Predicting long-term regional growth for European NUTS2 regions using the global structural change spatial CGE model[1]

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Abstract: Current paper develops innovative modelling approach to predicting long-term patterns of regional economic growth by combining econometric estimations with Spatial CGE model. We predict the development of GDP at NUTS2 regional level of EU28 for the period 2015-2050 in five year steps and calculate a number of important indicators of spatial concentration, specialization and inequality.

1. Introduction

Economies undergo large scale sectoral reallocations of employment and capital as they develop, in a process commonly known as structural change (Kuznets, 1973; Maddison, 1980; Herrendorf et al., 2014; Vries et al., 2014). These reallocations lead to a gradual fall in the relative size of the agricultural sector and a corresponding rise in manufacturing. As income continues to grow, services eventually emerge as the largest sector in the economy. Leading theories of structural change attempt to understand these sweeping transformations through mechanisms involving either supply or demand. Supply-side theories focus on differences across sectors in the rates of technological growth and capital intensities, which create trends in the composition of consumption through price (substitution) effects (Baumol, 1967; Ngai and Pissarides, 2007; Acemoglu and Guerrieri, 2008). Demand-side theories, in contrast, emphasize the role of heterogeneity in income elasticities of demand across sectors (non-homotheticity in preferences) in driving the observed reallocations accompanying income growth (Kongsamut et al., 2001).

The leading theories of structural change have been mostly applied to study long-term changes in country-level GDP, country level changes in sectoral structure and the development of international trade flows. Current paper presents the first application of structural economic change theories to the prediction of economic growth and sectoral structure at sub-national level of European NUTS2 regions. For the purpose of predicting regional economic growth in the period 2015-2050 we combine econometrically estimated multi-factors productivity projections for six aggregate economic sectors with th regional projections of active labour force by education level. These data is used as main input into spatial computable general equilibrium (SCGE) EU-EMS model for the world that includes detailed sub-national NUTS2 representation of EU28 countries. EU-EMS model has been developed by PBL Netherlands Environmental Assessment Agency as a part of EU-financed Horizon2020 MONROE project[3].

Studies that investigate the long-term regional economic growth at the level of EU28 NUTS2 or NUTS3 regions are quite rare and are usually based on the top-down approach (for example JRC(2016)) that is they disaggregate the national-level projections to the sub-national level using some indicators. One of the few existing econometrically estimated models of regional economic growth is the MASST model (Capello, 2007) that has been used in a number of ESPON projects to create scenarios of future regional economic growth. MASST model has as its basis regional

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[2] PBL Netherlands Envionmental Assesssment Agency

[3] https://www.monroeproject.eu/

econometrically estimated production function and links regional development to national-level factors via the inclusion of national growth component into the equation for regional GDP. The model does not differentiate between various sectors of production and belongs to the class of econometric VAR models.

In the current paper we do not only develop the methodology for predicting sectoral and regional economic development using the framework of structural economic change but also investigate the development of regional specialization, regional growth and regional income inequality in the period of 2015-2050 using Krugman specialization index, Theil-T inequality index, regional GDP and population growth. The main outcomes of our analysis are …..

The rest of the paper is structured as follows. Section 2 presents the empirical underpinning for main drivers of regional structural economic change including labour supply by education type, development of sector-specific multi-factor productivity and changes in demand for goods and services as a function of income per capita developments. Section 3 presents the description of SCGE model EU-EMS that has been used for the analysis in the paper. Section 4 illustrates our findings about the development of European NUTS2 regions in the period 2015-2040. Section 5 concludes the paper and provides some relevant policy insights.

2. Main drivers of long-term structural change

2.1 Demographic changes and labor participation rates

For the purpose of the forecasting we would like to have the projections of the active labor force by level of education attainment or socio-economic group for the period until 2050. The majority of the labor force projections are done by age and sex and do not consider education level as an additional attribute. For the projections of the labor force we make use of the methodology proposed by Loichinger (2015) (and being adopted by Eurostat). This methodology is based on a shift-share approach and has been sued to forecast force by two levels of education (tertiary education or not) in EU26 countries for the period until 2053. The proposed approach has a lot of sense since the level of education is strongly positively correlated with the labor participation rates for both males and females.

We rely on Eurostat projections of annual EUROPOP2008 population projections at the level of NUTS2 regions by age cohort and gender for the period until 2050 and combine them with our our projections of labor participation rate by gender and education level.

We make use for our model of the "Benchmark scenario approach" proposed by Loichinger (2015) which means that the labor participation rates are modelled towards a given benchmark distribution, This distribution is often based upon the participation rates that have been observed in another country or another population group. The benchmark distribution is seen a desired outcome that can be achieved given the right governmental policies. We use the target distribution of labor participation rates observed on Sweden in 2008 (Labour Force Survey of Eurostat) as the benchmark for other European countries and regions in 2050. Since the difference between males and females in Sweden is very low this approach leads to reduction in the gender gap over time.

The following formula has been used for the projection of the participation rates by age, sex and education level:

$$l_{a,s,e,t} = l_{a,s,e}^{\min} + \frac{l_{a,s,e}^{\max} - l_{a,s,e}^{\min}}{1 + e^{a_{a,s,e} + b_{a,s,e} t}} \qquad (1)$$

Where a refers to age, s refers to sex and e refers to education level. $l^{\max}$ is the maximum level of participation rates observed in Sweden and $l^{\min}$ is the minimum level across EU. Parameters of the function a and b can be fitted on the existing data from Labor Force Surveys of Eurostat.

In order to make projections of the population at NUTS2 level by age, sex and education level we combine the Eurostat projections with the data from the IIASA GET (Global Education Trend) scenario[4] that has been developed for 120 countries of the world for the period until 2050. Predictions of population by education level have been done for the following ILO education groups: (1)ISCED0_1 Low level of education, (2) ISCED2_4 Medium level of education, (3) ISCED5_6 High level of education.

The population projections of Eurostat by sex and age have been further disaggregated to the three education types using the population shares from IIASA GET database. The population projections described above have been combined (multiplied) with the projected participation rates by sub-group of the population in order to calculate the labor supply to education level for all NUTS2 regions of EU28.

