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**FROM THE GEOGRAPHY OF INNOVATION TO
DEVELOPMENT POLICY ANALYSIS:
THE GMR-APPROACH**

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From the Geography of Innovation to Development Policy Analysis: The GMR-approach

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Abstract:

Knowledge based local economic development policies (often labeled also as “cluster development” or policies designed to distribute Structural Funds over the EU territory within the framework of “national development plans”) are implemented with an explicit or implicit aim towards broader state, national or even supra national interests. The main issues are growth (at the supra regional level) and convergence (across regions). How different mixtures of the instruments of local development policies can help approach these aims – or more precisely to what extent these policies may serve either of the targets or perhaps both of them? The related theoretical and empirical literature in the new economic geography, economic growth and the geography of innovation fields is extensive. However economic models drawing from this literature and constructed for the aim of evaluating actual development policy decisions in the light of the growth and convergence targets are rare. This paper serves two aims. First it explains a manner how the geography of innovation literature can contribute to develop a sub-model that can be used for assessing the static impacts of development policy interventions in the GMR-Hungary model. Second to demonstrate the power of such a model that incorporates the lessons from the geography of innovation literature policy simulation results with GMR at the regional, interregional and macro levels are provided.

From the Geography of Innovation to Development Policy Analysis: The GMR-approach*

1. Introduction

Beginning in the early 1980's first in the USA then in Europe and in other parts of the World new types of local development policy instruments appeared. These policies are clearly related to the fact first evidenced by Robert Solow (1957) that technological change is the most important component of long-run economic growth. An important reason behind the emergence of these policies is also the positive experience of some highly successful regions (such as Silicon Valley and Route 168 in the USA, or the Cambridge Phenomenon in the UK) where indigenously developed technologies constituted the principal drive of economic growth. These policies are commonly called "technology-based" (or "knowledge-based") economic development policies (Isserman 1994, Cohen, Florida and Goe 1994, Coburn 1995, Reamer, Icerman and Youtie 2003). They are also often labeled as means of "innovative cluster development" (Bergman and Faser 1999, Rosenfeld 2002). Further examples include policies in the European Union designed to distribute Structural and Cohesion Funds over the EU territory within the framework of "national development plans" (EC 1999).

Instruments promoting technology-based local development may be classified into two sets. Interventions in the first class directly promote firm's technological potential by start-up and investment supports, tax credits, low interest rate loans or venture capital. The second set of instruments affects firms indirectly by supporting the local technological (or knowledge) environment by means of R&D promotion both at universities and private firms, human capital improvement, support of public-private interactions in innovation (e.g., university-industry technology centers, government-industry consortia, university-industry research collaboration) or by financing physical infrastructure building¹.

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¹ For a systematic overview of the subject see Reamer, Icerman and Youtie 2003

In case a regional development policy instrument is successful it is the source of static (short run) and dynamic (long run) geographic effects. Static effects include changes in technology (or the level of innovativeness) in the region in target or in other regions where (although unintentionally) impacts might also be detected due to spillovers. Dynamic effects are changes in the spatial structure of innovation and production resulting from the re-location of firms and labor. These changes could effect the relative positions of regions and enforce either convergence or divergence. Additionally, alterations in the spatial structure of innovation (e.g., R&D labs, innovative firms) might cause different paths of economic growth at the supra regional level (e.g., the state, the nation) due to changing patterns of knowledge spillovers and innovation related interactions.

How much do we know about the likely effects of these local development policy interventions? With respect to static effects empirical findings in the geography of innovation literature suggest that besides firm characteristics (e.g., absorptive capacity) spatial extent of knowledge spillovers could possibly be a decisive factor in policy success. An often cited reason for localized knowledge spillovers is that access to tacit knowledge requires personal interactions which are maintained easier if the actors in innovation are located in spatial proximity to each other. Geographical proximity may also speed up information flows irrespective of codification and help build trust and the common language of communication (Koschatzky 2000).

A series of papers (e.g., Jaffe, Trajtenberg and Henderson 1993, Audretsch and Feldman 1996, Anselin, Varga and Acs 1997, Keller 2002) demonstrates that a significant fraction of knowledge spillovers during innovation is bounded spatially. However there are differences across industries (Anselin, Varga and Acs 2000), with respect to firm size (Acs, Audretsch and Feldman 1994) or according to the stage of innovation (Mansfield 1995). The extent to which knowledge spillovers are localized influences the effectiveness of R&D support in the region. The larger the “stickiness” of knowledge geographically the more effective the support of R&D is for the targeted region. In case knowledge spills over the boundaries of the region policies promoting one region could possibly influence neighboring areas as well.

Turning to development policies targeting human capital improvement in the region migration patterns of graduates definitely influences policy effectiveness. Stephan (2006) for example found a very strong migration of Ph.D. graduates to technology regions. Faggian, McCann, Sheppard (2007) ended up with a similar conclusion. For infrastructure support the geographical reach of the effect of infrastructure investments measured by increasing accessibility of other regions besides the targeted one also influences policy outcomes. Cross-regional

spillover effect of transport infrastructure investment was found for example in Oosterhaven, Knaap (2003).

The size of static effects is also related to agglomeration. Even if knowledge spillovers are local the influence that an R&D support policy might exert on the region depends on the spatial concentration of innovating firms, industrial research labs, universities or business service firms. According to the empirical literature agglomeration of innovation is positively related to the change of technology (Feldman 1994, Varga 2000). Positive agglomeration effects are also reported for the migration of graduates (Stephan 2006) that suggest the scale effect in human capital promotion policies. For infrastructure investment support a positive size effect would also not be far from expectations considering that increasing accessibility might result in a higher level of innovation at places where actors of innovation are more concentrated.

However, agglomeration might be instrumental in shaping the geographical structure of an economy due to the dynamic effects of development policies. If spatial proximity is essential in the change of technology and agglomeration forces decrease the costs of innovation these could possibly release a cumulative process of spatial concentration of the system. As such lower costs of innovation (resulting from R&D support or increased human capital) attract firms into the region that further decreases the costs of innovation (at least until positive agglomeration effects dominate) and this effect is strengthened by further firm locations. Thus agglomeration forces are crucial in technological change and as such in economic growth explanation. Models of the new economic geography relate geography to macroeconomic growth. Even starting from different assumptions those models provide theoretical support for the existence of the linkage between agglomeration and growth e.g., (Baldwin, Forslid 2000, Fujita and Thisse 2002, Baldwin et al. 2003).

It directly follows from the above paragraphs that adequate modeling of the economic impact of development policies should consider the geographical aspect directly and as such, correct analysis of the effects of various development policy instruments has to be done in the spatial context. Current econometric models widely used in development policy analysis such as the HERMIN model in Europe (Bradley, Whelan and Wright 1995, ESRI 2002) or the REMI model in the United States (Treyz 1993, Fan, Treyz and Treyz 2000) have moved into the direction of incorporating geography and technological change into their basically demand-driven systems but they do not directly integrate the geography effects. On the other hand EcoRET (Schalk and Varga 2004) directly incorporates the geographical dimension, but the dynamic manner space contributes to macroeconomic performance is not modeled there yet.

