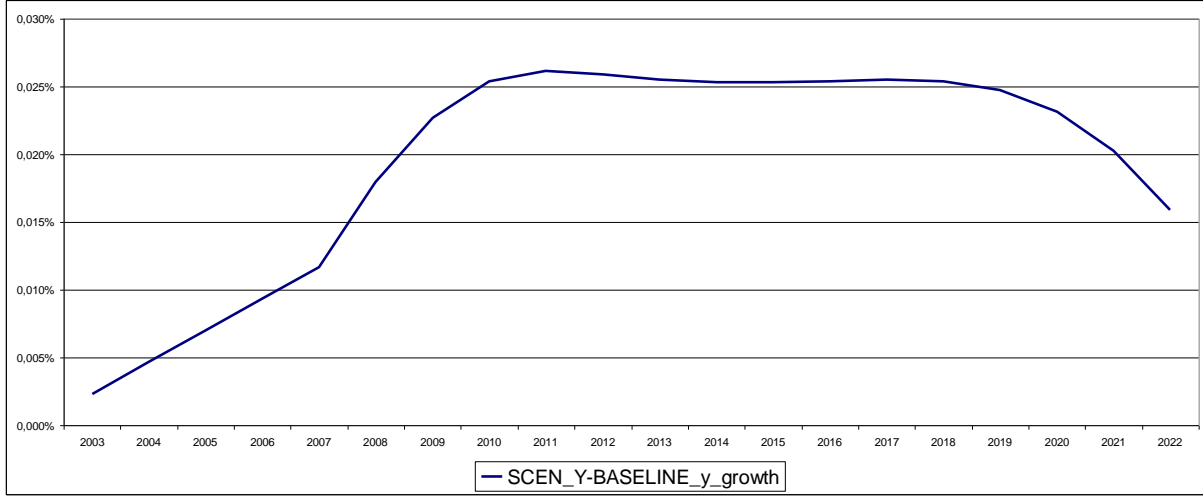

Figure 6. The impact of FP6 funds on EU-level GDP growth rates, Euro-zone, 2003-2022: percentage point differences between scenario and baseline values

as estimated equations in the TFP block describes it) . By the end of the study period EU level GDP is about 0.38 percent higher than it would be without the 6th Framework program.

Figure 6 shows percentage point differences between EU GDP growth rates with and without the FP6 program. The differences increases until 2010, then slightly declines until 2018 and starts to diminish dramatically after 2019 and are expected to reach the zero difference in later periods (not included in the simulations). This is in accordance with what is expected from temporally positive TFP shocks: they increase GDP levels but not the GDP growth rate in the long run.

4.2 R&D specialization and the impact of FP6

There is an ongoing policy debate among high level decision makers and experts of the European Commission about the necessity and potential impacts of R&D specialization (Pontikakis, Kyriakou, Bavel 2009). Should the European Commission and Member States concentrate R&D resources in technological or geographical areas with high research productivity in the expenses of regions lagging in this respect? What are the potential benefits of such specialization on economic growth and what are (if any) the costs in the sense of increased territorial inequalities in the EU?