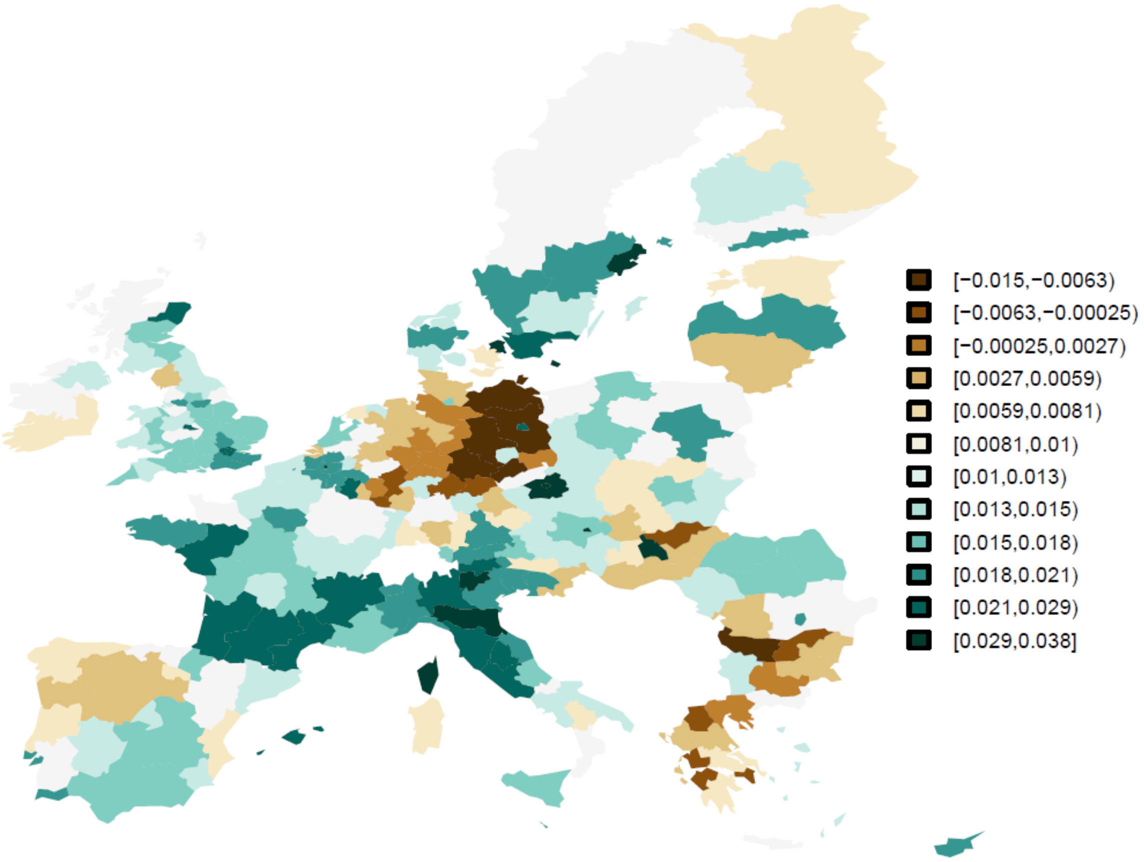

Figure 1: Average annual growth of high-skilled labour supply in the period 2015 - 2050

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[4] https://www.demographic-research.org/volumes/vol22/15/22-15.pdf

2.2 Development of sector-specific total factor productivity

Theoretical underpinnings

The theoretical underpinnings of our approach follow Acemoglu et al, (2006) who analyze an economy where firms undertake both innovation and adoption of technologies from the world technology frontier. In this context, the selection of high-skill managers and firms is more important for innovation than for adoption. As the economy approaches the frontier, selection becomes more important. Countries at early stages of development pursue an investment-based strategy, which relies on existing firms and managers to maximize investment but sacrifices selection. Closer to the world technology frontier, economies switch to an innovation-based strategy with short-term relationships, younger firms, less investment, and better selection of firms and managers. They show that relatively backward economies may switch out of the investment-based strategy too soon, so certain policies such as limits on product market competition or investment subsidies, which encourage the investment-based strategy, may be beneficial. However, these policies may have significant long-run costs because they make it more likely that a society will be trapped in the investment-based strategy and fail to converge to the world technology frontier.

Let us denote the growth of the world technology frontier, $\bar{A}_t$ by g so that

$$\bar{A}_t = \bar{A}_0 (1+g) \tag{2}$$

For each representative country its state of technology is less than the frontier technology $A_t \leq \bar{A}_t$. The productivity of sector that produces intermediate good v at time t is expressed as

$$A_t(v) = s_t(v)\left[\eta \bar{A}_{t-1} + \gamma_t(v) A_{t-1}\right] \tag{3}$$

Where $s_t(v) \in \{1, \sigma\}$ denotes the size of the investment with $s_t(v)=1$ for large sectors, $\gamma_t(v)$ denotes the probability of new innovation. Equation above captures the two dimensions of productivity growth: adoption and innovation. By adopting existing technologies firms benefit from the world state of technological knowledge. In addition to it there is a productivity growth due to innovation building on the local sector-specific knowledge A_{t-1} and success of innovation depends on the probability of new innovation. The larger is investment the higher is the productivity growth.

If we rearrange the terms we get the following equation that includes the distance to the technological frontier $\bar{A}_{t-1} / A_{t-1}$

$$A_t(v) / A_{t-1} = s_t(v)\left[\eta \bar{A}_{t-1} / A_{t-1} + \gamma_t(v)\right] \tag{4}$$

In case when the country and sector is far from the technological frontier the major source of growth is the technology adoption. In case when the technological gap becomes close to unity that is the country is close to the frontier innovation becomes an important source of productivity growth.

Human capital and technology diffusion

This part of the model is based on the papers by Benhabib and Spiegel (2002) “”Human capital and technology diffusion” and Helson and Phelps (1966) “Investment in human, technological diffusion and economic growth”. Helson and Phelps (1966) assume that there is a difference between actual level of the state-of-the-art technology and the theoretical level of technology that would prevail if technological diffusion was instantaneous. The technology diffusion can be modelled as follows:

$$\frac{\dot{TFP}_{i,t}}{TFP_{i,t}} = g\left(H_{it}\right) + c\left(H_{it}\right)\left(\frac{TFP_{m,t}}{TFP_{i,t}} - 1\right) \tag{5}$$

Where $TFP_{i,t}$ is the TFP of the country and $TFP_{m,t}$ is the TFP of the technological leader (country with the highest TFP) and $H_{i,t}$ is the human capital that is measured as the average number of years of education of the labour force/employed.

Another variation of the technology diffusion and catch-up processes is the logistic technology diffusion model which adds an extra term that captures the difficulty of adopting distant technologies:

$$\frac{\dot{TFP}_{i,t}}{TFP_{i,t}} = g\left(H_{it}\right) + c\left(H_{it}\right)\frac{TFP_{i,t}}{TFP_{m,t}}\left(\frac{TFP_{m,t}}{TFP_{i,t}} - 1\right) \tag{6}$$

TFP in our framework is explained by the combination of technology adoption via the technological diffusion process described above and technological innovation linked to the knowledge created by the industry itself ($I_{i,t}$):

$$\frac{\dot{TFP}_{i,t}}{TFP_{i,t}} = aH_{it} + bH_{it}\left(\frac{TFP_{m,t}}{TFP_{i,t}} - 1\right) + cI_{i,t} \tag{7}$$

The role of R&D in knowledge creation and knowledge adoption

Following the paper of Griffith, Redding and Van Reenen (2001) our model assumes that R&D has two roles in the development of TFP. The first role is in knowledge creation or stimulation of innovation that has received a lot of attention in both theoretical and empirical literature. The second role is in facilitation of adoption or imitation of knowledge that has been created in other countries or sectors. Griffith, Redding and Van Reenen (2001) use a panel of OECD countries and find a strong empirical evidence for the second role of R&D in adoption of knowledge. Griffith, Redding and Van Reenen (200) present a general equilibrium model of endogenous growth through increasing productivity that incorporates both role of R&D investments. They augment the conventional quality ladder model to allows the size of innovations to be a function of the distance behind the technological frontier and an equation for TFP growth of the following form is derived:

$$\Delta \ln A_{ijt} = \beta \Delta \ln A_{Fjt} - \delta_1 \ln\left(\frac{A_i}{A_F}\right)_{jt-1} - \delta_2 \left(\frac{R}{Y}\right)_{ijt-1} \ln\left(\frac{A_i}{A_F}\right)_{jt-1} - \delta_3 H_{ijt-1} \ln\left(\frac{A_i}{A_F}\right)_{jt-1} + \rho_1 \left(\frac{R}{Y}\right)_{ijt-1} + \rho_2 H_{ijt-1} + u_{ijt} \qquad (8)$$

Where the growth is TFP over a certain period of time $\Delta \ln A_{ijt}$ depend of the knowledge adoption that is captured by the growth of the technological frontier $\Delta \ln A_{Fjt}$ and interaction between technological gap $\ln\left(\frac{A_i}{A_F}\right)_{jt-1}$ and R&D per unit of sectoral output $\left(\frac{R}{Y}\right)_{ijt-1}$ as well as the interaction between technological gap $\ln\left(\frac{A_i}{A_F}\right)_{jt-1}$ and human capital H_{ijt-1}. The level of human capital and R&D capture the absorptive capacity of the particular sector. The growth of TFP is also linked to knowledge creation that is explained by R&D $\left(\frac{R}{Y}\right)_{ijt-1}$ and human capital stocks H_{ijt-1}.