There is a need for new generation development policy analysis models that are capable of studying simultaneously regional, interregional and macro level outcomes of policy interventions. This way a policy decision can be evaluated not only by its regional effects but also by the way it affects inequality patterns across spatial units and its impact on macro level outcomes especially on economic growth. Taking into account that the theoretical background has been substantially developed in the endogenous growth, innovation systems and new economic geography literatures (Acs and Varga 2002, Varga 2006) and considering the significantly improved computing power available for research the construction of such models is not unrealistic today.

On the basis of the GMR-Hungary model² (Geographic Macro and Regional model) which (according to my knowledge) is the first of those “new generation” policy analysis models this paper focuses on two issues. First it explains a manner how the geography of innovation literature can contribute to develop a sub-model of GMR that can be used for assessing the static impacts of development policy interventions (sections 2 and 3). Second to demonstrate the power of such a model that incorporates the lessons from the geography of innovation literature policy simulation results with GMR at the regional, interregional and macro levels are provided (section 4). Summary concludes the paper.

2. Regional development policy modeling and the geography of innovation

The GMR-Hungary model is constructed for the analysis of the likely economic impacts of CSF (Community Support Funds) assistance to be spent within the framework of the Second Hungarian National Development Plan (2007-2013). CSF funds include both EU sources and Hungarian co-financing. The aim of the modeling work was to construct a system that is capable of examining the regional effects of policy scenarios, their impact on the relative positions of regions to each other (i.e., the convergence-divergence issue) and the macroeconomic outcomes of different development policy variations.

Careful modeling of static regional effects of policy instruments is important not only for simulating short run regional effects but also to study the dynamic geographic effects since relative differences in positive static regional effects

² GMR-Hungary is the result of an international cooperation to extend EcoRET (Schalk and Varga 2004) with agglomeration dynamism by integrating it with RAEM-Light (Koike and Thissen 2005) a spatial computable general equilibrium (SCGE) model originally developed for the Netherlands. The model was constructed for the Hungarian National Development Agency. Consortium partners included: University of Pécs, Hungary (Attila Varga), University of Münster, Germany (Hans Joachim Schalk), Tottori University, Japan (Atsushi Koike), TNO, the Netherlands (Lori Tavasszy) and Transman Ltd., Hungary (János Monigl).

determines migration and firm location. Although there is a wide selection of empirical research methodologies in the geography of innovation literature (starting from regional innovation surveys, case studies, network analysis and ending at econometric studies of different kinds) for the purpose of policy modeling the choices are very much limited to econometric analyses. The particular functional form to be chosen is the “workhorse” of innovation modeling that is the geographic knowledge production function. The knowledge production function relates innovation to its sources in an econometrically estimated equation. The main sources considered in the literature are public and private R&D (Griliches 1979, Jaffe 1989).

Following the EC categorization (EC 1999) technology-related interventions are classified into the following categories: human capital development (including R&D, education and training) and physical infrastructure investment. These instruments should definitely be included on the right hand side of the knowledge production function. The question that naturally arises is the measure of new technology on the left hand side of the knowledge production function. Studying the literature there are different options: counts of innovations (Acs, Audretsch, Feldman 1994, Anselin, Acs, Varga 1997), patent counts (Jaffe 1989). Innovation counts are expensive to generate so it is a relatively rarely used measure but in geographic knowledge production function studies these are reliably substituted by patent counts (Acs, Anselin, Varga 2002). However, to be in accordance with the complex model system Total Factor Productivity is used to measure technology in the knowledge production function. TFP reflects technological progress and other elements. Constructing the TFP variable we followed the solution common in the growth accounting literature (Barro 1998, Barro and Sala-i-Martin 1995). In this literature where the focus is to empirically separate the effects of the changes in capital, labor and technology on economic growth the level of technology is measured as the residual after the contribution of the other two factors of production is accounted for. Our choice of a regionalized technological change model implies that TFP values are calculated for each of the spatial units³.

³ The production function has the following form: $Y = AK^\alpha L^{1-\alpha}$, where Y is regional output measured by regional GDP at 1995 prices, A is total factor productivity, K is capital, L is labor. The value of K is calculated from investment data following the perpetual inventory method (Hall and Jones 1999). The starting value of K in 1995 is calculated using the formula of $I_{95}/(g + \delta)$ where I_{95} is investment in 1995, g is calculated as the average growth rate from 1995 to 2000 of the investment series and δ is the depreciation rate for which (as it is in the macro-econometric model) we assumed the value of 0.10 which is in line with international standards and also used by the OECD in estimation of potential output growth for Hungary (OECD 2000). The values of the parameters in the production function are assumed to be equal to the income shares of K and L (with α is 0.33). To determine the values of TFP we followed the formula of $A = Y/Y'$, where $Y' = K^\alpha L^{1-\alpha}$.

Given that the TFP function is used in CSF policy analyses it is important to accommodate it to such a purpose. As indicated above we followed the EC categorization of CSF expenditures. According to this TFP-related expenditures are classified as human capital promotion (education/training and R&D) and infrastructure investment support. In this respect we draw on an extensive empirical literature that studies the extent to which human capital and basic infrastructure effect economic growth (e.g., Barro 1990, Christodoulakis 1993, Bajo-Rubio and Sosvilla-Rivero 1993, Mulligan and Sala-i-Martin 1995, Lee and Lee 1995, Engelbrecht 1997). In our modeling framework this growth effect is channeled via changes in Total Factor Productivity (Schalk and Untiedt 2000).

An important issue to be resolved is determining the exact data coverage of the human capital and infrastructure variables according to the types of expenditures CSF interventions commonly associated with. For the human capital variable it seems quite plausible that expenditures on education and training and R&D should be accounted for there. On the other hand for some types of infrastructure investments (such as transportation, utilities or telecommunications) it is quite natural that they need to be part of the infrastructure variable. However, finding the way expenditures supporting health care is being plugged into the equation needed some considerations. Our solution is based on both theoretical arguments as well as empirical experience. With respect to theoretical base we argue that the health care system works in many ways similar to the infrastructural sector as its service (i.e., workforce in a better shape to be employed) decreases costs of the same size of output very much similar to the way infrastructure investments increase productivity such as constructing new highways. Regarding empirical experience classifying health care in the infrastructural sector is supported first by the fact that most of the support in health care are in the form of investments (contrary to the human capital sector where most of them are expenditures) and second by the fact that health care investment enters the equation significantly only if it is part of infrastructure and not in cases when it is included in the human capital variable in any of the forms we experimented with. Other types of CSF supports most importantly environmental support is decided not to enter the TFP function as these types of expenditures do not seem to be clearly related to the supply side (at least not in the short and medium run) as their effects are mainly appear on the demand side.