Connected to the R&D specialization debate in the European Commission in this policy simulation we are interested if the impact of EU FP6 funds would be different at regional and macro levels if Members States followed a more efficient spatial distribution of their public support on R&D. Assuming that the selection of supported R&D projects in the EU Framework Programs in general follows stricter scientific quality standards than most of the programs of Member States we designed a scenario where 1 percentage of total national R&D expenditures is re-distributed according to the spatial pattern of FP6 funds for each year of the simulation period (2003-2022) and for each country included in the sample. Though the extent of redistribution is purposefully small the simulation is capable of providing information about the trends for regions belonging to different agglomeration tiers as well as for the EU aggregate.
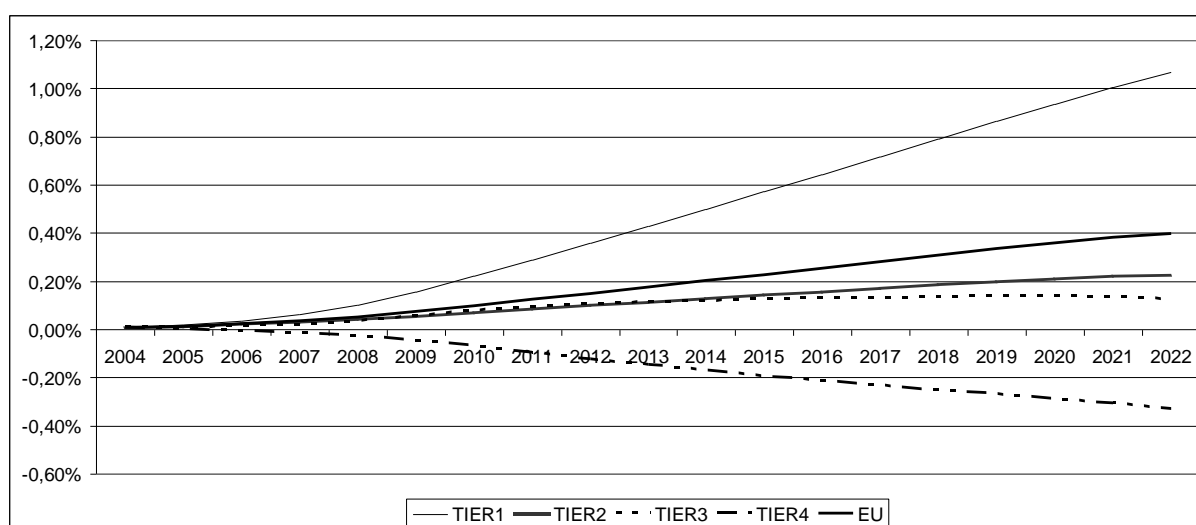

Figure 7. The effect of EU FP6 research support augmented with an annual 1 percent quality-oriented redistribution of national R&D expenditures, Euro-zone, 2003-2022: percentage differences between scenario and baseline values

Figure 7 clearly shows that even a 1 percent redistribution of national R&D expenditures would imply significant changes in regional and macro impacts of EU FP6 research support. Tier 1 regions are definite winners of such a quality redistribution. By the end of the simulation period (2022) their GDP would increase by 1.07 percent which is about 20 percent higher than the FP6 impact would be without the quality redistribution of national R&D funds. The impact on Tier 2 and Tier 3 regions is slightly smaller whereas the negative effect on Tier 4 regions would almost double the size of the impact without quality redistribution. There is also a slight positive impact at the aggregate EU level: in 2022 GDP is higher with about 0.46 percent than it would be without the FP6 program.