Econometric approach and database for panel data analysis

Our econometric framework is targeted to the use in macro-economic multi-sectoral models and hence to represent R&D decisions and productivity developments at the level of each economic sector. The total factor productivity of various economic sectors is determined by both innovation and adoption process that are both captured by the multifactor productivity econometric equation. This equation in turn constitute a reduced form representation of the basic Schumpeterian growth models, where innovation-imitation processes lie at the heart of productivity growth and allow poorer countries to catch-up with the richer ones.

The econometric equation explaining the multi factor productivity development is supplemented by an econometric equation that explains R&D intensity over time. This means that our model consists of two equations: (1) R&D decision and (2) multi-factor productivity growth,.

The econometric specification of Multi-factor productivity

The equation for the multi-factor productivity assumes that the TFP growth takes the following form:

$$\ln\left(\frac{TFP_{cst}}{TFP_{cst-1}}\right) = b_1 \ln\left(\frac{TFP^*_{st}}{TFP^*_{st-1}}\right) + b_2 \ln\left(\frac{TFP_{cst-1}}{TFP^*_{st-1}}\right) + b_3 H_{t-1} + b_4 H_{t-1} \ln\left(\left(\frac{TFP_{cst-1}}{TFP^*_{st-1}}\right) + b_5 RD_{t-1} + b_6 RD_{t-1} \ln\left(\left(\frac{TFP_{cst-1}}{TFP^*_{st-1}}\right) + d_s + d_{sc} + e_{sct} \qquad (9)$$

where the subscripts *c, s* are country and sector indexes respectively, while *t* denotes the time period taken to be 5 years. The level of total factor productivity is given by *TFP*, with *TFP** being leader's total factor productivity. The variable *H* denotes the level of human capital stock as measured by the share of high skilled people to total employment, and *RD* is the level of R&D intensity as measured by the private expenditures per value added (output). We estimate equation (9) using the least square dummy approach (or within group estimator), where we also add three different types of dummy varies that capture industry specific fixed effects (d_s), country-industry specific fixed effects (d_{sc}) and country specific trends (d_{ct}),.

The first two terms in equation (9) are standard in the literature and measure productivity growth at the frontier and the technological gap between the frontier and non-frontier sectors ("catch-up" term) respectively. The productivity growth of the technological leader captures the link between TFP growth for the catching-up sector through the innovation and knowledge spillovers. On the other hand, the catch-up term aims to explain how the adoption of new technologies affect the innovation process of sectors. The idea here is that there are greater potentials in adopting new technologies the higher the technological gap is. In other words, we assume that the adoption of existing technology and knowledge could occur via different channels (machinery and equipment, trade, employment, networks etc.) that show up in the productivity gap between industries.

Since there is no data on the number of patents per economic sector readily available we choose to use the R&D intensity directly in the econometric equation as another potential driver to multi-factor productivity. According to Griffith et al. (2006), R&D usually plays two separate roles in this equation: firstly because higher R&D spending could create new knowledge and secondly because it facilitates the adoption of knowledge or technology created elsewhere. For this reason, we directly include in our regression the interaction of RD and productivity gap. Benhabib and Spiegel (2005) have also proposed a similar idea holds for human capital. On the hand, higher human capital could create more knowledge in the economy, on the other hand, could increase the ability of a firm to adopt new technologies. To check, therefore, the latter effect we decided to include another interacting in our regression term between human capital and productivity gap.

Database for analysis

For our econometric exercise we combine four different databases that provide information about the variables of our model. For sectoral level data, we use the EU-KLEMS database which covers 28 countries of which most of them are OECD countries until the year 2015. Depending on the variable, the data series spans a wide time period from roughly 1970 for mainly Western European countries, Korea and Japan and from the 1990s from non-Western European countries.

In this database information is given for totally 107 categories of industries of which 37 categories form head categories on a 2-digit level of which one is a 1-digit level for total industries. The coverage for services counts 45 sectors in which both 3-and 2-digit category levels are included. Within the business services category 12 out of totally 32 represent head categories on a 2-digit level. The personal services category have in total 7 head categories on 2- digit level of which two services sector no data is given. We use the latest release of the database from end 2017 that uses NACE Rev2 sectoral classification that is presented in the table below.

For the sectoral analysis we grouped our industrial data into six different sectors and run different regression based on the sector specific sample. The sectors we decided to create are a) Traditional b) the high-, c) medium- and d) low-technology sectors, e) high knowledge intensity service sector and f) other services. The classification we used are presented in Table 1 and follow Eurostat's definitions where for the purpose of our analysis we put together the groups "High-technology" and "medium-high technology" together and call them "High-technology".

For measuring Human capital stock we used OECD country level data on the share of high skilled people to total employment. Finally, we supplement our dataset with OECD's main science and innovation indicators (MSTI). From this database we use series on government-financed expenditures on R&D, on education and social programs as percentage of government budget allocations for R&D, and on government expenditures on R&D policies. For the regressions we dropped countries with few or no observations and created a database of an unbalanced panel of thirteen OECD countries between 1995-2015 period.

Table 1 Sectoral classification used for econometric analysis

Sectoral classification	*NACE Rev2 codes*	*Names of the sectors*
Traditional	A01 A02 A03 B	Products of agriculture, hunting and related services; Products of forestry, logging and related services; Fish and other fishing products; aquaculture products; support services to fishing; Mining and quarrying
Low-technology manufacturing	C10-C12 C13-C15 C16 C17 C18 C31_C32	Food products, beverages and tobacco products; Textiles, wearing apparel and leather products; Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials; Paper and paper products; Printing and recording services; Furniture; other manufactured goods
Medium-technology manufacturing	C19 C22 C23 C24 C25 C33	Coke and refined petroleum products; Rubber and plastics products; Other non-metallic mineral products; Basic metals; Fabricated metal products, except machinery and equipment; Repair and installation services of machinery and equipment
High-technology manufacturing	C21 C26 C20 C27 C28 C29 C30	Basic pharmaceutical products and pharmaceutical preparations; Computer, electronic and optical products; Chemicals and chemical products; Electrical equipment; Machinery and equipment n.e.c.; Motor vehicles, trailers and semi-trailers; Other transport equipment
Knowledge intensive service sectors	H50 H51 J58 J59_J60 J61 J62_J63 K64 K65 K66 M69_M70 M71 M72 M73 M74_M75 N78 N80-N82 O84 P85 Q86 Q87_Q88 R90-R92 R93	Water transport services; Air transport services; Publishing services; Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services; Telecommunications services; Computer programming, consultancy and related services; information services; Financial services, except insurance and pension funding; Insurance, reinsurance and pension funding services, except compulsory social security; Services auxiliary to financial services and insurance services; Legal and accounting services; services of head offices; management consulting services; Architectural and engineering services; technical testing and analysis services; Scientific research and development services; Advertising and market research services; Other professional, scientific and technical services; veterinary services; Employment services; Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services; Public administration and defense services; compulsory social security services; Education services; Human health services; Social work services; Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services; Sporting services and amusement and recreation services
Other service sectors	C33 D35 E36 E37-E39 F G45 G46 G47 H49 H52 H53 I L68B L68A N77 N79 S94 S95 S96 T U	Repair and installation services of machinery and equipment; Electricity, gas, steam and air-conditioning; Natural water; water treatment and supply services Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services; Constructions and construction works; Wholesale and retail trade and repair services of motor vehicles and motorcycles; Wholesale trade services, except of motor vehicles and motorcycles; Retail trade services, except of motor vehicles and motorcycles; Land transport services and transport services via pipelines; Warehousing and support services for transportation; Postal and courier services; Accommodation and food services; Real estate services (excluding imputed rent); Imputed rents of owner-occupied dwellings; Rental and leasing services; Travel agency, tour operator and other reservation services and related services; Services furnished by membership organizations; Repair services of computers and personal and household goods; Other personal services; Services of households as employers; undifferentiated goods and services produced by households for own use; Services provided by extraterritorial organizations and bodies

Sector-specific multi-factor productivity regressions

Table 2 reports the main results of our analysis for the econometric regression used in our SCGE model. According to these results, there is a fairly consistent pattern across most sectoral regressions about the two main determinants of productivity growth. In line with the predictions of basic innovation-imitation Schumpeterian growth theories outlined before, our results show that both innovations taken at the technological frontier (first term) and the absorptive capacity of sectors to use new technologies ("catch-up" term) are essential drivers to productivity growth for the great majority of sectors.