For the completeness of the geographic TFP function specification the account for differently located knowledge sources in technological change is found necessary. Thus, in addition to the CSF variables (where RD and EDU are local knowledge sources) we included the variable KNAT to relate technological change to nationally available knowledge which is accessible without geographical limits and the variable KIMP to account for the effects of foreign knowledge sources.

The empirical TFP model has the following form:

$$(1) \quad \text{TFPGR}_{i,t} = \alpha_0 + \alpha_1 \text{KNAT}_t + \alpha_2 \text{RD}_{i,t} + \alpha_3 \text{KIMP}_{i,t} + \alpha_4 \text{INFRA}_{i,t} \\ + \alpha_5 \text{EDU}_{i,t} + \varepsilon_{i,t},$$

where

- TFPGR is the annual rate of growth of Total Factor Productivity at the county level,
- KNAT is domestically available technological knowledge accessible with no geographical restrictions,
- RD stands for private and public regional R&D,
- KIMP is imported technologies,
- INFRA is investment in physical infrastructure,
- EDU is investment in human capital (education and training),
- ε is the stochastic error term.

According to the framework outlined above, technological change depends to a large extent on local/regional factors of innovation. Thus the unit of empirical investigation applying equation (1) should be some sub-national geographical entity. Since the lowest level of spatial aggregation of the type of data we need for analysis is the county the selected unit of analysis is Hungarian counties. The spatial unit is denoted by i while t stands for time in equation (1).

To implement equation (1) in an empirical analysis we relied on different data sources. KNAT is measured by the number of patents available in Hungary obtained from the Hungarian Patent Office. In empirical estimations we measured RD alternatively either by R&D employment or by R&D expenditures aggregated from data at private, public and university research institutes. The Hungarian Central Statistical Office provides these data. The measure of KIMP is the share of foreign direct investments in total private investments. To measure foreign direct investments we used data on the number of firms in different size groups and percentage of firms in manufacturing. Data come from regional and county statistical yearbooks published by the Hungarian Central Statistical Office. Investments in infrastructure measure INFRA. Data on infrastructure investments include investments in transportation, telecommunication, health care and utilities. Data sources are regional statistical yearbooks. HUMCAP is measured by all (private and public) expenditures on education and training. Data sources are Hungarian National Accounts by the Central Statistical Office. All the variables measured in monetary terms are in 1995 Hungarian Million Forints.

The estimated form of equation 1 is used to generate static development policy effect on the regions in target. In order to understand if the effect spill over to

other regions at all we run tests of spatial error and lag on each estimated versions of the TFP equation.

Estimation results of equation (1) are presented in Table 1. While KNAT (stock of knowledge, measured as the number of available patents in Hungary) is significant in all the variants of the equation RD (R&D expenditures measuring research input in technological development) is not when included separately from other human capital expenditures (Models 1 and 3). Out of the potentially important alternative variables measuring the regional innovation environment, KIMP, the share of FDI in total investments turns out to be the most influential for regional technological development. Its parameter enters the equation with the expected sign and also it is highly significant and quite stable through all the empirical models presented in Table 1. The knowledge stock KNAT affects TFP growth with a two-year time lag.

Changes in public infrastructure investments, $d(\text{INFRA})$, and changes of expenditures in education, training and R&D, $d(\text{HUMCAP})$, represent the CSF instruments in the empirical model. After structural changes on the time domain is taken care of, the parameters enter the equation with the expected signs as well as with high significances. The TFP model is used in impact analysis and as such forecasting power is a crucial aspect while selecting its final estimated version. To increase in-sample forecasting power of the TFP equation we included the lagged dependent variable as well on the right hand side which enters the function with high significance. DUM99 is a year dummy to account for a structural brake in the data.

The size order of the parameters is also in accordance with expectations. The highest coefficient value is given for technology import, KIMP that is not surprising taken into consideration that the crucial role of multinationals in Hungarian technology development is well recognized in professional circles. It might be taken as a good sign that TFP growth rate is affected by the knowledge stock with a relatively high coefficient suggesting an increasing importance of indigenous technological development. Turning to the role of the CSF instruments in TFP growth, spending on education, training and R&D, HUMCAP seems to be a more effective instrument (at least in a short and medium run) to influence firms' productivity than infrastructure investments, INFRA. It should be emphasized here that our model (at least at this stage of development that is determined dominantly by data constraints)

Table 1: Pooled FGLS estimation results for TFP growth rates (TFPGR) and for 20 Hungarian counties, 1996 – 2003

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Final Model
C	-2.5434 (0.2989)	-2.4740 (0.2910)	-2.4797 (0.2919)	-2.4965 (0.2735)	-2.2423 (0.2728)	-1.8243 (0.2372)	-1.0389 (0.3408)
TFPGR(-2)							-0.2587 (0.0749)
KNAT (-2)	0.0002 (2.68E-05)	0.0002 (2.59E-05)	0.0002 (2.60E-05)	0.0002 (2.45E-05)	0.0002 (2.44E-05)	0.0002 (2.10E-05)	8.84E-5 (3.04E-05)
KIMP (-3)		0.1582 (0.0449)	0.1526 (0.0456)	0.1455 (0.043)	0.0892 (0.0430)	0.1219 (0.0393)	0.0826 (0.0392)
RD (-2)			1.29E-06 (1.77E-06)				
d(INFRA(-1))				3.79E-06 (9.60E-07)	1.46E-06 (1.34E-06)	1.56E-06 (9.41E-07)	2.11E-06 (8.44E-07)
d(HUMRES(-2))					6.95E-06 (2.84E-06)	4.74E-06 (2.47E-06)	5.63E-06 (2.41E-06)
DUM99						-0.0601 (0.0081)	-0.0610 (0.0080)
<i>Weighted Statistics</i>							
R ² -adj	0.31	0.37	0.37	0.42	0.42	0.59	0.62
F-statistic	54.02	35.71	23.83	31.15	18.44	29.27	28.36
Prob (F-statistic)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Durbin-Watson stat	1.90	2.06	2.07	2.02	1.68	2.22	2.42
N	120	120	120	120	100	100	100
<i>Unweighted Statistics</i>							
R ² -adj	0.14	0.19	0.20	0.21	0.23	0.35	0.42
ML Spatial error Neighb	21.3**	16.18**	18.55**	14.79**		2.13	1.25
ML Spatial lag Neighb	21.3**	19.23**	20.64**	18.12**		4.95*	3.78

Notes: estimated standard errors are in parentheses; Neighb is first order neighborhood standardized weights matrix; ** is significance at 0.01, * is significance at 0.05; Because of computational problems the spatial statistics for Model 5 could not be calculated.

can capture only short and medium run effects and the inevitable long run impacts of R&D, infrastructure investments as well as education developments are only suggestive here.

