

Impact of R&D investments on the economic growth of the Czech Republic – a recursively dynamic CGE approach

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Abstract

The paper investigates how results obtained with standard CGE models can be improved by incorporating the effects of the R&D activities in a recursively-dynamic CGE model built for the economy of the Czech Republic. The main objective of the paper is to quantify the impact of the R&D activities on the long-term economic growth of the Czech Republic in the recursively dynamic CGE framework. The effects of R&D investments are modelled via the accumulation of knowledge that is treated as a specific production factor.

Main findings show that knowledge accumulation can contribute to higher economic growth, but the impact of the dynamisation in the CGE model is very low. However, in terms of structural changes in the economy, the omission of knowledge capitalization might underestimate the tertiary sector in the longer run. The paper also investigates the efficiency of R&D investments and concludes that in the longer run, the investments to capital goods are more efficient in reaching higher economic growth. In the concluding chapter, related factors that may improve the impact of knowledge in the CGE model are discussed.

Key words: R&D investments, CGE model, Czech Republic, knowledge accumulation, economic growth.

1. Introduction

Developed economies are facing a problem of declining competitiveness on a global scale. The perspectives for sustaining the world economic leadership are associated with stimulating technological progress through innovations and investments to R&D. This is a challenge for the private sector but also for governments in prioritizing their policies in line with the goal of sustaining the competitive advantage. Within the EU, the debates are often centred on the effective allocation of subsidies from the EU budget, in which certain support of policies, such as the Common Agricultural Policy, occupy a considerable part. However, the ideas of reallocation of the agricultural subsidies to the prospective sectors of the economy such as the sector of Research and Development should be supported with a thorough research, revealing possible impacts on the whole economy.

Computable General Equilibrium models provide appropriate instruments in assessing the ex-ante impact of different policy scenarios. However, in the field of Research and Development, standard CGE models do not capture properly the R&D effects, due to several reasons. First of all, the national accounts usually do not explicitly involve the investments to R&D; second, the sector of R&D included in the input-output tables does not capture all investments into Research and development.

Third and most important, the R&D activities are not capitalized properly in the CGE model to stimulate the economic growth.

This paper investigates how results obtained with standard CGE models can be improved by incorporating the effects of the R&D activities in a recursively-dynamic CGE model built for the economy of the Czech Republic. The main objective of the paper is to quantify the impact of the R&D activities on the long-term economic growth of the Czech Republic in the recursively dynamic CGE framework. The paper is structured as follows: in the second section, a review of approaches to modelling R&D investments in CGE models is provided, which is followed by the description of the methodological approach applied in this paper. An overview of the expenditures on research and development in the Czech Republic is provided in the fourth chapter. Fifth chapter includes the results of the simulations. First of all, the economic growth predicted by a model with knowledge is compared to a model without knowledge and the impact is also analysed concerning different initial knowledge endowment levels. The second simulation concerns the efficiency of R&D investments, which is compared to the efficiency of the physical investments. Finally, the model with knowledge is applied to assess the impacts of an R&D stimulated shock on the economy. In particular, the impacts on GDP, other macroeconomic variables and the value added are discussed.

Main findings show that knowledge accumulation can contribute to higher economic growth, but the impact of the dynamisation in the CGE model is very low. However, in terms of structural changes in the economy, the omission of knowledge capitalization might underestimate the tertiary sector in the longer run. In the concluding chapter, the findings are put in perspective with the evidence of other authors and related factors that may improve the impact of knowledge in the CGE model are discussed.

2. Review of theoretical approaches for modelling R&D investments

The progress made in understanding the endogeneity of economic growth at the beginning of the 1990s raised the attention to incorporate the endogenous growth theories into the CGE models. According to Zürn et al. (2007), Computable General Equilibrium (CGE) models are suitable to fulfil the requirements on the instrument of the analysis regarding the sectoral, regional and chronological dimension. This can be very useful considering that innovations are not restricted to certain industries or certain areas of the economy but they include the economy as a whole. Furthermore, several authors agree that the CGE models are especially appropriate for the top-down modelling of technical change with a particular focus on the investments to R&D (Wang and Chen, 2006; Peace and Weyant, 2008).

One of the earliest contributions on implementing endogenous growth theory formalized by Romer can be found in the work of Diao, Roe and Yeldan (1999) who incorporate imperfect competition and forward-looking dynamization. As Gillingham, Newell and Pizer (2008) point out, “*unfortunately, theoretical models with continuous intermediate goods and abstract representations of blueprints are not well-suited to match up to measurable real-world variables or technologies that most numerical models attempt to represent*”. Therefore, various recent practical applications of the R&D based theory

of economic growth have been performed in the recursively dynamic CGE framework. For instance, Garau and Lecca (2009) estimate the impact of R&D subsidies on the region of Sardinia in a regional CGE model with a recursive dynamization and perfect competition setting. The research and development activities are incorporated through knowledge capital, which is treated as a specific production factor. Contrary to original models, the authors also consider a depreciation of knowledge. The main findings show that cross border spillovers could increase the long run rate of growth.

Yungchang et al. (2010) have applied an R&D-driven recursively dynamic CGE model to assess whether the research and development should be financed by private or the public sector. The results showed ambiguous findings; on one hand the public R&D investments have a positive effect on the real wage, on the other hand they also bring certain negative crowding-out effects.

Endogenous growth theory based on the R&D has seen increasing applications in the field of climate change modelling and environmental policy. The impacts of climate change can be mitigated via the technological change brought by investments into the research and development, which can increase the energy efficiency of the production. For instance Wang, Wang and Chen (2009) developed a computable general equilibrium (CGE) model with an endogenous technological change for Chinese climate change policy analysis. The technological change is introduced by creating a nested production structure with knowledge capital derived from the R&D investments and other primary factors (such as physical capital, labour or intermediate inputs) as imperfect substitutes on the highest hierarchical level.

To add to the review of recent works, research on R&D investments and knowledge input has been also carried out in the Institute of Energy Economics and Rational Use of Energy, Germany. Zürn et al. (2007) applies global CGE model NEWAGE-W¹ to estimate economic and environmental impacts of R&D investments. The authors consider knowledge as a primary factor input into production derived from the accumulation of the R&D investments, which are endogenously modelled as a part of the utility maximization problem of the representative agent. Derived model is used for an interesting application – to compare the efficiency of subsidizing direct knowledge, or R&D investments. Zürn et al. (2007) shows that whereas direct input subsidy of knowledge provides benefits only from knowledge reallocation, subsidizing investment to R&D is more efficient as it decreases relative price of this activity as opposed to the alternatives of consumption and physical investment activity and it leads to faster accumulation of knowledge.