	Pooled	Traditional	High-tech manufacturing	Medium-tech manufacturing	Low-tech manufacturing	Knowledge intensive services	Other services
D.TFP*	0.100**	0.24***	0.20***	0.036	0.041	0.049**	0.034
Gap	-0.47***	-0.21***	-0.22***	-0.51***	-0.13***	-0.077***	-0.14***
HC	0.027	-1.23***	0.26	0.68	0.51*	-0.099*	0.29***
HC # Gap	0.29**	-0.029	0.57**	-0.26	0.18	-0.028	0.17*
RD	0.26	0.60	0.11	2.38	4.05***	0.20**	1.63**
RD # Gap	0.47*	1.69	-0.43	4.94*	3.51***	0.17***	2.36**
Time Dummy	No	No	No	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector FE	Yes	Yes	No	No	No	No	No
Country FE	No	No	Yes	Yes	No	No	No
Observations	5750	372	744	572	788	1863	1411
Adjusted R^2	0.354	0.389	0.345	0.324	0.203	0.328	0.277

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2 Estimation of multi-factor productivity growth

On average, leader's productivity growth is positive and statistically significant, suggesting that there are particularly important positive spill-overs from technological innovations occurring at the frontier that help increase the pace of innovations elsewhere. The strength of such spillovers appears to vary across industries with the strongest among them found in industries comprising the traditional sector. Neverthless, spill-over are statisticaly insignificant for the medium and low-tech manufacturing sector, as well as for the service industry which are not knowledge intensive. In this sense, when assessing the role of the spill-overs effects from frontier growth it appears to matter the distinction between the technology needed or used within the manufacturing sector.

A similar, yet more robust across different industries, picture emerges when looking at the catch-up term. On the aggregate, According to our findings, there are significant potentials for closing the productivity gap within industries by either adopting or investing in new technologies. Such ascertainment, , holds true for all sectors. from the quantitative point of view, however, the gains are weak for the knowledge intensive service industries.

With regards to the other determinants of TFP growth considered important in the literature results are rather mixed. Starting with human capital, our results show that its importance to TFP growth is rather insignificant and in some cases may even contribute negatively to technological progress. Such negative effects, for example, found to operate into the traditional and, perhaps surprisingly, the knowledge-intensive service sector,. We also find no particular evidence about human capital's role in absorbing new technologies.

With regards to the RD intensity, while our evidence suggests that indeed there is a positive on average effect on TFP growth, our results indicate that such an effect cannot be generalized across sectors.,. . , our results, therefore, seem to reject the hypothesis for the "dual" face of RD expenditures. Looking, for example, at the interaction term between RD intensity and the catch-up term, the estimated coefficient found to be statistically insignificant in most cases. Such findings, therefore, compare against the study of Griffith et al, (2004), who were the first to show the dual face of RD

Development of R&D intensity

To model R&D intensity we simply assume that RD decision follow an AR(1) process with a constant term as follows:

$$RD_{cst} = a * RD_{cst-1} + c + e_{cst} \qquad (10)$$

where a and c are the parameters to be estimated and e_{cst} is the error term. This specification assumes that current RD decision are affected by past RD decision with the parameter a to determine their persistence over time. The inclusion of the constant term c determines the average RD expenditures around which all RD decisions deviate in each period. Based on this equation we make projection for the development of the RD intensity across sectors in the future, and therefore are able to calculate the expected long-run values for research intensity. For example, under standard stationarity assumptions, calculating the long-run first moment of the variable RD in equation (10), we are able to uncover the expected value to which RD investment decision are expected to evolve in the long-run.

The estimation methodology uses standard dynamic panel procedures relying principally on the work of Arellano and Bond. The data used to estimate equation (10) is based on the EU-KLEMS dataset as described before. Following standard practices, our measure for the RD intensity is based on private R&D expenditures as a share of value added - defined as the output of each industry excluding intermediate goods - in constant prices.

On average, R&D expenditures are equal to roughly 3 per cent of total value added, with the highest shares being observed in industries comprising the high-tech manufacturing sector equal to roughly 10 per cent of total value added while the lowest R&D investments as a fraction of value added is found within the traditional sector and equal about 0,9 per cent. The results in Table (6) show that in all but the medium-tech manufacturing equation (10) fits the data quite well with RD intensity exhibiting a significant degree of persistent. This means that the levels of R&D investment do not significantly change from one period to another and likely to remain roughly the same in future periods. Exception to this finding is the medium-tech sector, where the estimated coefficients fund to be low in absolute value while are also statistically insignificant. Our methodology, uses the above estimates – regardless of whether a coefficient is statistical significant or not – to develop a theoretical baseline scenario used for the development of RD intensity.

	Pooled regression	Traditional	Manufacturing	Services	High-tech manufacturing	Medium-tech manufacturing	Low-tech manufacturing	Knowledge intensive services	Other services
RD_t-1	0.976^{***}	0.990^{***}	0.902^{***}	0.986^{***}	0.958^{***}	0.113	0.928^{***}	0.985^{***}	0.907^{***}
_cons	0.00129^{***}	0.000278^{*}	0.00640	0.000326^{***}	0.00627^{**}	0.0227	0.00161^{***}	0.000522^{***}	0.000366^{***}
N	7347	472	2646	4229	925	725	996	2375	1854

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3 Estimation of the Research Intensity equation

2.3 Changes in consumption preferences over time

Modeling a time-varying and income-dependent structure of household consumption implies introducing a sufficiently sophisticated demand system, capable of capturing what Matsuyama (2016) terms Generalized Engel Law: the fact that budget shares in consumption expenditure (and, more generally, industrial shares in terms of employment, value added or output) do not vary monotonically over time at progressively higher income levels.

Several demand systems, utility and expenditure functions, all with differentiated income elasticity, have been proposed. Desirable properties for their utilization in applied economic models are: (1) relative simplicity and analytical tractability; (2) generation of well-behaved demand curves; (3) easiness of parameters estimation. Assessing long run changes in the structure of consumption demand means considering significant changes in income, with variations in relative prices entering only as a second order effect. Therefore, the selection of a demand system should be restricted to functional forms that, at higher income levels but constant relative prices, simulate structural changes consistent with historical stylized facts .

A demand system for structural change simulation should be sufficiently flexible or, technically speaking, full rank. Rank one demands, the most restrictive demand systems, are independent of income; rank two demand systems are less restrictive, allowing linear Engel curves not necessarily through the origin; while rank three (i.e., full rank) demand systems are least restrictive, allowing for non-linear Engel responses (Cranfield et al., 2003). Among the many full-rank demand systems which have been proposed, AIDADS (An Implicitly, Directly Additive Demand System; Rimmer and Powell 1992) appears to be especially suited for implementation in multi-sector, applied general equilibrium models.

The AIDADS can be seen as a generalization of the Linear Expenditure System (LES). The demand for good i is expressed as:

$$q_i = \gamma_i + \phi_i \frac{y - \sum_j p_j \gamma_i}{p_i} \tag{9}$$

Where y is the total income or consumption budget, γ is the parameter and ϕ (that would be in case of LES be a fixed parameter) is given by:

$$\phi_i = \frac{\alpha_i + \beta_i e^u}{1+e^u} \tag{10}$$

Where α and β are parameters and u is the implicitly defined utility function.