Regression fit is good (the adjusted R-square has the value of 0.62 in the final model) taken into account the presence of cross sectional data for a relatively short time period. The overall performance of the equation is also impressive as suggested by the highly significant F-statistics. Given the wide variety in TFP growth rates across counties it is not surprising, that heteroscedasticity is a major issue in estimation. Different econometric modeling approaches have been applied (such as fixed effect model, random effect model, SUR) but the most effective estimation technique (in the sense of regression fit, parameter stability and parameter significances) was Feasible Generalized Least Squares (FGLS) with cross-section weighting and White heteroscedasticity consistent standard errors and variance. The magnitude of the problem of heteroscedasticity in the data is indicated by the significant differences between respective regression fits with and without weighting⁴.

Spatial dependence in the final model is non-significant both in the forms of spatial error and spatial lag that suggest that the out-of region impact of a development policy intervention is only negligible⁵.

Given that the estimated equation in Table 1 does serve a highly practical aim of impact analysis it is necessary to relate the size of the estimated parameters of the two policy variables to findings in the related literature in order not to

⁴ This heteroscedasticity is caused to a large extent by the determining role of Budapest in the Hungarian economy. We also tried to capture the „Budapest effect” by a dummy variable. This variable remained insignificant suggesting that the applied regression technique sufficiently takes care of the heteroscedasticity problem of the data. For further discussions on the heteroscedasticity problem caused by the „Budapest effect” and its treatment in knowledge production function-type regression analyses see Varga (2007). Note that according to the Hungarian National Development Plan (2007-2013) the main focus of government support will not be Budapest. As such the funds targeting the capital are relatively small in size and their effects are also not expected to be decisive.

⁵ Model 6 exhibits spatial lag dependence at the 5 percent level of significance. To obtain the final model both the spatial lag and the time lag models were run. Given, that first in the spatial lag model the problem of heteroscedasticity remains present (the Spatial B-P test is significant at the 5 percent level) and second regression fit of the unweighted time lag model exceeds that of the unweighted spatial lag model (with R^2 values of 0.42 and 0.39, respectively) the final model includes the time lag. As seen from the Table spatial dependence disappears in the final model. Since the data have both space and time dimensions we also tested for cointegration. The D-W test refused non-cointegration of the data at the 1% significance. The short length of the time series does not allow us to run the Dickey-Fuller test.

calculate unrealistic policy effects. Since no similar geographical knowledge production function study has been carried out to the best of my knowledge it is not possible to relate the estimated parameters directly to other estimations. However, it is possible to calculate infrastructure and human capital investment elasticities in GMR. We compare those values to findings in the literature. In the followings we rely on the survey made by Bradley Morgenroth and Untiedt (2000). Our calculated elasticity values are situated well in the range of the surveyed studies⁶. For infrastructure the estimated elasticities in the literature range between 0.1 and 0.8 whereas our calculated elasticity is 0.40. With respect to human capital the range in other studies is 0.15-0.40 and the GMR elasticity is 0.30.

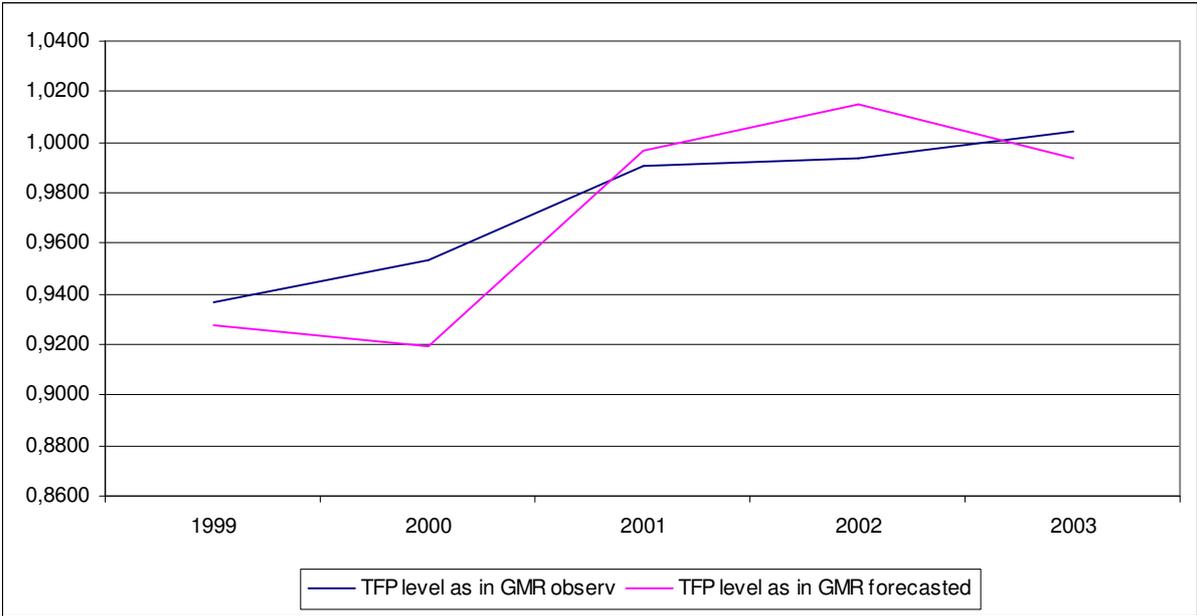


Figure 1: Observed and predicted levels of national TFP

The historical forecasting power of the estimated final equation in Table 1 is also appropriate considering the aim it serves in the complex model: MAPE (mean absolute percentage error) of forecasting TFP at the national level is 1,87 and the correlation between observed and predicted TFP values is 92 percent. Fig. 1 depicts observed and predicted TFP values at the national level.

⁶ For the calculations we used the scenario data provided by the National Development Agency and presented in details in Chapter 7. Elasticities were calculated for each year and then averaged over the planning period.

3. Regional, inter-regional and macro effects: the GMR modeling approach

The focus of this paper is on the way lessons from the geography of innovation literature have been implemented in a complex macro-regional development policy impact model. There is no space here to explain the rest of the model parts in details⁷. However, to understand how the simulated values for each of the scenarios have been calculated it is important to provide a short outline of the model system and how the parts are connected together. The model has three sub-models: the TFP sub-model, the SCGE sub-model and the MACRO sub-model.

A. The TFP sub-model

The TFP equation (equation 1) is placed to the center of this sub-model. This equation estimates the effects of geographically differently located knowledge sources (local, national, international) as well as the impact of specific CSF instruments (human capital, infrastructure) on TFP growth rate. The equation is estimated on a space-time data set. It is used to generate static effects (direct short-run effects on TFP levels in each region) as a result of CSF interventions. Macro level static and dynamic TFP changes are also calculated in the TFP sub-model.