4.2 Compensation for R&D specialization 1: regional human capital support

The simulation in the previous sub-section clearly indicates that not every region is equally well-prepared for R&D-based development policies. Whereas Tier 1 regions absorb research funds in a more effective manner (due to high agglomeration of technological knowledge and their extensive interregional research collaboration networks) regions belonging to the rest of the tiers might need additional policy measures to catch-up. In this and the next sub-section the potential effects of the support of two intangibles are in the focus: the impacts of human capital development and the support of regional social capital.
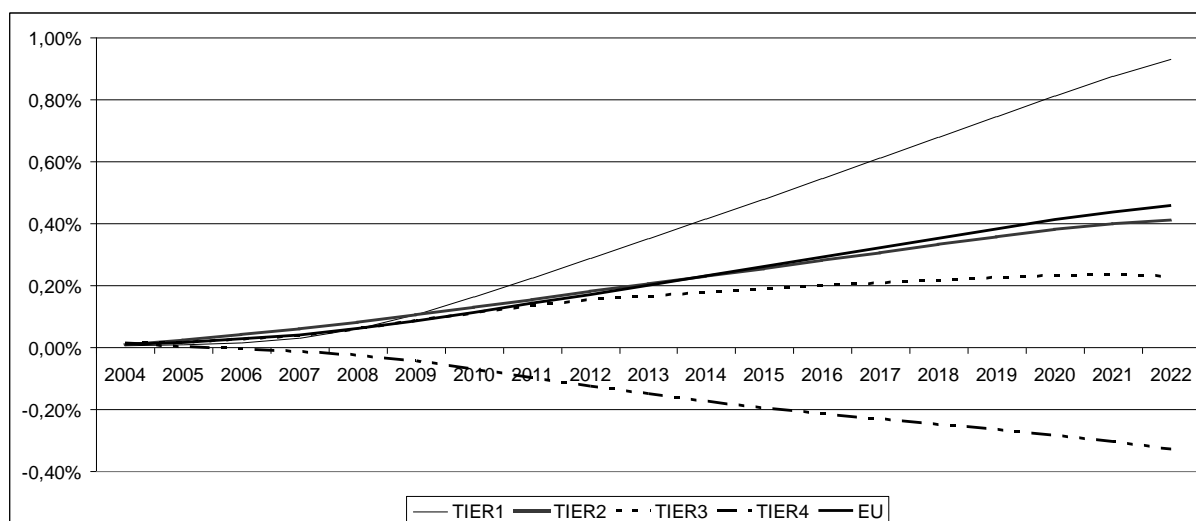

Figure 8. The effect of a 0.5 percent annual increase of human capital in Tier 2, 3 and 4 regions to compensate for the impact of the quality-oriented redistribution of national R&D expenditures, Euro-zone, 2003-2022: percentage differences between scenario and baseline values

To what extent regional human capital development is able to compensate the adverse effects of a quality redistribution of national R&D for relatively less developed regions? In this simulation the previously detailed policy mix of EU FP6 research support and a 1 percent quality redistribution of national R&D funds is extended with a 0.5 percent annual increase of human capital (that cumulates to an about 10 percent increase of regional human capital over the simulation period) in Tier 2, Tier 3 and Tier 4 regions. The impacts are depicted in Figure 8. Tier 2 and Tier 3 regions absorb human capital development in a very effective way: by the end of the study period the impact of FP6 is about two times higher in these regions than what it would be without the compensation for the quality redistribution of R&D. However for Tier 4 regions human capital development has a practically zero impact as compared to the results in Figure 7. The impact on GDP in the Euro-zone is about 10 percent higher when the policy mix of FP6 and regional quality distribution of R&D is extended by human capital development.

4.3 Compensation for R&D specialization 2: regional social capital development
Though changing regional culture is perhaps the most challenging policy task it is interesting to speculate about the likely effects of social capital development. Figure 9 shows the impacts of a policy scenario where regional social capital is increased annually by 0.05 percent (which