Following recent approaches, this paper incorporates the R&D effects into the recursively dynamic CGE model built for the economy of the Czech Republic. The necessity to construct a dynamic CGE model for the Czech economy is supported by the fact that the Czech Republic as a small opened economy is vulnerable to any external shocks that might have severe repercussions in longer time horizons. For this reason, CGE models have gained popularity in the field of policymaking in the Czech Republic, particularly in the field of natural resources and environment. In connection to prepared environmental tax reform, the Czech ministry of environment has applied a dynamic CGE

¹ (National European Worldwide Applied General Equilibrium Modeling System)

model for the quantification of environmental policy impact on macroeconomic aggregates (Pavel, 2008). The macroeconomic effects of the environmental taxation are further analysed in Ščasný, Píša, Pollot et al. (2009) who apply structural macroeconometric E3M3 European model adjusted to the Czech economy. In the structural equations, R&D investments to energetic sector are incorporated to improve its energetic efficiency. Another CGE model applied in connection to natural resources is the model developed at the Czech National Bank in cooperation with Netherlands Bureau of Policy Analysis (Dybczak and van der Windt., 2008) which has been used for the predictions of the oil price shocks effects on the Czech economy. Concerning fiscal policy, Hurník (2004) applies a non-stochastic dynamic general equilibrium model to assess the impact of alternative fiscal consolidation programs on the Czech economy.

Despite various uses and model alternatives as described above, the issue of R&D investments and knowledge formation following the endogenous growth theory has not been sufficiently analysed in the Czech Republic, at least not in the CGE framework. However, it should be noted that there is an extensive research done on modelling the endogenous growth and knowledge accumulation using other modelling approach, see for instance Kejak, Seiter and Vávra (2004) or Kejak and Vávra (2002), who develop a two-sector endogenous growth model to assess the transitional behaviour after the EU accession in the CEEC countries including the Czech Republic.

By explicit incorporation of knowledge as a production factor and R&D investments in the gross capital formation this paper aims at contributing to the existing CGE model studies done in the Czech Republic and to improve the understanding of the role of research and development activities in the Czech economy. The description of the CGE model applied in this research, required data source for the SAM construction and the main model modifications that incorporate investments to R&D are described in the following chapter.

2. Description of the methodological approach applied in the paper

2.1 Construction of the Social Accounting Matrix with capitalized R&D investment

The Social Accounting Matrix (SAM) was constructed from the Czech national accounts. The base year for the calibration of the model was determined by the availability of the supply-use tables, which were used for building the production and commodity accounts of the SAM. At the time of the SAM construction, the most updated edition of the supply-use tables was available for the year. The SAM contains 18 production sectors and 19 commodities. The choice of the production structure was determined by the structure of R&D expenditures available per sector in the R&D statistics.

The general version of the SAM was further extended to incorporate knowledge accounting. In the studies that apply CGE models, knowledge accounting is often incorporated with use of the Terleckyj method, see for instance Zürn et al. (2007) or Wang, Wang and Chen (2009). The Terleckyj method requires construction of the R&D input-output matrix, in which the input-output coefficients are derived from the matrix of total intermediate consumption. Another possibility is to apply Yale Technology Matrix that approximates the structure of R&D flows among industries, this approach is used for instance by Garau and Lecca (2008).

Parallel to the efforts of the CGE modellers to incorporate knowledge into SAM, there has been a continuous progress of the Statistical Offices to properly capture the effects of Research and Development in National Accounts. Following the SNA 1993 revision, the expenditures on R&D will no longer be considered as a part of intermediate consumption (in case of private research) or governmental consumption (in case of public research), but as a component of the gross fixed capital formation. This process is commonly known as capitalization of Research and Development in the SNA. As a part of the revision, the whole concept of the Research and Development is redefined. Whereas the current version of SNA considers R&D predominantly as “*activity carried out with the aim to increase efficiency, productivity and future benefits*” which is closely related to the concept innovation, the definition of OECD included in the Frascati manual² is broader – “*R&D is a creative work undertaken on a systematic basis in order to increase the stock of knowledge including knowledge of man, culture society and the use of this stock of knowledge to devise new applications* “ (OECD, 2003).

All the EU-member state Statistical offices are obliged to adopt the 1993 SNA/1995 ESA Revision involving the R&D capitalization until 2014. Basically, there are two sources of data that can be used for this R&D capitalization. First of all, R&D activity is recorded within the supply-use tables under the NACE 72 production sector; however, this sector does not represent all R&D activities as it excludes research carried out as a complementary activity in the departments of private businesses and public institutions. The second R&D source can be obtained from the surveys based on Frascati manual, which comprehensively captures all research activities in the domestic economy; however, it is not fully consistent with the National Accounts. Thus, the process of capitalization requires harmonizing the two data sources. Bridge tables that translate Frascati manual data (FM) to National Accounts (SNA) are described in various sources, for instance see de Haan and van Rooijen-Horsten (2004) for Netherlands, Salem and Siddiqi (2006) for Canada, Galindo-Rueda (2007) for UK, Robbins for Australia (2005) and Daniels (2007) for Sweden. In this research, the Frascati manual data were translated to the SNA format using bridge tables described in Ptáčková (2007) specifically for the Czech Republic.

The SAM extension involved various steps. At first, private and public expenditures on R&D carried out in the Czech Republic were obtained from the Frascati surveys for 2008 published by the Czech Statistical Office (CSO, 2011). Consequently, Gross R&D production separately for private and public research was derived following Equation 1, as for the public R&D production, operating surplus was excluded. According to Equation 1, in order to derive values of R&D production consistent with SNA, it is necessary to add depreciation and profit to the R&D expenditures obtained from the Frascati surveys. As these components are normally not available, they must be estimated. In this case, the depreciation of the R&D sector was estimated based on calculations made by the Czech Statistical

² *Frascati Manual* contains proposed standard practice for surveys of Research and Development as initially agreed during OECD national R&D experts meeting in Frascati, Italy, 1963. The newest – sixth edition – was released in 2002.

Office (see Ptáčková, 2007). The operating surplus was estimated with use of the profitability ratio of the R&D sector in the SNA, assuming thus that all R&D activities have a uniform profitability rate approximated by the sector NACE 72. Net taxes on production were estimated as a sum of net taxes paid by NACE 72 sector and the subsidies granted to private R&D sector by public sector, obtained from the Frascati surveys.

$$\begin{aligned}
 \text{R\&D Gross production} = & \text{Labour costs (FM)} + \text{Other current expenditures (FM)} + \text{Intermediate} \\
 & \text{consumption of R\&D commodity by R\&D sector (SNA NACE 72)} + \text{Consumption of Gross Fixed} \\
 & \text{Capital (estimate)} + \text{Operating Surplus (estimate)} + \text{Net taxes on production (estimate)} - \text{R\&D} \\
 & \text{expenditures on Software (FM)}.
 \end{aligned}
 \tag{1}$$