B. The SCGE⁸ sub-model

The reason this sub-model is integrated into the framework of GMR is to make it suitable for studying the longer run spatial effects of the shocks CSF interventions exert on the economy. This model is calibrated in a way that without interventions it represents a full spatial equilibrium of the economy (both regionally and interregionally). This basically means that no migration of labor and capital is assumed as there are no differences across regions in utility levels. CSF-related shocks interrupt this state of equilibrium and the model describes the gradual process towards a new full spatial equilibrium. As such this model predicts the likely dynamic effects. Compared to static effects (estimated by way of the TFP equation) dynamic spatial effects incorporate changes in the spatial structure of the economy resulting from CSF-interventions followed by labor and capital migration.

Changes in the geographic structure are determined by the relative weights of centrifugal (changes in local knowledge measured by TFP) and centripetal (transport cost, congestion) forces. Agglomeration plays its role right in the

⁷ A detailed description of the complex model is given in Varga (2007b).

⁸ SCGE (spatial computable general equilibrium models) are empirical counterparts of the new economic geography. These models are used for impact analysis. For any of the shock the model calculates the equilibrium values of prices and quantities following an iteration process.

beginning of the process as the change in TFP in any region depends both on the size of support and on employment (which is a crude measure of agglomeration externalities in technological change) already in the region (this is what was referred to in the Introduction as static agglomeration effects). Agglomeration forces are also present in later stages of the dynamic process. This happens not only because of the fact that interregional differences in TFP determine the intensity of migration but also because the intensity of migration further reinforces these differences. The strength of this cumulative process depends first on the propensity of labor to migrate and second on the importance of negative agglomeration externalities.

As a result the SCGE sub-model calculates dynamic regional TFP changes and values of output, employment, investment and wages at the level of counties. It might seem paradoxical but despite it describes the dynamism of the spatial structure this sub-model does not incorporate all the forces necessary to build a full spatio-temporal system. Crucial elements of this dynamism such as changes in technology, employment and capital are exogenous in the system. These effects are formulated in the MACRO sub-model.

C. The MACRO sub-model

Based on dynamic TFP effects (calculated by the TFP and the SCGE sub-models) the MACRO sub-model estimates the likely macroeconomic effects on several variables such as the level and growth of output, investment, employment, wages, unemployment, inflation and so on. The MACRO sub-model provides a complete picture of the macro economy with supply, demand and income distribution blocks included. This model is estimated as an a-spatial system. As such it incorporates agglomeration forces in estimation as they are present in macro data but studying the effects of their changes is out of its possibilities. The results bear spatial features only because of its extension with the TFP and SCGE sub-models. The MACRO baseline describes the economy assuming no CSF-interventions occur. As such it is built on the proposition that the spatial structure of the economy does not change compared to the period of estimation. With policy simulations the effects of TFP-related (infrastructure and human capital) and not directly TFP-related (investment support) instruments are estimated.

Figure 2 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.

Step 1: the monetary value of TFP-related CSF instruments (human capital support, infrastructure investments) enter the TFP equation (equation 1) to calculate static changes in TFP growth rates for each county and for each year.

Step 2: Static changes in TFP growth rate enter into the SCGE model to estimate medium run dynamic spatial effects. Determined by positive agglomeration effects (regional changes in TFP) and negative agglomeration forces (transport costs, congestion in the housing market) the SCGE sub-model calculates the values of TFP, output, investment, employment and wages for each county for the whole period of intervention.

Step 3: Dynamic TFP values for each year enter the TFP sub-model to calculate national TFP growth rate changes. The way to calculate these first include calculation of national TFP levels as weighted averages of regional TFP values (where county employment is used for weighting to incorporate agglomeration effects). As referred to earlier this procedure ends up with a precise estimate of national TFP. Then national TFP growth changes are calculated from TFP levels and these values channel into the macro model with the help of the following equation:

$$(2) \quad CSFTFP = ELEFFU^\alpha e^{DNTFPGR} = e^{\alpha \cdot \lambda \cdot TIME} e^{DNTFPGR}$$

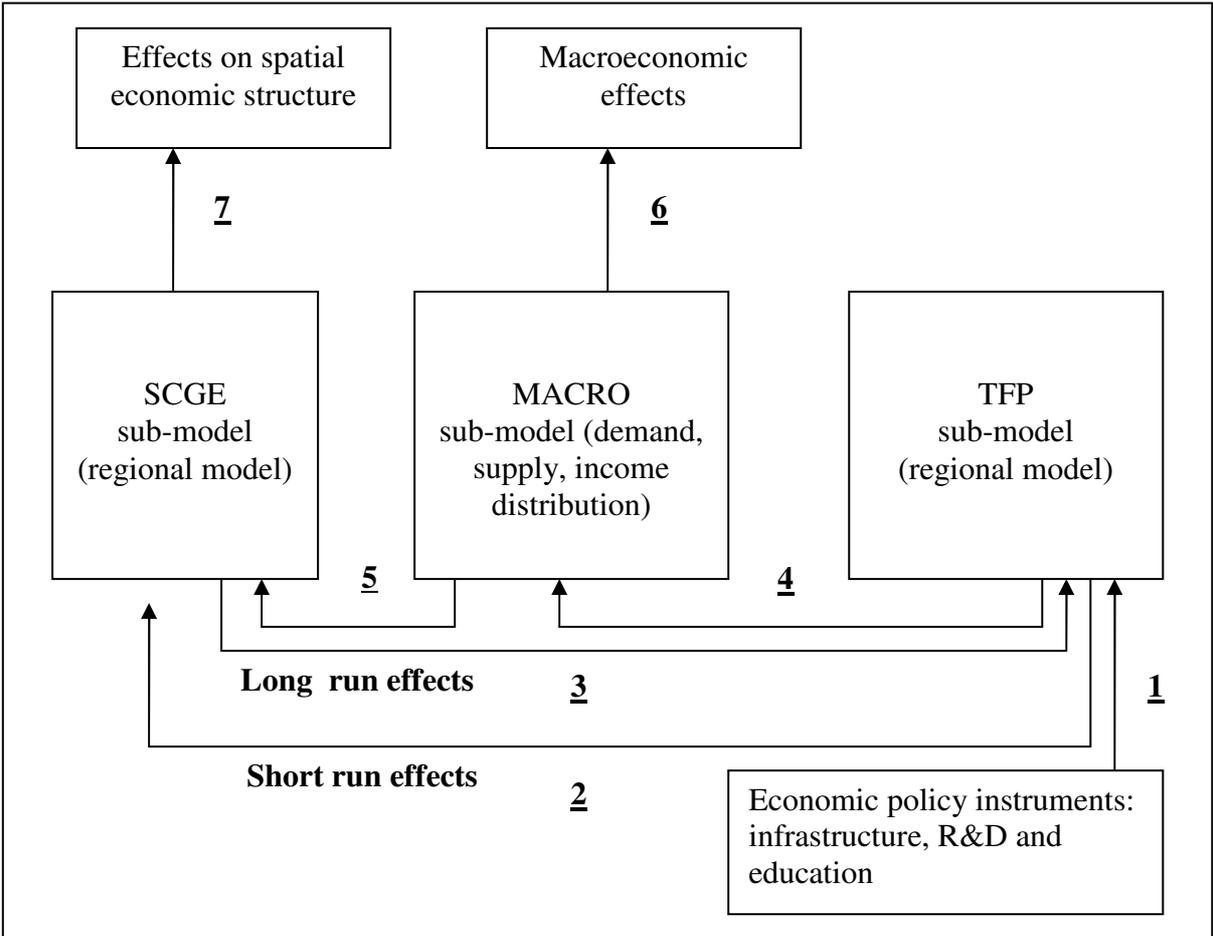


Figure 2: Regional and national level short run and long run effects of TFP changes induced by development policy scenarios