For the estimation of the AIDADS parameters one can use the following equation that is formulated in terms of the market shares:

$$w_{ir} = \frac{p_{ir}\gamma_i}{y_r} + \frac{\alpha_i + \beta_i \exp(u_r)}{1+\exp(u_r)}\left(1 - \frac{\sum_i p_{ir}\gamma_i}{y_r}\right) + \varepsilon_{ir} \tag{11}$$

Where w is the observed household budget for the item i in region/country r , p is the corresponding price index, y stands for total per capita expenditure or income and ε is the error term. All the remaining parameters including the cardinal utility u need to be estimated. The following restrictions should apply: $\sum_i \alpha_i = 1$ and $\sum_i \beta_i = 1$, both of the parameters are positive.

We use the following econometrically estimated AIDAS parameters for the six aggregate consumption categories based on Roson(2017):

Table 4 Estimated parameter values of the AIDADS demand system

Name of the consumption category	Alpha	Beta	Gamma
Traditional	0.40	0.00	116
Low-technology industry	0.04	0.03	29
Medium-technology industry	0.07	0.09	6
High-technology industry	0.10	0.10	16
Knowledge intensive services	0.08	0.14	98
Other services	0.02	0.20	38

3. Description of spatial CGE model for European NUTS2 regions

3.1 General description

EU-EMS is a spatial computable general equilibrium (SCGE) model build by PBL Netherlands Environmental Assessment Agency that includes the representation of 62 countries of the world and one Rest of the world region. The model uses database for 2013 that has detailed regional dimensionality for EU28 countries and includes them as consisting of 276 NUTS2 regions. Sectoral and geographical dimensions of the model are flexible and can be adjusted to the needs of specific policy or research question.

The database[5] of the model has been constructed by PBL using the combination of national, European and international data sources and represents detailed regional level (NUTS2 for EU28 plus 34 non-EU countries) multi-regional input-output (MRIO) table for the world. The main datasets used for the construction of this MRIO include OECD database, BACI trade data, Eurostat regional statistics and national Supply and Use tables as well as detailed regional level transport

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[5] http://themasites.pbl.nl/winnaars-verliezers-regionale-concurrentie/

database of DG MOVE called ETIS-Plus[6]. The later dataset has allowed us to estimate the inter-regional trade flows at the level of NUTS2 regions that are currently not available from official statistical sources.

The model is used for policy impact assessment and provides sector-, region- and time-specific model-based support to Dutch and EU policy makers on structural reforms, growth, innovation, human capital and infrastructure policies. The current version of EU-EMS covers 276 NUTS2 regions of the EU28 Member States and each regional economy is disaggregated into 63 NACE Rev. 2 economic sectors. Goods and services are consumed by households, government and firms, and are produced in markets that can be perfectly or imperfectly competitive. Spatial interactions between regions are captured through trade of goods and services (which is subject to trade and transport costs), factor mobility and knowledge spill-overs. This makes EU-EMS particularly well suited for analyzing policies related to human capital, transport infrastructure, R&I and innovation. The model includes New Economic Geography (NEG) features such as monopolistic competition, increasing returns to scale and migration.

In the current application of the model we have aggregated the economic sectors to the following six large groups following the Eurostat classification of the economic sectors according to their R&D intensity: (1) Traditional, (2) Low-tech industry, (3) Medium-tech industry, (4) High-tech industry, (5) Knowledge intensive services and (6) Other services. The aggregated groups of the sectors can be directly linked to the econometric analysis and estimations that have been done for TFP projections using EU-KLEMAS database.

3.2 Regional structure of the model

EU-EMS is built upon the framework of Spatial CGE (SCGE) modelling and incorporates the representation of 276 NUTS 2 regions and 34 non-EU countries of the world. Within the SCGE framework the regions are connected by trade in goods and services, relocation of factors and economic activity and income flows. The trading of goods between regions is costly, as it is necessary to pay for the services of the national transport sector. This implies positive transportation costs. Transportation costs in EU-EMS are both good-specific and differentiated between the origin and destination regions.

Regions differ by the type of production sectors which dominate overall production activities in the region. Some specialize in traditional sectors like agriculture, whereas others specialize in modern sectors such as finance and industry. Those sectors are characterized by different level of agglomeration and its importance. Traditional sectors do not experience any agglomeration effects whereas modern sectors do and that allows some sectors to grow faster than the other ones. The prototype model will incorporate the regional difference in sectoral specialization and hence the difference of agglomeration economies between the regions.

Table 5 *Overview of countries represented in the EU-EMS model*

AUS	Australia	ARG	Argentina
AUT	Austria	BGR	Bulgaria
BEL	Belgium	BRA	Brazil
CAN	Canada	BRN	Brunei Darussalam
CHL	Chile	CHN	China
CZE	Czech Republic	CHN.DOM	China Domestic sales only
DNK	Denmark	CHN.PRO	China Processing
EST	Estonia	CHN.NPR	China Non processing goods exporters

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[6] http://viewer.etisplus.net/

FIN	Finland	COL	Colombia
FRA	France	CRI	Costa Rica
DEU	Germany	CYP	Cyprus
GRC	Greece	HKG	Hong Kong SAR
HUN	Hungary	HRV	Croatia
ISL	Iceland	IDN	Indonesia
IRL	Ireland	IND	India
ISR	Israel	KHM	Cambodia
ITA	Italy	LTU	Lithuania
JPN	Japan	LVA	Latvia
KOR	Korea	MLT	Malta
LUX	Luxembourg	MYS	Malaysia
MEX	Mexico	PHL	Philippines
MEX.GMF	Mexico Global Manufacturing	ROU	Romania
MEX.NGM	Mexico Non-Global Manufacturing	RUS	Russian Federation
NLD	Netherlands	SAU	Saudi Arabia
NZL	New Zealand	SGP	Singapore
NOR	Norway	THA	Thailand
POL	Poland	TUN	Tunisia
PRT	Portugal	TWN	Chinese Taipei
SVK	Slovak Republic	VNM	Viet Nam
SVN	Slovenia	ZAF	South Africa
ESP	Spain	RoW	Rest of the world
SWE	Sweden		
CHE	Switzerland		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		

3.3 Household preferences and governmental sector

The households' and governmental demand for goods and services is represented by the linear expenditure (LES) system that is derived as a solution to the Stone-Geary utility maximization problem:

$$U_r = \prod_i \left(C_{ri} - \mu_{ri}\right)^{\gamma_{ri}} \tag{12}$$

The resulting demand system where I_r denotes households' disposable income and P_{ri} are consumer prices of goods and services that include taxes, subsidies, transport and trade margins can be written as follows

$$C_{ri} = \mu_{ri} + \gamma_{ri} \cdot \frac{1}{P_{ri}} \cdot \left(I_r - \sum_j \mu_{rj} \cdot P_{rj} \right) \tag{13}$$

Households always consume a certain minimum level of each good and services where this level reflects the necessity (or price elasticity) of the good or service. Necessities such as food have low price elasticity and hence higher minimum level of consumption. The disposable income of the households consist of wages, return to capital, social transfers from the government minus the income taxes and households' savings.

The government collects production, consumptions and income taxes. The tax revenue is further used to pay social transfers and buy goods and services for public consumption. The governmental savings can be either endogenous or exogenous in the model depending on the type of simulation and the type of chosen macro-economic closure.

For the purpose of simulations in the paper we update the parameters of the LES expenditure system according to the AIDADS formulas as the income per capital developed over time.

3.4 Firms production

Domestic production X_{ri}^{D} is obtained using the nested-CES production technology of KLEM type, where K is the capital, L is the labour, E is the energy and M is the materials. **Error! Reference source not found.** represents the nests in the KLEM production function used in the model with services between used according to the fixed Leontief input coefficients in the production process. The energy in the model is differentiated between electricity and other types of energy with some substitution possibilities between them. The labour is differentiated according to three education levels according to International Labour Organization (ILO) classification.