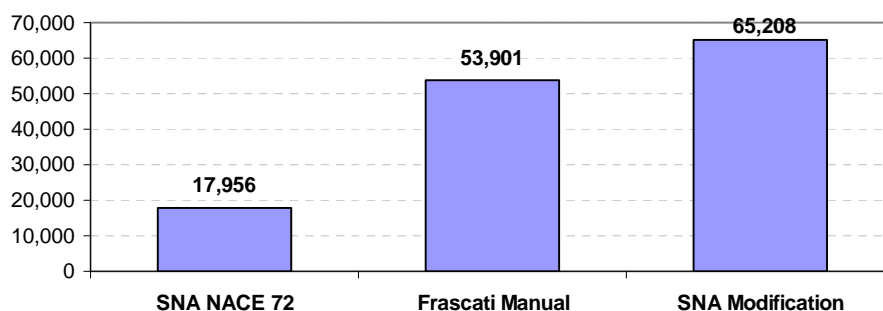
The values of the R&D expenditures obtained from the Frascati manual and the translation to the SNA is displayed in Table 1. Table 1 shows that harmonizing the Frascati manual data with SNA increases R&D estimates by about 20%. Even stronger discrepancy is found out when comparing the R&D data obtained from Frascati with the R&D values reported in the current version of SNA. As reported in Figure 1, the gross production of R&D sector reached CZK 18 bln. in 2008, however, the surveys from Frascati manual reported expenditures in the amount of CZK 53 bln. After harmonizing with SNA standards, the final value of gross R&D production reaches CZK 65 bln., being more than 2.5 times higher than the original values in the supply-use tables. These results confirm that in the current version of National Accounts, the size of the R&D sector is significantly underestimated. Therefore, the SAM derived from the current SNA should be properly modified in order to avoid this bias.

Table 1: Estimation of Private R&D Gross Production (CZK mln.)

	Private Research and Development		Public Research and Development	
	Frascati	SNA	Frascati	SNA
	Manual	Modification	Manual	Modification
Domestic production of R&D commodity				
Current Expenditures	30,073	30,621	17,875	18,210
Labour expenditures	12,680	12,680	9,096	9,096
Other expenditures	17,393	17,941	8,779	9,113
Capital expenditures	3,413		2,539	
Land, buildings and constructions	490		973	
Machinery, equipment, incl. software	2,923		1,566	
Gross capital consumption		12,636		7,511
Operating surplus		2,493		
Taxes and subsidies on production		-3,581		
Software development		2,681		
Gross domestic production	33,486	39,487	20,415	25,721

Source: author's calculations

Figure 1: Comparison of total R&D gross production reported in SNA and Frascati Manual in 2008 (mln. CZK)



Source: author's calculations

After obtaining a reliable size of the R&D domestic production, the balance of private and public R&D commodity was calculated, based on equation 2. The split between public and private commodity in case of imports and indirect taxes was performed based on their share in the domestic production.

$$\text{Total R\&D resources} = \text{Total gross domestic R\&D production (estimation above)} + \text{R\&D imports (SNA NACE 72)} + \text{indirect taxes (SNA NACE 72)} \quad (2)$$

Finally, the gross fixed capital formation (GFCF) of both R&D commodities was derived, following equation 3:

$$\text{R\&D GFCF} = \text{Total R\&D resources (estimated above)} - \text{R\&D exports (SNA NACE 72)} - \text{Intermediate consumption of R\&D commodity by R\&D sector (SNA NACE 72)} - \text{R\&D stocks (SNA NACE 72)}. \quad (3)$$

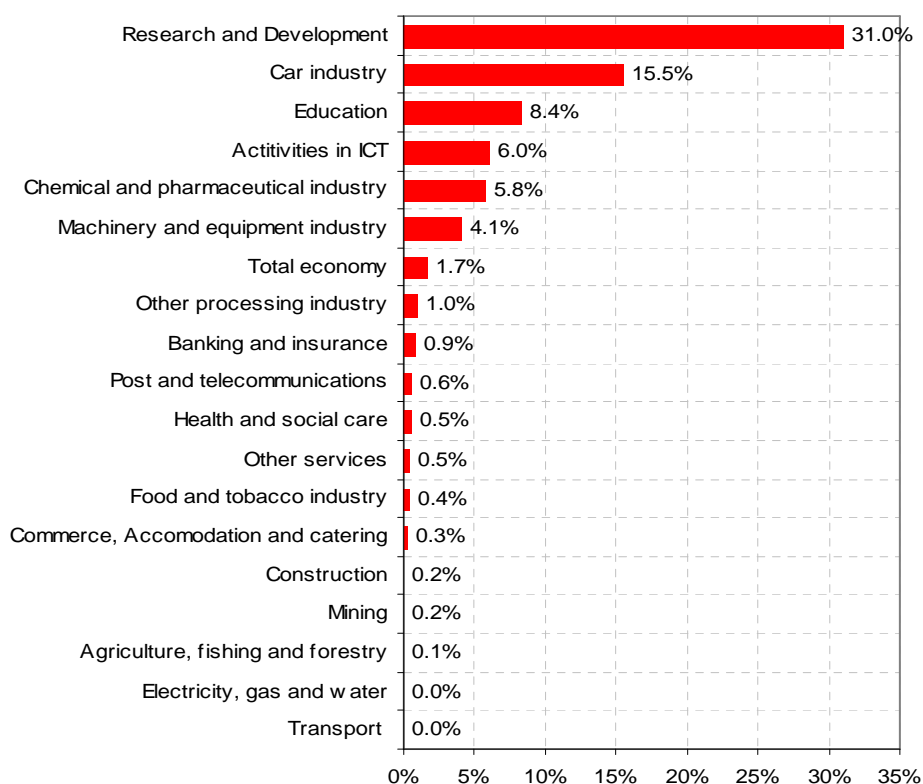
Having obtained values of the gross R&D capital formation, its incorporation to the SAM was performed. Technically, there are two ways of SAM modification:

- ❖ *Alternative of disaggregation:* In the commodity account, investments to R&D are subtracted from the intermediate consumption and added to the account of Gross fixed capital formation. In the production account, the reduction of intermediate consumption is compensated by increase of value added, which is attributable to knowledge. This is the principle of the methods mentioned above, applied in Zürn et al. (2007) or Wang, Wang and Chen (2009).
- ❖ *Alternative of imputation:* In this alternative, the investments to R&D are also newly incorporated into the gross fixed capital formation account, but in order to maintain the balance in the commodity account, the compensation is done via increase of domestic production in the supply table. The advantage of this method is that it leaves the matrix of intermediate consumption unchanged and omits the bias caused by an inaccurate estimation of the input-output R&D flows.

It must be noted that both methods lead to an increase of GDP compared to the original state, from the expenditure side it is attributed to the increase of investments, from the production side it is caused by growth of value added³.

In this paper, the method of imputation was chosen, which is also in line with the preference of the Czech Statistical Office. After the incorporation of R&D investments into the Gross capital formation account, the gross production in each sector was increased proportionally. This increase was translated partially to value added in form of knowledge and partially to the consumption of gross fixed capital. Consequently, knowledge income was redistributed to households, firms and government in the proportion of total capital income and further fully transmitted to the savings account. The impact of the capitalization on the SAM is recorded in Figure 2, which displays a percentage change of gross value added after the capitalization per sector. The strongest increase of value added is noticed in the R&D sector (+31%), which participates significantly in the total R&D expenditures. However, value added is also elevated in other sectors of the economy, mainly in car industry (+16%), education (+8%), ICT, chemical and pharmaceutical sector (+6%). The effect on total gross value added is 1.7% which gives the idea of the impact of R&D capitalization on the GDP.