cumulates to an about 1 percent increase in social capital over the whole study period) in Tier 2, Tier 3 and Tier 4 regions. Though the targeted increase in social capital is small the results show that policies aiming at such development can be very powerful. Very similar to the results of the previous scenario Tier 2 and Tier 3 regions absorb social capital development in a very effective way: by the end of the study period the impact of FP6 is again about two times higher in these regions than what it was without the compensation. However for Tier 4 regions social capital development again has a practically zero impact as compared to the results in Figure 7. Similar to the findings of the previous scenario the impact on GDP in the Euro-zone is about 10 percent higher when the policy mix of FP6 and regional quality distribution of R&D is extended by social capital development.
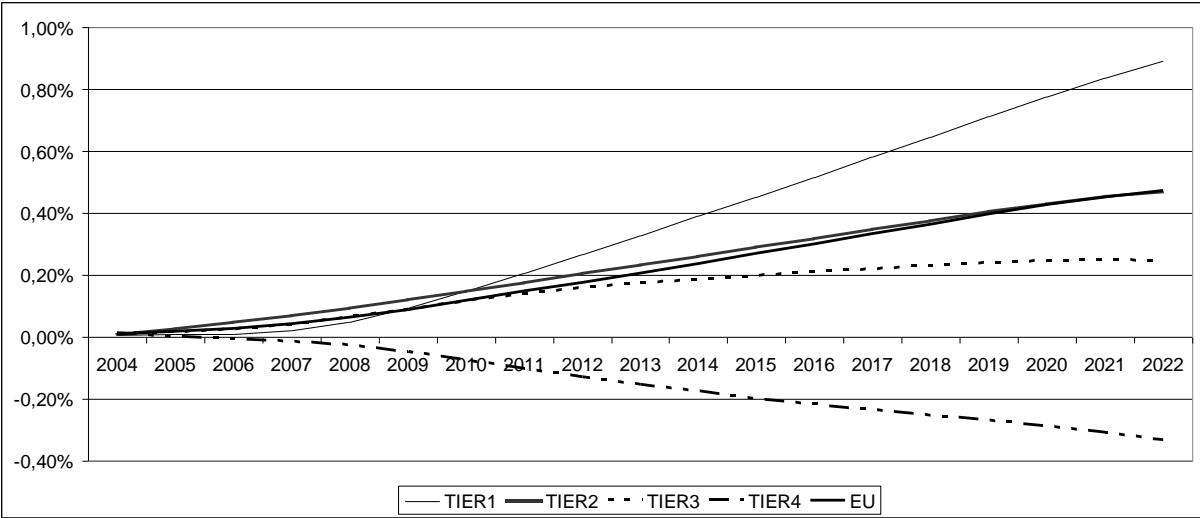

Figure 9. The effect of a 0.05 percent annual increase of social capital in Tier 2, 3 and 4 regions to compensate for the impact of the quality-oriented redistribution of national R&D expenditures, Euro-zone, 2003-2022: percentage differences between scenario and baseline values

4.4 Policy implications
Policy analyses in the previous sub-sections lead to the following implications for regional policies aiming at supporting intangible assets in the forms of R&D, human capital and social capital.

- Compared to the relatively small share of EU Framework Program research support in Member States' R&D budgets regional and EU level economic impacts of FP6 expenditures are considerable. It suggests that this policy instrument is an effective tool not only for promoting scientific publication activities but also for supporting regional and macro level productivity and economic development.

- Redistributing R&D funds to regions where research productivity is the highest is a promising economic policy instrument in the hands of Member States. This instrument increases regional GDP in the most agglomerated regions as well as at the level of the European Union. However, as expected there is a small negative effect on regions with average development and a more adverse effect on lagging regions.

- There are policy instruments to compensate for the negative effects of specialization in the form of a spatial quality redistribution of R&D resources. Continuous regional human capital development can successfully overcompensate the adverse effects in regions where

technological knowledge is about medium developed. There is also a considerable impact of regional human capital development on GDP at the macro level.

- Compensating for R&D specialization in the form of persistent social capital development is also a powerful tool for Member States to improve economic positions of regions with medium-level agglomeration of technological knowledge. This policy option results in a significant macro level GDP impact as well.

- It is clear from the policy analyses that EU regions where agglomeration of technological knowledge shows the lowest levels are not responsive to compensations in forms of either human capital or social capital development. These regions should be considered separately when local development policies are formed. They are not (yet) able to be the sites of future knowledge-based development. Instead, specific sectoral policies aiming at leisure or tourism would be more effective for those regions.