The domestic production is generated according to nested production CES function that is described by the following set of composite CES functions that follow the production structure from top to the bottom nest

$$X_{ri}^{D} = \left[\left(a_{ri} \cdot M_{ri} \right)^{\rho_{M,KLE}} + \left((1-a_{ri}) \cdot KLE_{ri} \right)^{\rho_{M,KLE}} \right]^{1/\rho_{M,KLE}} \tag{14}$$

$$KLE_{ri} = \left[\left(b_{ri} \cdot E_{ri} \right)^{\rho_{E,KL}} + \left((1-b_{ri}) \cdot KL_{ri} \right)^{\rho_{E,KL}} \right]^{1/\rho_{M,KLE}} \tag{15}$$

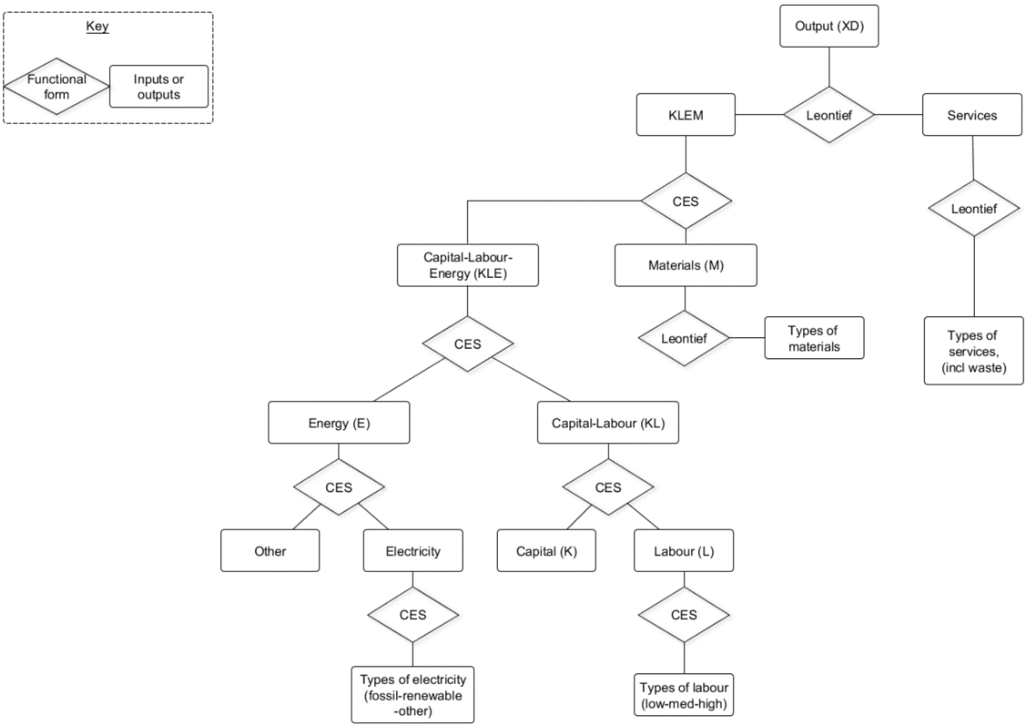
$$KL_{ri} = \left[\left(c_{ri} \cdot K_{ri} \right)^{\rho_{K,L}} + \left((1-c_{ri}) \cdot L_{ri} \right)^{\rho_{K,L}} \right]^{1/\rho_{K,L}} \tag{16}$$

$$E_{ri} = \left[\left(d_{ri} \cdot E_{ri}^{NELEC} \right)^{\rho_{E}} + \left((1-d_{ri}) \cdot E_{ri}^{ELEC} \right)^{\rho_{E}} \right]^{1/\rho_{E}} \tag{17}$$

$$L_{ri} = \left[\sum_{e} \left(f_{rie} L_{rie}^{ED} \right)^{\rho_{L}} \right]^{1/\rho_{L}} \tag{18}$$

Where a_{ri}, b_{ri}, c_{ri}, d_{ri} and f_{rie} are the share parameters of the corresponding production function nests and $\rho_{M,KLE}$, $\rho_{E,KL}$, $\rho_{K,L}$, ρ_{E} and ρ_{L} represent the substitution possibilities for each of the production function nests. The inputs into the production are denoted as M_{ri} input of materials, KLE_{ri} composite capital-labor-energy nest, E_{ri} energy inputs, KL_{ri} composite capital-labor nest, K_{ri} capital input, L_{ri} labor input, E_{ri}^{NELEC} input of non-electric energy, E_{ri}^{ELEC} input of electric energy and L_{rie}^{ED} inputs of labor by type of education e .

Figure 2 Structure of KLEM production functions in the model



3.5 International and inter-regional trade

The total sales X_{ri} of tradable goods and services i in region r in the model is an Armington Constant Elasticity of Substitution (CES) composite between domestic output X_{ri}^{D} and imports X_{ri}^{M} such that

$$X_{ri} = \left[\left(\alpha_{ri}^{D} \cdot X_{ri}^{D} \right)^{\rho_i} + \left(\alpha_{ri}^{M} \cdot X_{ri}^{M} \right)^{\rho_i} \right]^{1/\rho_i} \qquad (19)$$

Where α_{ri}^{D} and α_{ri}^{M} are the calibrated share parameters of the CES function and $\rho_i = \dfrac{\sigma_i - 1}{\sigma_i}$ with σ_i being the Armington elasticity of substitution between domestic and imported tradable goods and services. The elasticity of substitution varies between different types of goods and services depending on the available empirical estimates. In case of non-tradable the composite is equal to the domestically produced product.

Imported goods can come from various regions and countries represented in the model and the composite imported goods and services are represented by CES composite that uses a higher Armington elasticity of substitution as compared to the upper Armington nest. We assume as in the GTAP model that the elasticity of substitution between the same type of goods and services coming from different countries is twice as large as the elasticity of substitution between domestic and aggregate imported goods and services. The aggregate imported good is calculated according to the following CES composite function

$$X_{ri}^{M} = \left[\sum_{s} \left(\alpha_{sri}^{T} X_{sri}^{T} \right)^{\rho_i^T} \right]^{1/\rho_i^T} \tag{20}$$

Where α_{sri}^{T} is the calibrated share coefficient of the CES production function, X_{sri}^{T} is the flow of trade in commodity i from country S to country r .The coefficient $\rho_i^T = \frac{\sigma_i^T - 1}{\sigma_i^T}$ where σ_i^T is the elasticity of substitution between commodities produced in different countries.

3.6 Labour, capital and goods markets

Market equilibrium in the economy results in equalization of both monetary values and quantities of supply and demand. Market equilibrium results in equilibrium prices that represent in case of CGE models the solution to the system of nonlinear equations that include both intermediate and final demand equations as well as accounting constraints that calculate households' and government incomes, savings and investments as well as trade balance. EU-EMS model represent a closed economic system meaning that nothing appears from nowhere or disappears into nowhere in it. This feature of the CGE model constitutes the core of the Walrasian equilibrium and ensures that even if one excludes any single equation of the model it will still hold. This is the property of CGE models called Walras law that tells us that in the closed economic system if n-1 markets are in equilibrium the last nth market will also be in equilibrium.

In our EU-EMS model the static equilibrium is described by the set of commodity and factor prices, total outputs, final demands of households and government, investments, savings and net transfers from abroad such that (1) markets for goods and services clear, (2) total investments are equal to total savings, (3) total households consumption is equal to their disposable income minus savings, (4) total governmental consumption is equal to its net tax revenues minus transfers to households minus savings, (5) total revenue of each economic sector is equal to its total production costs and (6) difference between imports and exports is equal to the net transfers from abroad.