where $\alpha \cdot \lambda$ is the national growth rate of TFP as estimated by the macro-model and DNTFPGR is its *change* resulting from CSF interventions. Thus, CSFTFP is the *level* of Total Factor Productivity at each point in time due to CSF policies and other factors. (2) is the key equation in linking the dynamic regional models (TFP and SCGE sub-models) of technological change to the macroeconomic sub-model.

Step 4: The simulated new national TFP value in equation 6.1 channels productivity change induced by CSF interventions into the macroeconometric sub-model as the variable TFP feeds directly or indirectly into several equations of the system, as depicted in the Appendix.

Step 5: As a result of CSF interventions channeled by dynamic TFP changes, demand side effects and investment support (the latter are not detailed here) employment and investment changes are estimated in the macro model. As underlined earlier the SCGE model takes changes in technology, labor and capital exogenous. For consistency of the system changes in employment and investment generated in the MACRO sub-model enter the SCGE sub-model to calculate the final spatial distribution of labor, investment, wages and output. This was necessary as the SCGE model part does not provide an endogenous approach for employment and investment growth.

Steps 6 and 7: The complex model system provides the effects of CSF interventions in the form of percentage differences to the baseline (i.e., the state of affairs without policy impacts) both at the regional level (output, investment, employment, wages) and at the macro level (output, employment, investment, wages, unemployment, inflation rate, productivity etc.).

4. Convergence and growth: Policy impact simulations

In this section a policy simulation exercise is presented to demonstrate the power of models that incorporate both static and dynamic geographic effects into a macro-regional modeling framework. Figure 3 exhibits the allocation of CSF support between 2007 and 2015 according to the scenario provided by the National Development Office of the Hungarian government. Values are in 1995 Hungarian Forints. All the five possible categories are shown in the Figure. Since our main interest is in how the geography of innovation literature can help construct better models for policy impact analysis we focused on the three TFP-related instruments: infrastructure investment, R&D expenditures and human capital support. The model also includes private investment support while some of the CSF investments are considered to have demand side effects only. In the

simulations the effects of spatially differently distributed TFP-related instruments are presented. In the hypothetical scenarios

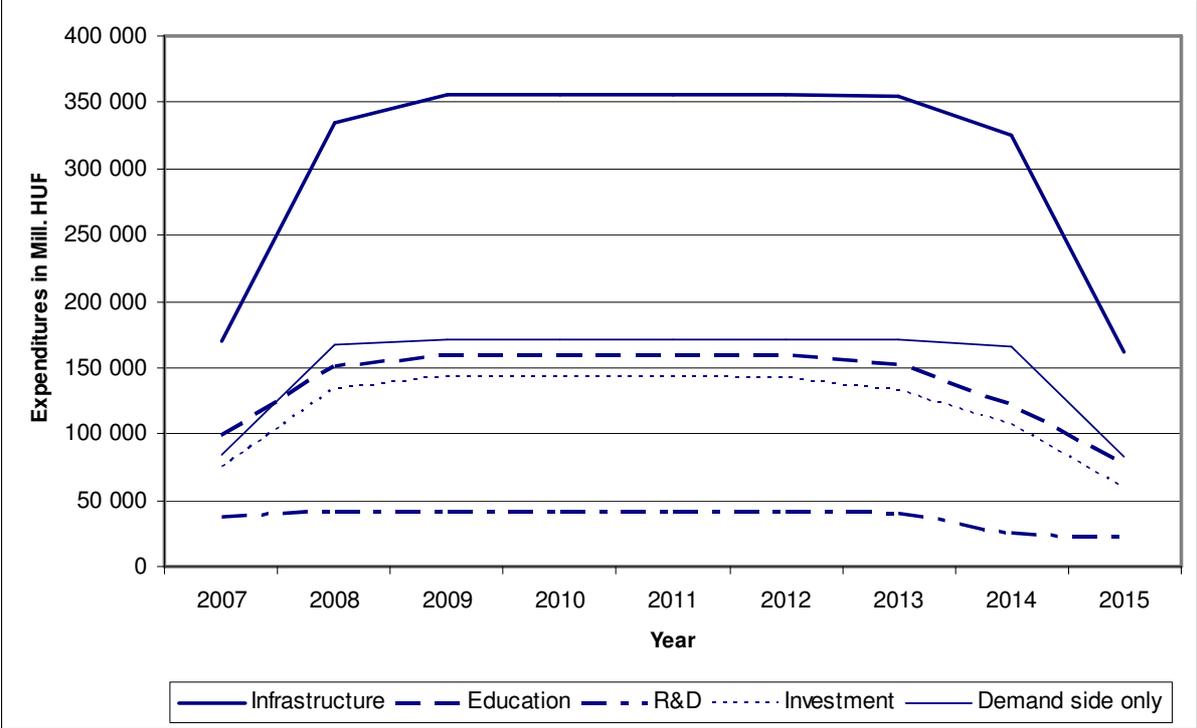


Figure 3: CSF expenditures spent over the period of 2007 and 2015 in Mill. 1995 HUF