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APPENDIX

Table A1. Regression Results for Log (Patents) for 189 EU regions, 2000-2002
(N=567)

Model	(1)	(2)	(3)	(4)	(5)	(6)
Estimation	OLS	OLS	OLS	OLS	OLS	2SLS- Spatial Lag (INV2)
Constant	-1.6421*** (0.1776)	-0.3107 (0.2316)	-0.5391* (0.2806)	-1.7864*** (0.2381)	-1.7227*** (0.2372)	-2.3006*** (0.2743)
W_Log(PAT)						0.2455*** (0.0631)
Log(GRD(-2))	1.0822*** (0.0308)	0.8453*** (0.0407)	0.9585*** (0.0886)	0.7142*** (0.0377)	0.6879*** (0.0384)	0.7088*** (0.0377)
Log(GRD(-2))*Log(δ(-2))		0.3242*** (0.0389)	0.3222*** (0.0389)	0.2443*** (0.0351)	0.2136*** (0.0363)	0.1439*** (0.0396)
Log(GRD(-2))*Log(NETRD(-2))			-8.675E-05 (6.03E-05)			
Log(PSTCK(-2))				0.2502*** (0.0203)	0.2536*** (0.0202)	0.1804*** (0.0272)
PAHTCORE					0.4814*** (0.1568)	0.4614*** (0.1526)
R^2-adj	0.69	0.72	0.72	0.78	0.78	
Log Likelihood	-885.30	-852.36	-851.32	-784.69	-779.98	
Sq. Corr.						0.80
Multicollinearity Condition Number	7	10	24	13	13	
F on pooling (time)	0.9071	0.6777	0.5644	0.8143	0.6425	
F on slope homogeneity	0.4815	0.7613	0.5836	0.6485	0.4645	
White test for heteroscedasticity	0.7529	1.0462	12.8409	3.6634	12.1852	
LM-Err						
Neighb	111.78***	69.36***	66.85***	26.95***	23.46***	
INV1	252.17***	129.64***	117.26***	29.87***	26.13***	
INV2	215.12***	121.59***	114.45***	32.40***	29.24***	
LM-Lag						
Neighb	142.53***	100.88***	99.03***	24.99***	25.89***	
INV1	247.03***	159.07***	153.47***	28.16***	27.96***	
INV2	237.99***	148.93***	145.48***	31.42***	30.95***	

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: Neigh is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; W_Log(PAT) is the spatially lagged dependent variable where W stands for the weights matrix INV2. *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$. In model (6) the Durbin-Wu-Hausman test for Log(GRD(-2)) and Log(GRD(-2))* Log(δ(-2)) does not reject exogeneity. The instruments were selected following the 3-group method. For the spatial lag term the instruments are the spatially lagged explanatory variables.

Table A2. Regression Results for Log (Publications) for 189 EU regions, 2000-2002 (N=567)

Model	(1)	(2)	(3)	(4)	(5)	(6)
Estimation	OLS	OLS	OLS	OLS	OLS	2SLS Heteroscedasticity Robust
Constant	1.4026*** (0.1298)	2.3886*** (0.1645)	2.196*** (0.202)	2.3395*** (0.1711)	2.4568*** (0.1697)	2.6137*** (0.3199)
Log(GRD(-2))	0.942*** (0.0225)	0.445*** (0.0597)	0.480*** (0.633)	0.4158*** (0.066)	0.4523*** (0.0602)	0.4317*** (0.1262)
Log(GRD(-2))*Log(δ(-2))			-0.0462 (0.0282)			
Log(GRD(-2))* WFP5_Log(RD(-2))		0.0004*** (4.40E-05)	0.0004*** (4.40E-05)	0.0004*** (4.56E-05)	0.0004*** (4.68E-05)	0.0003*** (9.26E-05)
Log(PSTCK(-2))				0.01758 (0.01689)		
PUBCORE					0.2247** (0.1032)	0.3293*** (0.0977)
R^2-adj	0.76	0.79	0.79	0.79	0.79	
Log Likelihood	-707.30	-670.05	-668.70	-669.51	-667.89	
Sq. Corr.						0.79
Multicollinearity Condition Number	7	22	23	27	24	
F on pooling (time)	0.6694	0.9269	0.6712	0.7141	0.7055	
F on slope homogeneity	0.2059	0.357	0.2752	0.2683	0.2501	
White test for heteroscedasticity	44.575***	77.378***	84.013***	92.231***	86.884***	
LM-Err						
Neighb	0.7199	0.7727	0.7518	0.9808	0.5749	
INV1	3.3586*	2.5407	1.8767	3.4006*	2.6595	
INV2	0.3687	0.9367	0.8782	1.2604	1.020	
LM-Lag						
Neighb	12.214***	3.0067*	2.4689	4.2311**	3.7861*	
INV1	1.6479	0.0642	0.4640	0.061	0.0069	
INV2	5.2928**	0.6649	0.1242	1.9522	1.1352	