**Figure 2: Impact of R&D capitalization in the modified SAM on gross value added per sector
(% change against the original SAM)**



Source: author's calculations

³ Furthermore, it should be added that for the public R&D commodity, the incorporation of public R&D expenditures to the gross fixed capital formation account should be accompanied with proportional reduction of the governmental consumption, as non-market R&D expenditures already included in the SNA.

The final SAM after capitalization is a matrix of 54x54 size. Compared to the original version, it is extended for following accounts: (i) account of gross R&D investments, (ii) account of knowledge as a new production factor in the value added per each production sector and (iii) account of knowledge depreciation per each production sector.

2.2 Description of the CGE model with knowledge and R&D investments

In this research, national CGE model of the Czech economy built by the author is applied. The production side of the economy is modelled following a standard CGE model structure (see Lofgren, 2002) and is described in detail in Křístková (2010,a). The model assumes that the total gross production is a fixed factor Leontief combination of intermediate consumption and value added under perfect competition and constant returns to scale, which can be expressed by a nested production structure. Consumption behaviour of households is modelled with use of Stone-Geary utility function, leading to the Linear Expenditure System.

Total supply in the market is represented by a composite commodity consisting of the bundle of domestically produced goods supplied to domestic markets and imports. The composite commodity is a result of two simultaneous forces in the model, first the intention of producer to find the most profitable combination of supply between foreign and domestic markets, modelled with a Constant Elasticity of Transformation (CET) function, and the intension of the consumer to find an optimal combination of imported and domestically produced commodity, modelled with a CES Armington function. Two non-domestic institutions are disaggregated between the EU and the Rest of the World (RoW).

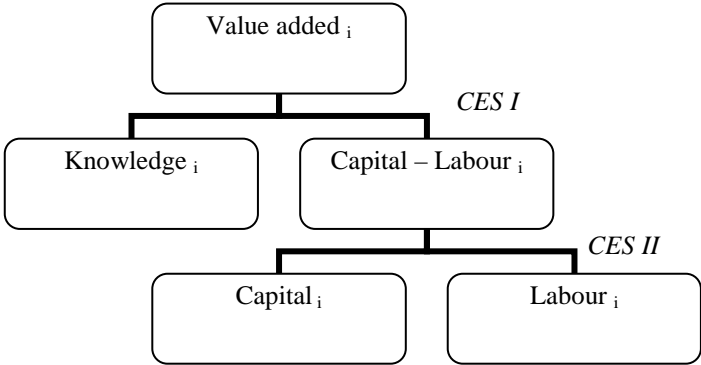
The CGE model considers six closure and factor market assumptions: i) supply of labour and land is fixed; capital stock grows at the rate of net investments; ii) labour unemployed is allowed and determined by the Phillips curve; iii) the model follows a standard macroeconomic balance of savings and investment; iv) the closure of the governmental account is arranged by fixing a ratio of governmental consumption to GDP; v) export and import prices are fixed; vi) both foreign sector closures (for the EU and the RoW) assume fixed foreign savings and endogenously adjusting exchange rates.

Several modifications were made to the original structure of the model in order to incorporate the effects of research and development. First of all, as knowledge is regarded as a new production factor, it must be incorporated into the production structure of the CGE model. Different alternatives can be considered, which are mainly related to the role of knowledge in technological progress. In general, the technological progress can increase productivity of capital, in this case it is regarded as Sollow type of technological progress, or it can increase productivity of labour, i.e. the Harrod technological progress. The technological process can also contribute to productivity growth of both production factors, which is attributed to Hicks type of the technological progress. In case of knowledge, all alternative ways of incorporating technological progress can be found in the CGE models. The original work of Romer (1990) considers knowledge as a Harrod type, nevertheless the arrangements

of the Solow type where knowledge is considered as a substitute of physical capital can be found in other works too, see for instance Youngchan et al. (2010).

In this paper, Hicks type of technological progress is chosen for incorporation of knowledge. As Gillingham, Newell and Pizer (2008) point out, “a Hicks-neutral knowledge stock is a common choice for numerical models that include an economy-wide production function”, which is supported for instance by Zürn et al. (2007) or Wang, Wang and Chen (2009) who adopt the same approach. By incorporating knowledge following the Hicks-neutral technological progress it is assumed that with increasing stock of knowledge, the productivity of all other production factors increases, which means that with more knowledge there is less labour and capital required. Even though there is no sufficient empirical evidence that could support the choice of this arrangement, this seems to be the most plausible option with respect to the neutrality of knowledge in this type of technological progress and with respect to its common adoption by other authors.

Scheme 1: Nested production structure used in the CGE model

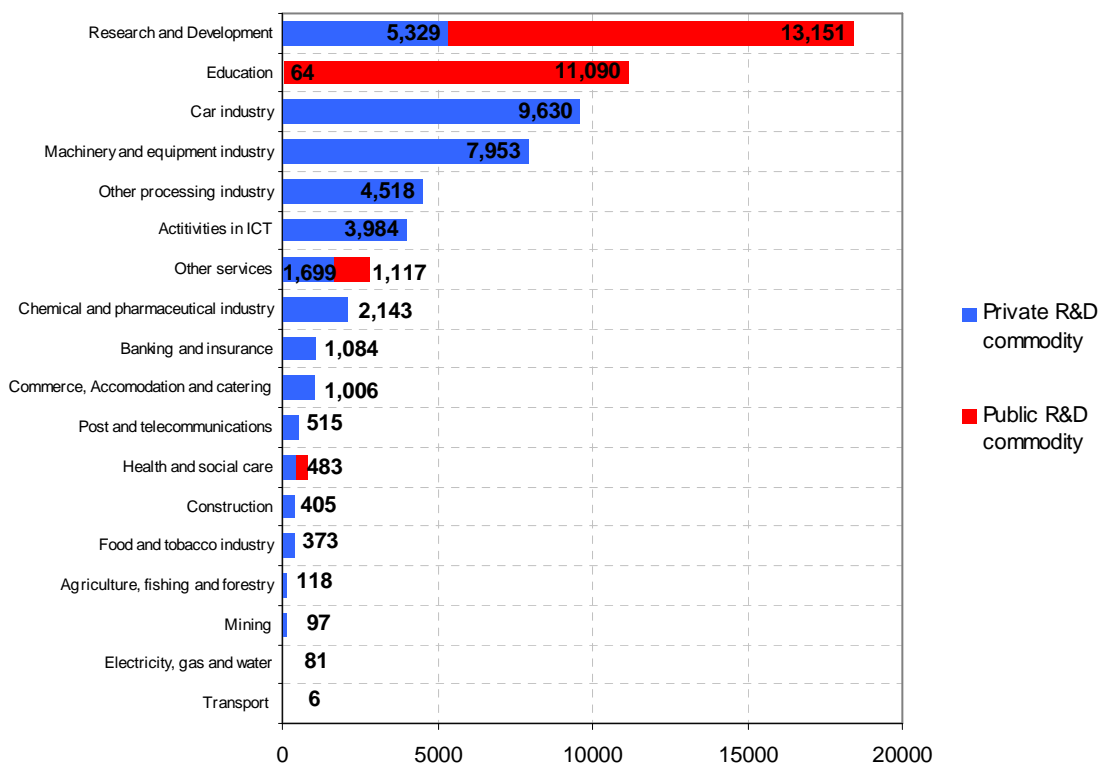


The nested production structure used in the CGE model is provided in Scheme 1. On the higher level of the nest, the value added is a combination of knowledge and capital-labour bundle using *CES I* production function. Due to lack of empirical evidence, the elasticity of substitution between knowledge and capital-labour was chosen $\sigma_H = 2.0$, which is close to Wang Wang and Chen (2009) who apply $\sigma_H = 2.5$. On the lower nest, split between capital and labour is determined by the demand equations derived from the *CES II* production function. The substitution elasticities between capital and labour were taken over from the GTAP estimates (Dinamaran, 2006).