3.7 Recursive dynamics

EU-EMS is a dynamic model and allows for the analysis of each period of the simulation time horizon. This horizon is currently set at 2050 but it can be extended to longer time periods. For each year of the time horizon, EU-EMS calculates a set of various economic, social and environmental indicators. The economic growth rate in EU-EMS depends positively on investments in R&D and education. By investing in R&D and education each region is able to catch up faster with the technological leader region and better adopt its technologies.

Time periods in EU-EMS are linked by savings and investments. By the end of each time period, households, firms and government in the model save a certain amount of money. This money goes to the investment bank, distributing it as investments between the production sectors of the various regions. The allocation decisions of the investment bank sectors depend on the sector's financial profitability. The model runs in time steps of five years for the period 2015-2050.

The capital stocks evolve according to the dynamic rule presented below, where the capital stock in period t is equal to the capital stock in period t-1 minus the depreciation plus the new investments into the capital stock

$$K_{tri} = K_{t-1ri}(1-\delta_i) + I_{tri}\,. \tag{21}$$

At the end of each period there is a pool of savings S_r available for investments into additional capital stocks of the sectors. This pool of savings comes from households, firms and foreign investors.

The sector investments I_{tri} are derives as a share of the total savings in the economy according to the discrete choice formula

$$I_{tri} = \frac{ST_{t-1r} B_{ri} K_{t-1ri} e^{\vartheta \cdot WKR_{t-1ri}}}{\sum_j B_{rj} K_{t-1rj} e^{\vartheta \cdot WKR_{t-1rj}}}\,. \tag{22}$$

with

$$WKR_{t-1ri} = \frac{r_{t-1ri}}{PI_{t-1r}} \cdot (g_r + \delta_{ri})\,. \tag{23}$$

Where WKR_{t-1ri} denotes the capital remuneration rate, g_r the steady-state growth rate, B_{ri} the calibrated gravity attraction parameter and ϑ the speed of investment adjustments.

4. Regional economic growth in Europe until 2050

4.1 Spatial patterns of economic growth

Using structural economic change scenario as input to Spatial CGE model we produce predictions of average annual economic growth for 267 NUTS2 regions of EU28. Differences in regional economic growth are driven by demographic changes in combination with differences in sectoral structure of NUTS2 regions.

Figure 3 below illustrates the spatial spread of average annual regional level GDP growth rates in the period 2015-2050. The highest growth rate is about 3% per year and the lowest growth rate is about -5% per year. The highest economic growth is concentrated mostly in the regions of Eastern Europe whereas Scandinavian regions face decline of their economies, which is mostly due to demographic changes. Regions of South of Europe experience very low economic growth over the period 2015-2050.

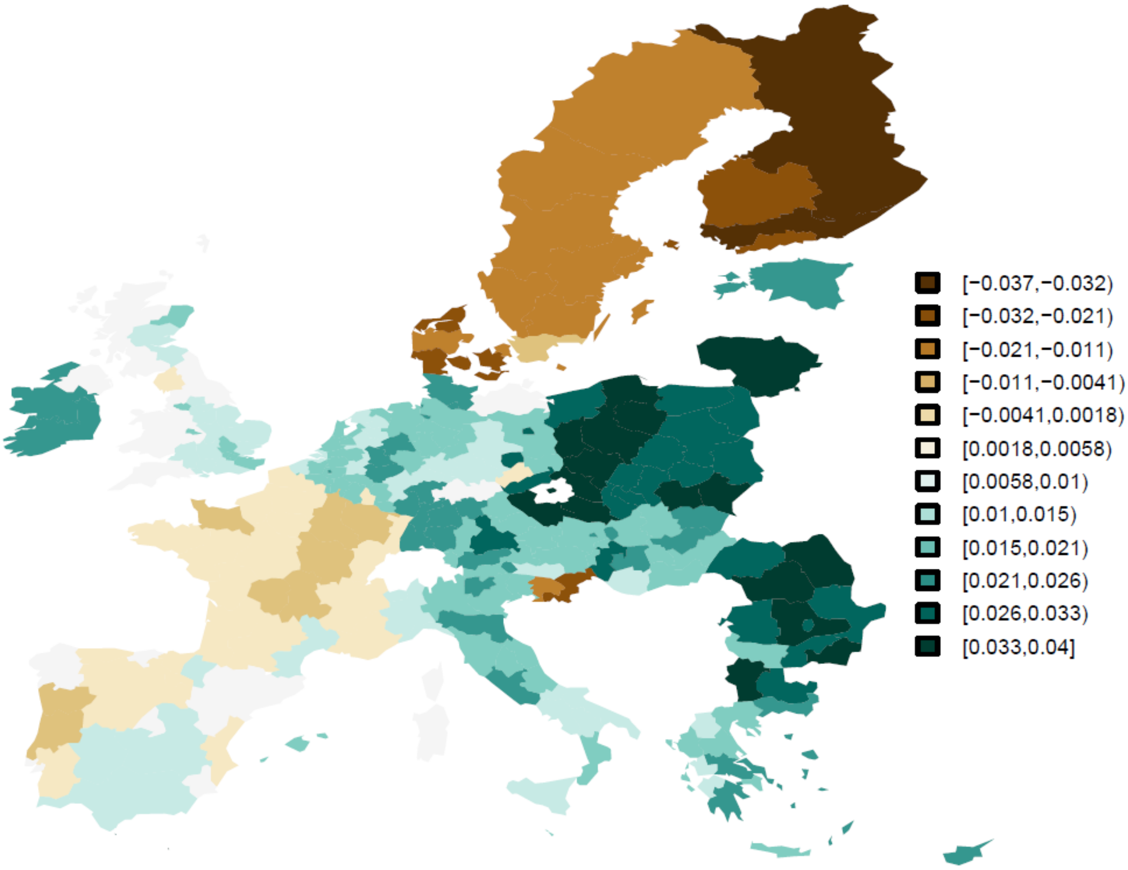


Figure 3: Average annual growth of regional GDP in the period 2015 - 2050.

4.2 Regional specialization over time

Each EU region has its own comparative advantage which according to modern trade theories including New Trade Theory developed by Krugman would result in spatial specialization pattern. This pattern of dynamic specialization of production can be seen on Figure 4 that present absolute changes in region-specific Krugman specialization indexes in the period 2015-20850. Krugman specialization index shows how different is the sectoral structure of a particular region from country or European average. One can clearly see that Krugman specialization index is increasing over time which means more regional specialization with the highest values being attributed to Scandinavian and Baltic regions.