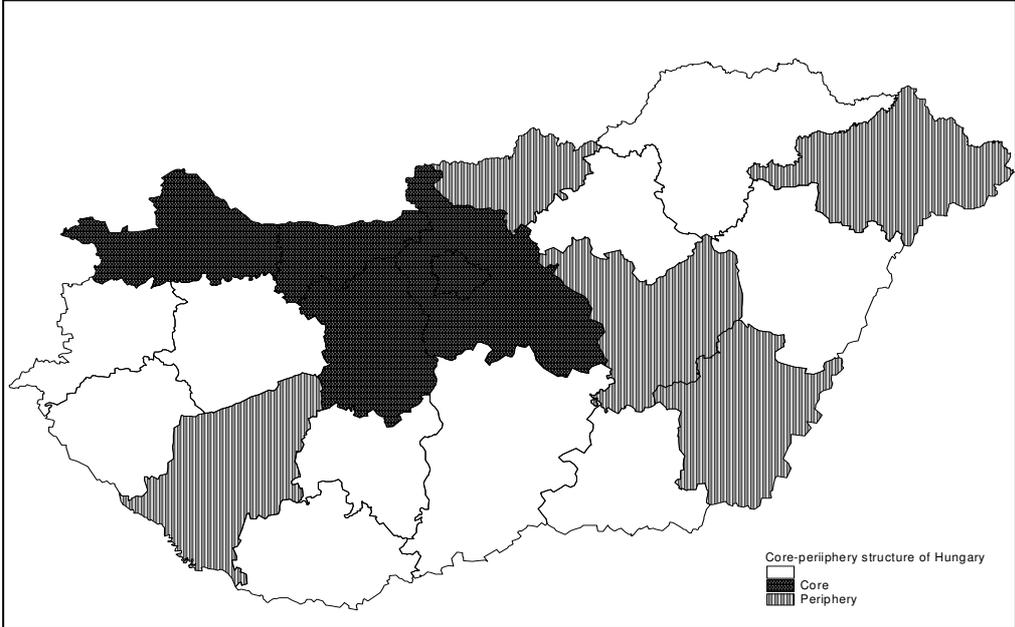


Figure 4: Core-periphery structure of Hungarian counties with respect to Gross Value Added per employee

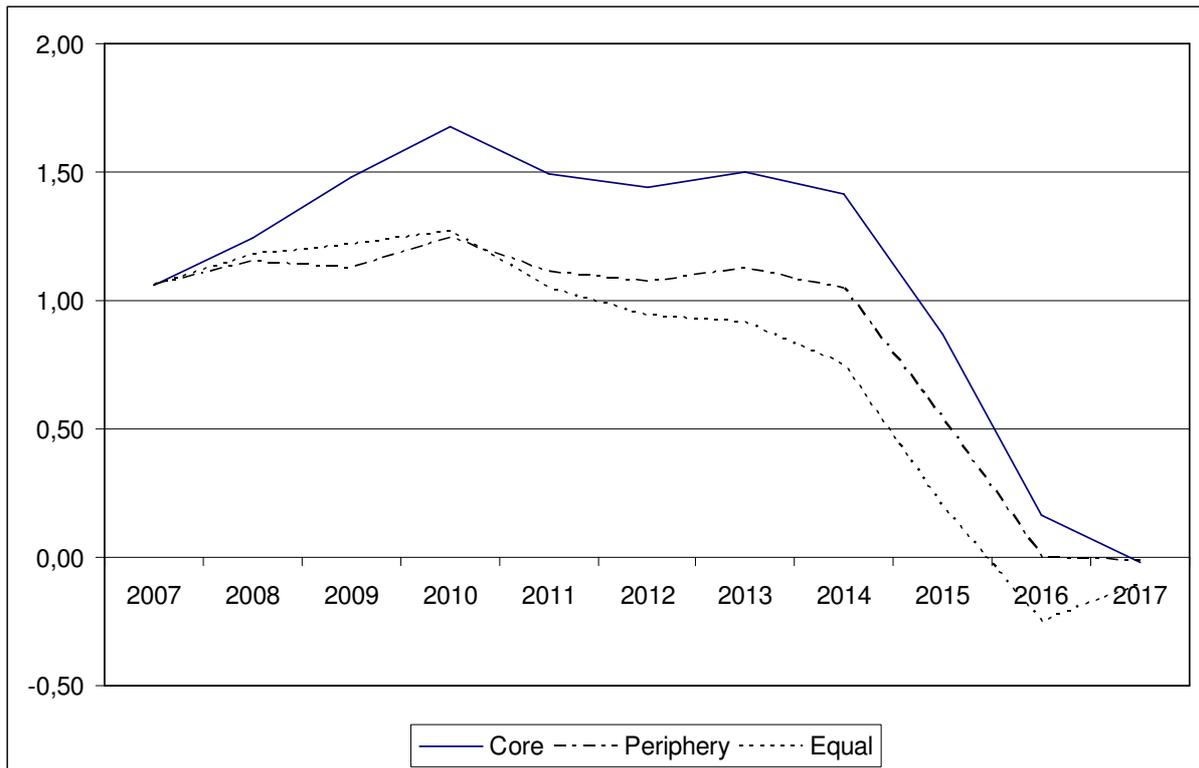


Figure 5: The effects of policy scenarios on the GDP growth rate

three possibilities for distributing CSF expenditures are considered: concentration resources in the core regions, distributing the expenditures equally over the country and supporting the periphery. Figure 4 classifies Hungarian counties according to GVA per employee into the core and the periphery⁹.

The aim of the simulations is to evaluate the three scenarios with respect to their effects on national growth and convergence. Figure 5 presents the growth effects of the three scenarios. It is clear that concentrating resources is the most efficient choice to promote the growth target: the percentage point difference to the baseline (i.e., the case when no policy intervention occurs) reaches the highest values during the whole simulation period. However, the relative differences with respect to the other two scenarios are an empirical manner and cannot be determined without concrete simulations. What is interesting from the figure and not evident without running GMR-Hungary is that after three years supporting the periphery serves the growth target better than the scenario of equal spatial distribution of resources.

How the three policy choices would affect regional convergence? The size of regional inequalities is measured by the standard deviation of regional value

⁹ First, counties were ordered according to their average GVA per employee in 2000-2003. Then the upper 5 regions (where GVA per employee equals to or exceeds the national average) are considered the core and the lower 5 regions (of which GVA per employee is less than the 80 percent of the national average) are classified into the periphery.

added. Figure 6 presents the simulation results. Concentration of resources into the core widens regional inequalities to the largest extent, however, the relative differences with respect to the other two scenarios for each year are not known without the simulations. Even equal spatial distribution of resources results in slightly increasing divergence and only the policy supporting the periphery leaves relative regional positions unaffected.