Instead of modelling R&D within a uniform representative production sector, it is assumed that all production sectors carry out a complementary research activity, which is further distinguished between private and public R&D. In this way, the R&D commodity has a role of a by-product, respecting cost structure of each industry. As for the private commodity, the R&D production can be directly determined from the surveys. In case of public commodity, it is not directly attributable per production sector, but it can be derived based on the type of institution where the research is carried out. In this work it is assumed that the research carried out for instance under the Ministry of Agriculture directly stimulates knowledge in agriculture, analogically for other resort research. In case of the research performed by the Czech Academy of Sciences, knowledge is attributed directly to the sector of R&D.

Figure 3 shows the participation of each sector in production of both public and private R&D commodities. It can be noted that there are four production sectors that are important in producing public R&D commodity, which are the sectors of R&D itself, the sector of education, health care sector and other services sector that involves activities of public administration, museums and libraries. Majority of research is however performed in the private sector (60%), with the domination of car and other processing industry. From the tertiary sector, ICT, banking and commerce are mostly active in private research.

Figure 3: Production of R&D commodities per sector (mln. CZK)



Source: author's calculations

Further modification to the original model was carried out in the investment function. Total investment resources ($INVRES$), which are determined by total savings and depreciation are distributed between physical investments ($INVT$) and R&D investments ($INVTRD$) on the basis of the Cobb-Douglas investment function, which maximizes bank's investment utility subject to available investment resources. Derived investment demand functions are displayed in equation 4 and 5. The choice between investing in R&D or capital goods is determined by the total investment resources and corresponding prices. $PINVT$ and $PINVTRD$ represent weighted average prices of both types of investments, calculated from the composite commodity prices. Parameters α_{INVT} and α_{INVTRD} are calibrated from the equation and represent a share of the respective investment type in total investment resources. In the benchmark period (2008) the parameters are $\alpha_{INVT} = 0.93$ $\alpha_{INVTRD} = 0.07$, showing a negligible share of R&D investments in total investment resources. In the following step, the demand

for individual investment goods is determined on the basis of fixed coefficients, calibrated from the SAM.

$$INVT = \frac{\alpha_{INVT} \cdot INVRES}{PINVT} \quad (4)$$

$$INVTRD = \frac{\alpha_{INVTRD} \cdot INVRES}{PINVTRD} \quad (5)$$

The allocation of investments into the production sectors is crucial for capturing the R&D effects in future periods. The CGE model follows a recursive form of dynamization, which is fully described in Křístková (2010,b). The investment allocation function is modelled following the Tobin's Q specification as used by Lemelin or Thorbecke:

$$\frac{ISi}{KS_i} = \gamma_i \left(\frac{RK_i}{USC_i} \right)^{\sigma_{IS}} \quad (6)$$

where ISi is the physical investment allocation per sector, KS_i is capital stock per sector, and (RK_i / USC_i) is the Tobin's Q ratio where RK_i represents the return to capital and USC_i are the respective user costs per sector. γ_i is a calibrated distribution parameter of the investment function, and parameter σ_{IS} is the elasticity of substitution which indicates the response of investments to the change in the Tobin's q value.

Equation (7) specifies that the proportion of new investment allocation to the capital stock in each sector (ISi/KS_i) is determined by the ratio of the return to capital and the respective sector's user cost of capital. Tobin's Q theory indicates that if the Q ratio > 1 , the particular sector will attract new investments since the expected profit from unit of capital exceeds its costs, whereas if Q ratio < 1 , there are pessimistic conditions for attracting new investments.

The allocation of R&D investments per sector ($ISRDi$) is arranged analogically to the physical investments:

$$\frac{ISRDi}{HS_i} = \gamma_i \left(\frac{RH_i}{USCRDi} \right)^{\sigma_{IS}}, \quad (7)$$

where HS_i represents knowledge stock per sector i , RH_i is the return to knowledge in the respective sector, $USCRDi$ are user costs of R&D capital. It is assumed that the elasticity of substitution is equal in both Tobin Q functions and reaches value $\sigma_{IS} = 2.5$ ⁴.

The calculation of return to capital follows the classical Return on Capital (ROC) calculation which is adopted on the sector level:

$$RK_i = \frac{PVA_i \cdot VA_i - PL_i \cdot (1 + pldiff_i) \cdot L_i - PH_i \cdot HS_i}{KS_i}, \quad (8)$$

where PVA_i is the price of net value added in the i -th sector, VA_i is net value added of the i -th sector, $PL_i \cdot (1 + pldiff_i)$ is the price index of labour adjusted for sector wage difference, L_i is the number of employees per sector i -th sector, HS_i and PH_i are stock of knowledge and knowledge price index respectively. The return to knowledge is calculated analogically.

⁴ For more discussion on the value of the Tobin Q elasticity and the corresponding sensitivity analysis see Křístková (2010, b).

The modified version of the CGE model contains two dynamic equations, which provide link between the amount of capital and knowledge stock in the current and following periods:

$$KS_{i,t+1} = (1 - sdep_i).KS_{i,t} + IS_{i,t}, \quad (9)$$

$$HS_{i,t+1} = (1 - sdepH_i).HS_{i,t} + ISR D_{i,t} \quad (10)$$

Equation 9 indicates that the amount of capital stock in the current period is determined by the depreciated amount of capital stock in the previous period, raised by the physical investments. Analogically, the stock of knowledge in the current period is determined by net R&D investments carried out in the previous period (equation 10).

2.3 Scenario definition

The modifications introduced into the CGE model enable now to properly address the impact of R&D investments on the Czech economy. More specifically, following research questions will be analysed:

1. What is the impact of the knowledge stock accumulation on the predicted economic growth in the Czech Republic?
2. What is the efficiency of R&D investments compared to physical investments?
3. What would be the impact of a potential increase of EU policy driven R&D investments on the macroeconomic behaviour and structural changes in the Czech economy?

In order to response the first research question, the CGE model was used in two different settings. In the first setting that represents *Model without knowledge*, the economy grows only on basis of the physical stock accumulation, which means that the dynamic knowledge stock equation (10) is excluded from the model. The results of this model represent a provisional baseline, against which the economic growth derived from the *Model with knowledge* that incorporates the dynamic knowledge stock equation (10) is compared. The second and the third research questions are analysed only within the Model with knowledge. Concerning the efficiency of R&D investments, the impact of different investment mix on the GDP is analysed. The third research question investigates the impact of R&D stimulating shock on the economy, induced by the EU policy aiming at supporting the expenditures on research and development.