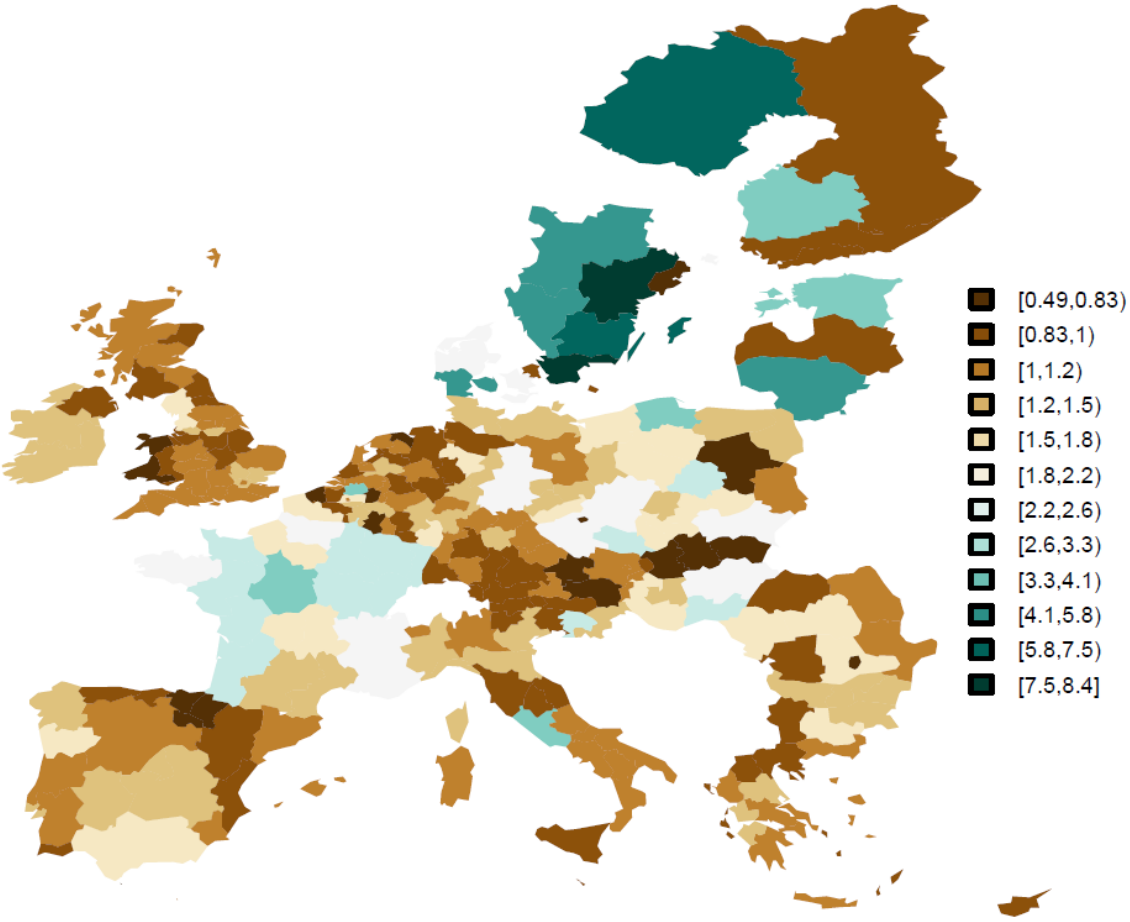


Figure 4: Absolute change in the Krugman index of regional specialization in the period 2015-2050.

Over time the spatial concentration of economic sectors changes and some of them in particular High-technology industry and Knowledge intensive services experience increase in their spatial concentration in particular EU28 regions (see Figure 5). In case of Other Services and Medium-technology industry their spatial concentration is decreasing meaning that production of these sectors being spread more equally between the European regions.

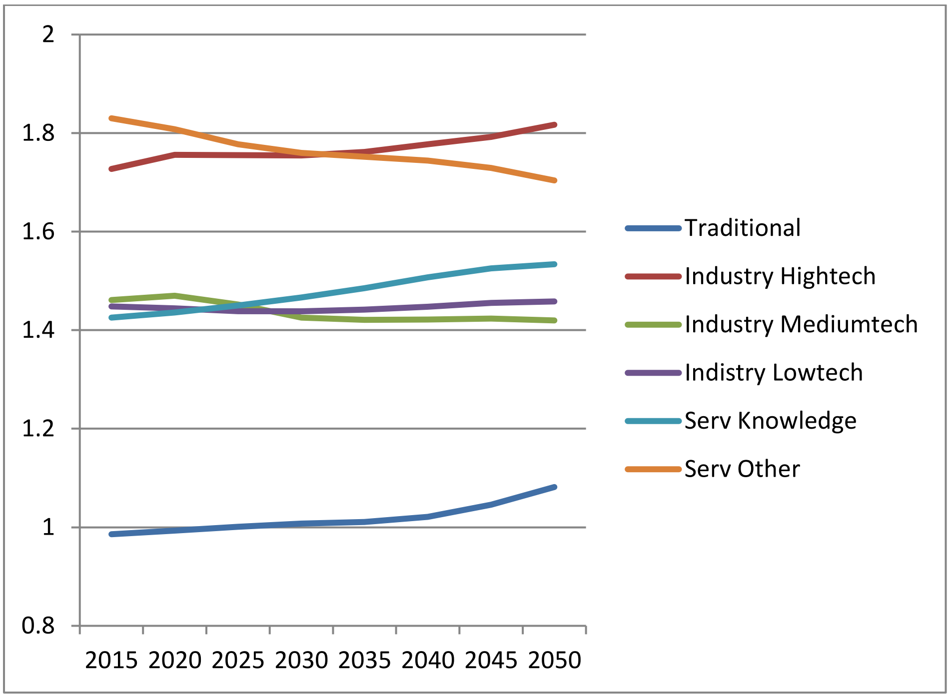


Figure 5: Development of industry concentration index in the period 2015 - 2050.

4.3 Development of spatial inequality over time

Regional disparities in economic analysis are frequently measured using Theil's T inequality index using GDP per capita as the measure of regional income. In order to understand how the changes economic development over time impacts the regional disparities in EU28 we calculate this index for the period 2015-2050 (see Figure 6 below).

$$Theil\_T = \frac{\theta_i}{\sum_i \theta_i} \sum_{i=1}^{N} \log\left(\frac{\gamma_i}{\mu}\right)$$

Where θ_o is GDP of each NUTS2 region, γ_i is GDP per capita in each region and μ is the average GDP per capital across EU28 NUTS2 regions.

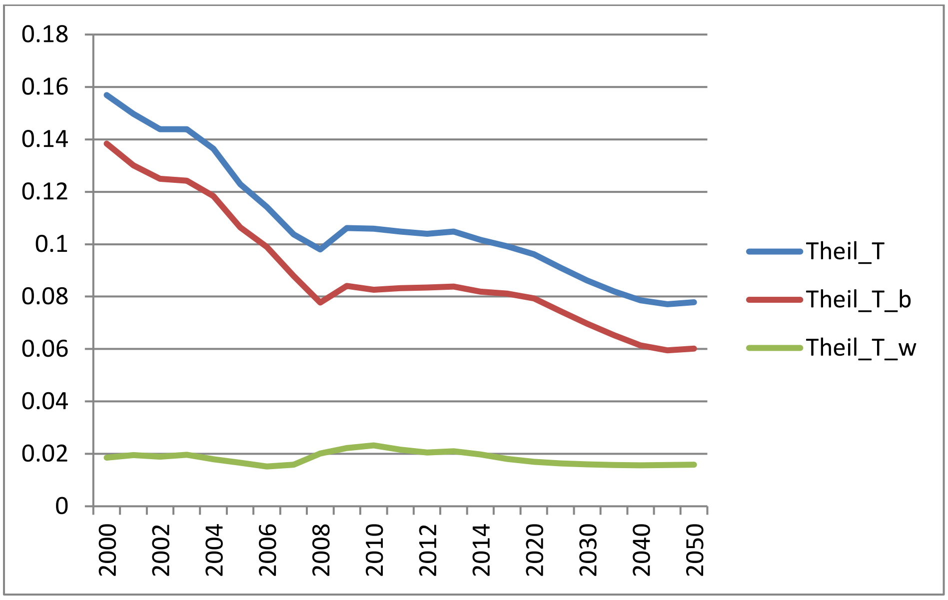


Figure 6: Development of Theil-T inequality index in the period 2000 - 2050.

Figure 6 combines the historical development of Theil-T index (Theil_T) decomposed into variation between countries (Theil_T_b) and within countries (Theil_T_w) with the values for the period 2015-2050 that are based on the outcomes of our model simulations. One can see that inequality in GDP per capita between countries is slowly decreasing over time whereas the inequality between the regions of same country is first somewhat increasing and after that stays stable over time. This means that the existing patterns of spatial inequality within the EU countries are stable and represent most probably an equilibrium allocation of economic activities in space that are linked to scale advantages and agglomeration economies. The largest variation in the levels of Theil-T inequality index is related to the financial crisis of 2008. Financial crisis have resulted in increase of spatial inequality and acted as a trend-breaker in the development trajectory of Theil-T index for EU.

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