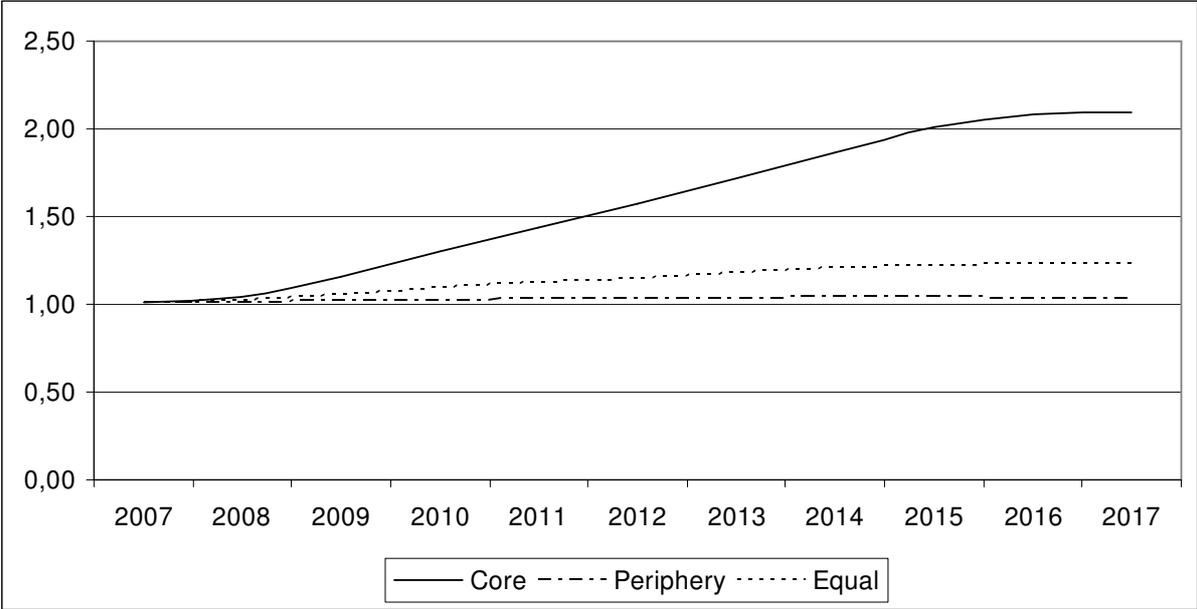


Figure 6: The policy effects on convergence measured by standard deviation of regional value added

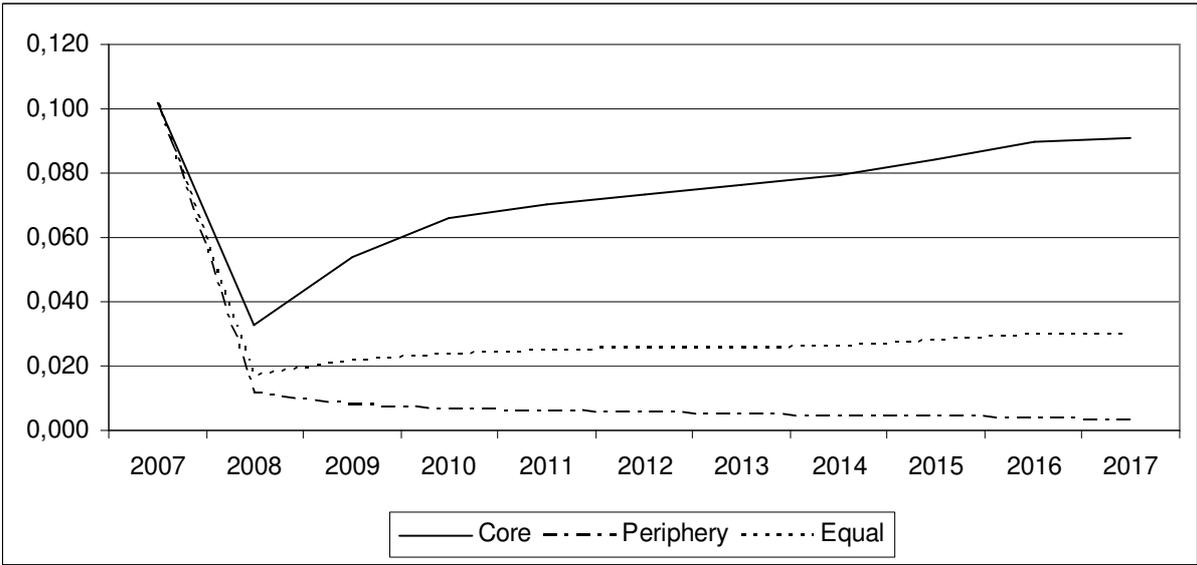


Figure 7: Elasticity of the standard deviation of regional GVA with respect to GDP

Note: changes are calculated relative to the respective baseline values

From figures 5 and 6 it seems clear that the cost of growth promotion measured by regional inequalities is the highest while the core is targeted. However, the surprising result is that the policy promoting convergence (i.e., focusing resources in the periphery) results in a higher growth effect than equal distribution of resources. This is again a result which comes from concrete simulations and not from ex-ante theoretical derivations. Figure 7 depicts this clearly. Divergence cost of growth promotion is measured by the elasticity of the standard deviation of regional GVA (relative to the baseline) with respect to GDP (relative to the baseline)¹⁰. The figure suggests that considering both policy targets simultaneously promoting the periphery is the less costly alternative. Table 2 summarizes the results of the three simulations.

Table 2: The effect of regional policies on growth and divergence and the costs of growth promotion

	Growth effect			Divergence effect			The cost of growth promotion		
	Core	Periphery	Equal	Core	Periphery	Equal	Core	Periphery	Equal
2007	1,06	1,06	1,06	1,01	1,01	1,01	0,10	0,10	0,10
2008	1,24	1,15	1,18	1,04	1,01	1,02	0,03	0,01	0,02
2009	1,48	1,13	1,22	1,16	1,02	1,05	0,05	0,01	0,02
2010	1,68	1,25	1,27	1,30	1,02	1,09	0,07	0,01	0,02
2011	1,50	1,11	1,05	1,44	1,03	1,12	0,07	0,01	0,02
2012	1,44	1,07	0,94	1,57	1,03	1,15	0,07	0,01	0,03
2013	1,50	1,13	0,91	1,72	1,04	1,18	0,08	0,00	0,03
2014	1,41	1,04	0,75	1,87	1,04	1,20	0,08	0,00	0,03
2015	0,87	0,54	0,20	2,01	1,04	1,22	0,08	0,00	0,03
2016	0,17	0,00	-0,25	2,09	1,03	1,23	0,09	0,00	0,03
2017	-0,02	-0,01	-0,11	2,10	1,03	1,23	0,09	0,00	0,03

5. Summary

The focus of this paper is to demonstrate that incorporating the lessons from the geography of innovation literature into development policy analysis opens up the possibility of new generation models with such simulations where both regional, inter-regional and macro effects of different scenarios can be studied and compared to each other. Both in presenting the modeling solution and hypothetical scenarios the paper follow the GMR approach.

¹⁰ Formally: $\varepsilon_{c,g} = [(\sigma_{RGVA, scen} - \sigma_{RGVA, bline}) / \sigma_{RGVA, bline}] / [(GDP_{scen} - GDP_{bline}) / GDP_{bline}]$; where $\varepsilon_{c,g}$ is the elasticity of the change in the standard deviation of regional GVA relative to the baseline with respect to the change in GDP relative to the baseline, $\sigma_{RGVA, scen}$ and $\sigma_{RGVA, bline}$ are standard deviations of regional GVA in the scenario and the baseline, whereas GDP_{scen} and GDP_{bline} are GDP at the national level in the scenario and the baseline.

Besides emphasizing the positive features of such an approach the current limitations of the GMR approach should be disclosed as well. These include the crude account for agglomeration with a simple employment size measure the limitations of TFP as the index of technology development (Hulten 2000) or the limits of the knowledge production function approach in capturing knowledge spillover effects (Feldman 2000). In future research to overcome these limitations incorporation of alternative empirical methods into the model system will be considered.

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