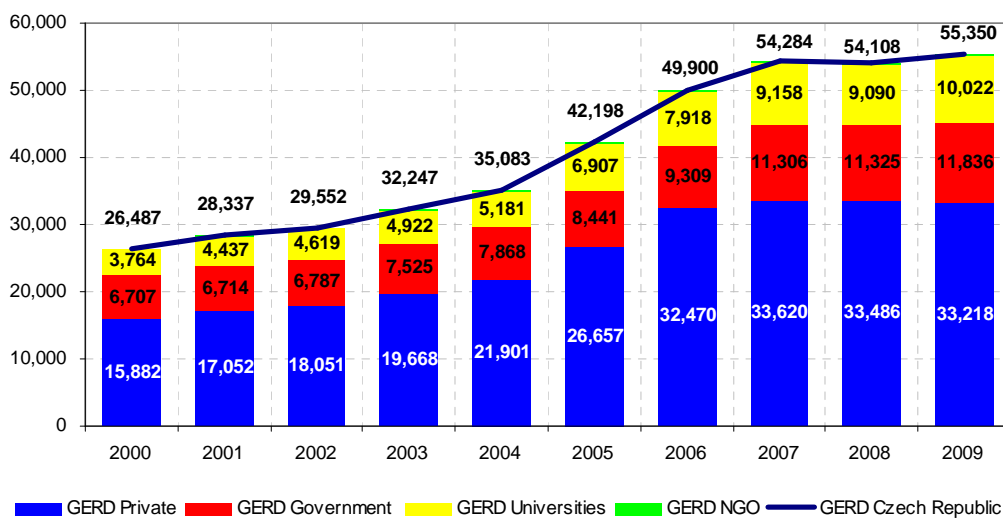
3. Overview of Research and Development expenditures in the Czech Republic

In this section, an overview of the total expenditures on research and development in the past 10 years is presented. This analysis is based on data provided by the Frascati manual surveys carried out by the Czech Statistical Office.

3.1 Overview of total Gross Expenditures on Research and Development

The overview of total R&D expenditures and their structure according to the performing sector provides Figure 4. In 2000, total gross expenditures (GERD) represented CZK 26 bln and at the end of the analysed period, GERD reached CZK 55 bln, which is a two-fold increase. Also, the share of R&D expenditures in GDP grew from 1.2% to 1.5%. It can be noted, that within 2007-2009, private research stagnated, which can be attributed to the economic and financial crisis. Such development is not observed in case of public research, where the increasing trend continued. Observing the structure of R&D expenditures, it can be observed that private GERD participate in total R&D expenditures with a stable share of 60%.

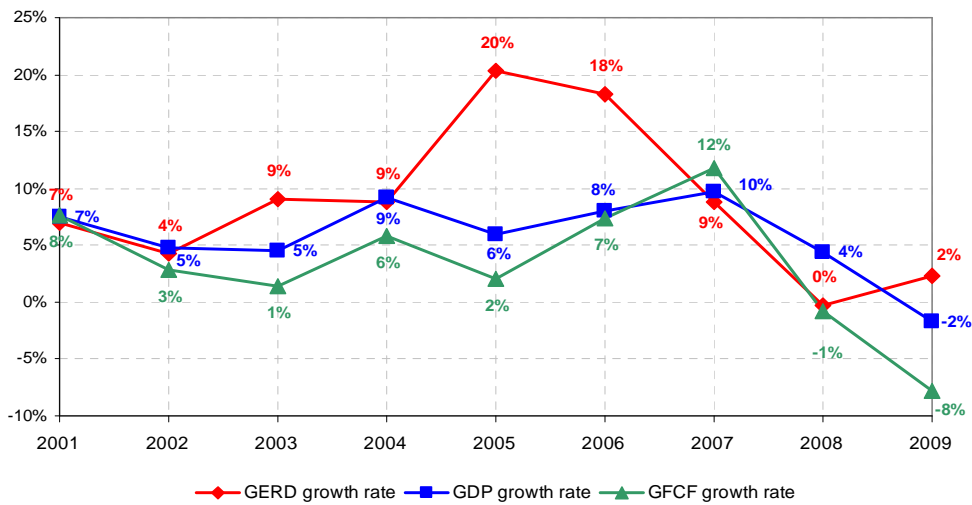
Figure 4: Overview of Gross R&D expenditures per performing sector (CZK mln.)



Data source: CZSO, Frascati Manual

Another point of view on the development of R&D expenditures provides Figure 5 where R&D growth rates are compared with growth rates of GDP and Gross Investments. Periods of excessive growth of R&D expenditures are noticed between 2002-2003 where GERD exceeded GDP growth by 4 percentage points and in the period 2004-2006, when R&D growth was even more than 10 percentage points above GDP growth. This development can be attributed to the accession of the Czech Republic to the European Union in 2004. Observing growth of expenditures before and after the EU accession, the highest increase can be attributed to university research (80% compared with pre-accession level), whereas the lowest increase occurred in case of the governmental research (47%). Private and NGO research was stimulated after EU accession by 72%.

Figure 5: Growth rates of GERD, GDP and Gross Fixed Capital Formation (calculated from current prices)

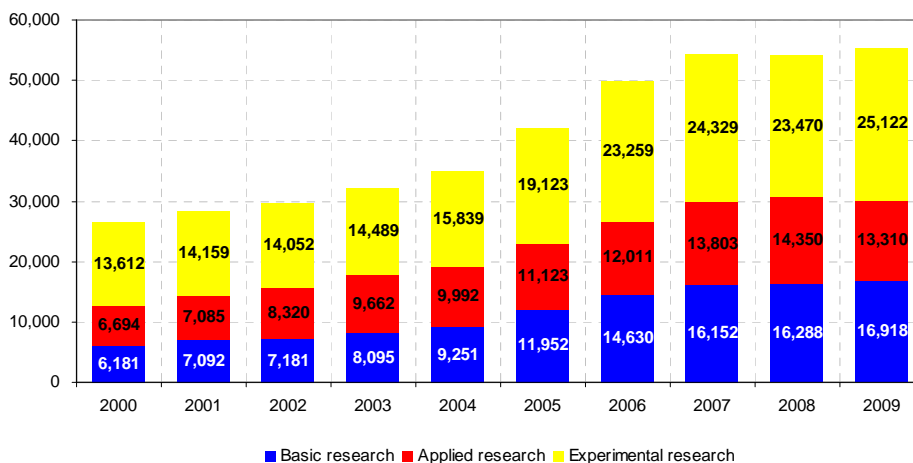


Data source: CZSO

3.2 Activities and areas of R&D

Another point of view on the expenditures on R&D provides Figure 6, where different R&D activities are demonstrated. In 2000, more than 50% of total GERD was devoted to experimental research. During the analysed period, the share of experimental research slightly decrease (45% in 2009), but it still represents the most important research area. Contrary to that, the basic research has seen an increasing share in total expenditures; whereas in 2000 basic research formed only 23% of GERD, in 2009 it was 31% and exceeded the participation of applied research, which remains at 25% share. This development is closely related to the increasing activity of universities within the total research and development.