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: Neigh is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$. In Model 5 the Durbin-Wu-Hausman test for Log(GRD(-2)) and Log(GRD(-2))* Log(NETRD(-2)) rejects exogeneity at the level of $p < 0.1$. In Model 6 the instruments were selected following the 3-group method.

Table A3. Regression Results for (GRD2001-GRD1998) for EU regions (N=189)

Model	(1)	(2)	(3)	(4)
Estimation	OLS	OLS	OLS	OLS-Heteroscedasticity Robust (White)
Constant	-604.429***	-735.41***	-299.107***	-299.107***
	(90.8252)	(101.405)	(78.3494)	(68.7176)
BETAPAT1998	1145.6***	910.258***	351.824***	351.824***
	(147.511)	(167.819)	(125.294)	(118.165)
BETAPUB1998		364.853***	190.322**	190.322***
		(131.181)	(93.4943)	(69.8948)
RDHCORE			360.98***	360.98***
			(26.3212)	(47.4151)
R^2-adj	0.24	0.27	0.63	0.63
White test for heteroscedasticity	52.3206***	57.8899***	42.2263***	
LM-Err				
Neighb	0.1133	0.0231	0.0674	
INV1	0.0092	0.1976	1.1476	
INV2	0.0895	1.8205	0.9415	
LM-Lag				
Neighb	0.0960	0.0434	0.1026	
INV1	2.6971	0.9635	1.9972	
INV2	0.5956	0.5309	1.9896	

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: Neighb is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix. *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$.

Table A4. Regression Results for (EMPKI2001-EMPKI1998) for EU regions (N=189)

Model	(1)	(2)	(3)	(4)
Estimation	OLS	OLS	OLS	ML – Spatial Error (INV2) with Heteroscedasticity weights
Constant	5399.78*	8821.36***	9955.96***	11168.3***
	(3032.61)	(3314.62)	(3267.78)	(2879.48)
EMPKI1998	0.071***	0.054***	0.032***	0.0262**
	(0.006)	(0.009)	(0.012)	(0.011)
EMPKI1998*GRD1998		3.788E-06**	5.043E-06***	5.624E-06***
		(1.582E-06)	(1.604E-06)	(1.604E-06)
RDCORE			19896.5***	21321.1***
			(6614.64)	(6366.96)
LAMBDA				-0.0181**
				(0.009)
R^2-adj	0.41	0.42	0.45	0.45
Multicollinearity Condition Number	2	4	6	
White test for heteroscedasticity	27.37***	28.182***	34.522***	
LM-Err				
Neighb	0.922	0.164	0.042	
INV1	0.052	0.023	0.28	
INV2	1.008	3.263*	5.878**	
LM-Lag				
Neighb	2.181	1.846	1.916	
INV1	0.479	0.043	0.645	
INV2	4.000*	4.574**	4.316**	

Notes: Estimated standard errors are in parentheses; spatial weights matrices are row-standardized: LAMBDA is the spatial autoregressive coefficient; Neighb is neighborhood contiguity matrix; INV1 is inverse distance matrix; INV2 is inverse distance squared matrix; *** indicates significance at $p < 0.01$; ** indicates significance at $p < 0.05$; * indicates $p < 0.1$.

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