Figure 6: Activities of Research and Development (CZK mln.)

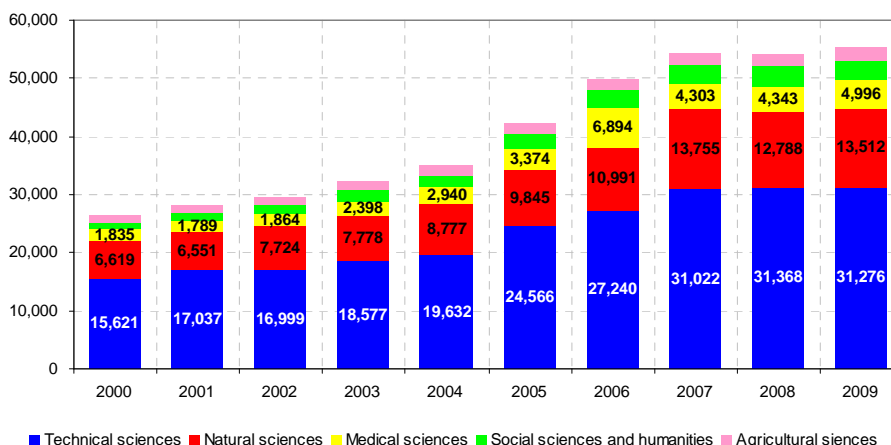


Data source: CZSO, Frascati Manual

According to the Frascati survey, it can be further stated that a substantial part of the R&D in the Czech Republic is performed in the area of technical sciences (almost 60%) (Figure 7). Other areas are

less significant, however it can be noted that after the EU accession in 2004, expenditures in medical and social sciences are growing faster.

Figure 7: Areas of Research and Development (CZK mln.)

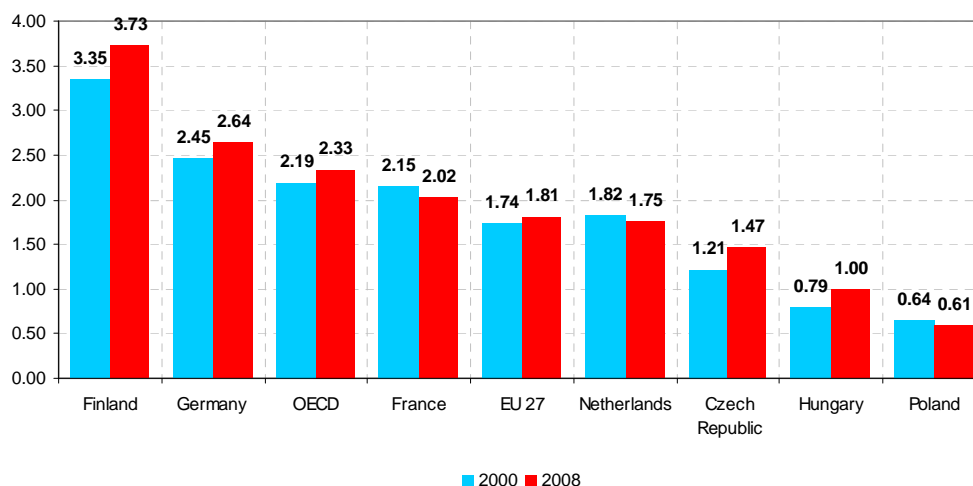


Data source: CZSO, Frascati Manual

3.3 R&D in international comparison

Figure 8 provides a comparison of GERD share in GDP among selected European countries and countries of OECD. From the group of countries, Finland reaches the highest share of R&D expenditures (3.7%), which is double compared to Czech Republic (1.47%). Other EU-15 countries report higher share as well, such as Germany (2.6%) or France (2.15%). The average EU-27 level is still above the Czech Republic (1.81%), even larger is the gap with the average OECD standard (2.3%). However, comparing to other newly accessed EU countries such as Hungary and Poland, the GERD expenditures in the Czech Republic are relatively high.

Figure 8: Share of GERD in GDP in selected countries



Data source: CZSO, Frascati Manual

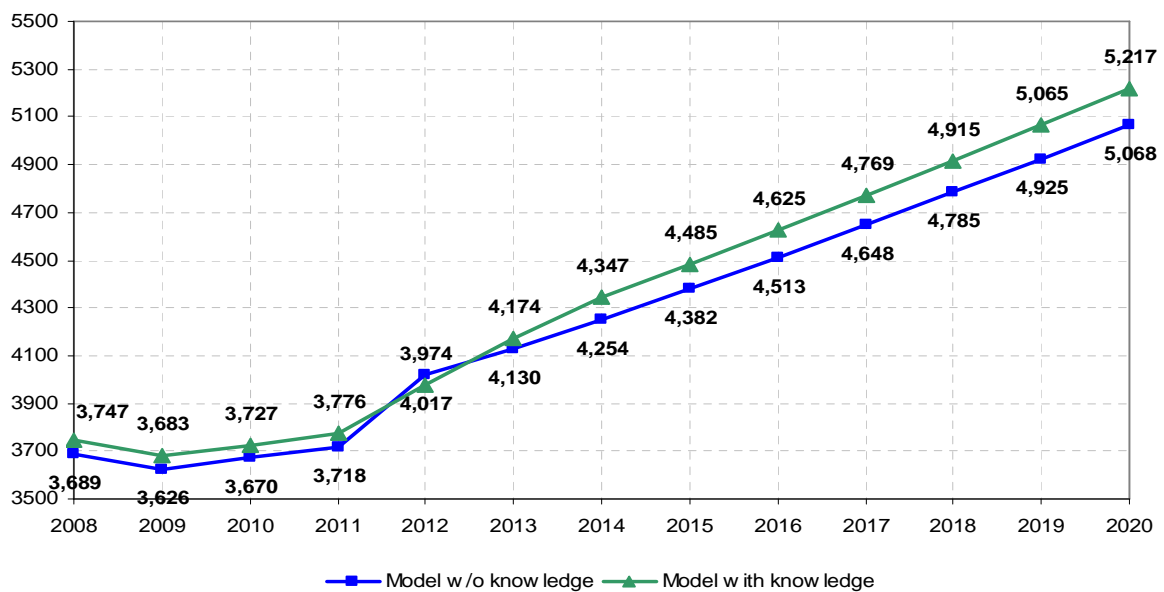
4. Simulation results

4.1 Impact of R&D capitalization on the dynamics of economic growth

In this chapter, the effect of knowledge accumulation driven by the R&D investments on the dynamics of the economic growth is investigated. For this purpose, two models - one which includes knowledge capitalization and one in which knowledge is omitted - are analysed and their macroeconomic behaviour compared.

According to the endogenous growth theory, it is expected that the inclusion of knowledge will have a positive impact on the economic growth. This hypothesis is confirmed observing development of nominal GDP values in the two respective models (Figure 9). However, due to the inclusion of the R&D investments into GDP in the initial period, the benchmark equilibrium states in the two models slightly differ. Therefore, it is not possible to fully compare the two GDP indicators in their nominal values, rather to assess their relative performance in form of growth rates.

Figure 9: Comparison of nominal GDP (CZK bln., c.p.) in models with and without knowledge



Source: author's calculations

GDP growth rates of both models are presented in Table 2. The development of GDP growth is affected by the financial and economic crisis; in 2009 GDP declines by 4%, followed by a slow growth in years 2010 and 2011. From 2012, the model without knowledge reports higher GDP growth rates, but the dynamics of the model is soon slowed down. Contrary to that, GDP growth rates in model with knowledge report lower revival in 2012 but already from 2013, they exceed growth rates from model without knowledge.

Table 2: GDP growth rates of both models

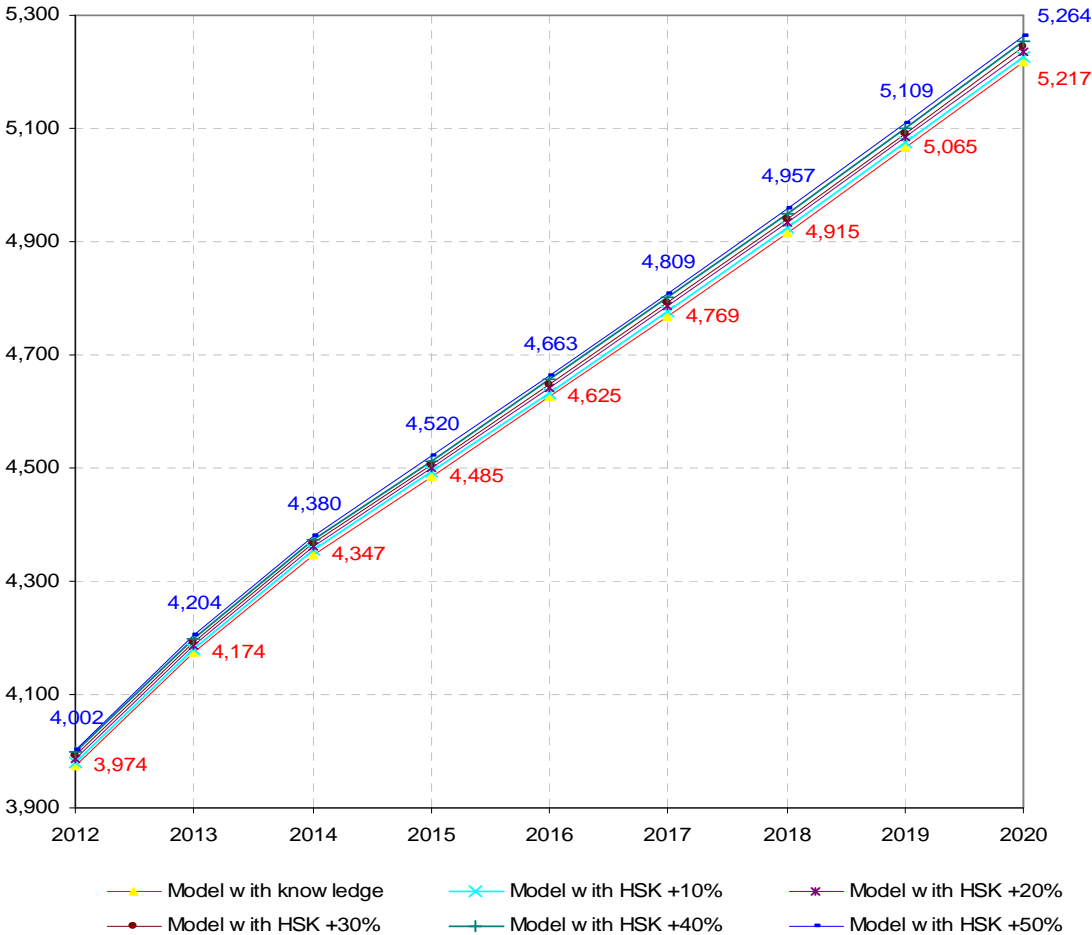
t	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Model w/o knowledge	-4.20%	2.30%	1.90%	5.27%	1.24%	1.19%	1.20%	1.19%	1.17%	1.15%	1.12%	1.09%	1.71%
Model with knowledge	-4.20%	2.30%	1.90%	2.54%	3.43%	2.31%	1.37%	1.31%	1.29%	1.26%	1.23%	1.19%	1.83%

Source: author's calculations

Even though Table 2 confirms the initial expectation that knowledge based CGE model provides higher GDP growth rates, the impact is surprisingly very small. It can be concluded that capitalization of knowledge can trigger average growth rates only by 0.12 percentage points. On the other hand, this finding is plausible if we take into account that in the benchmark period, the share of knowledge in total gross value added is estimated at 5% level, with considerable differences per sectors; the car industry sector and the sector of R&D employ 10% of knowledge in total value added, in most other sectors, knowledge accounts for less than 1% of GVA.

The importance of initial knowledge stock is further examined in an exercise which considers increasing knowledge stock gradually by additional 10%. The impact of this simulation on GDP is displayed in Figure 10. It is found out that with growing knowledge stock endowment, the economic growth can be accelerated. However, even the model with 50% higher knowledge stock stimulates GDP growth only by a negligible rate.

Figure 10: Simulation of increasing Knowledge stock (HSK) by 10% (GDP bln. CZK, c.p.)

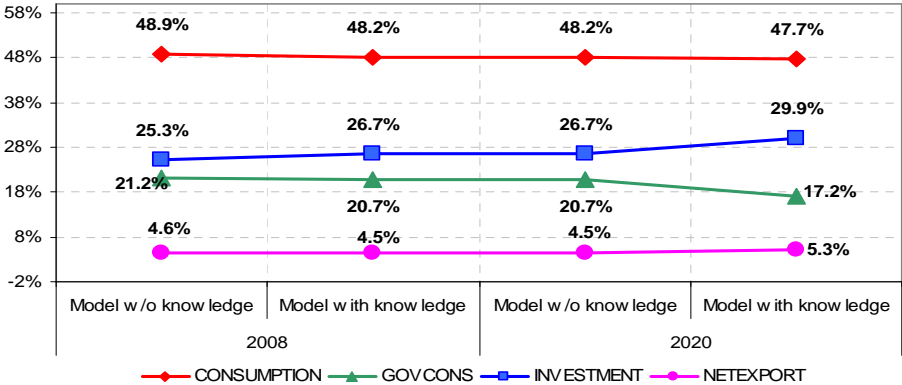


Source: author's calculations

The two different dynamic models also offer to investigate the structural changes that accompany knowledge capitalization (Figure 11). First of all, the effects on GDP components are analysed. In

2008, the structure of GDP is almost identical in both models. In the process of knowledge and capital accumulation, the structure of GDP is slightly changed. In 2020, model with knowledge has higher share of investments and net exports compared to model without knowledge. It can be concluded that including knowledge into the capital formation reduces the share of final consumption on account of investments.

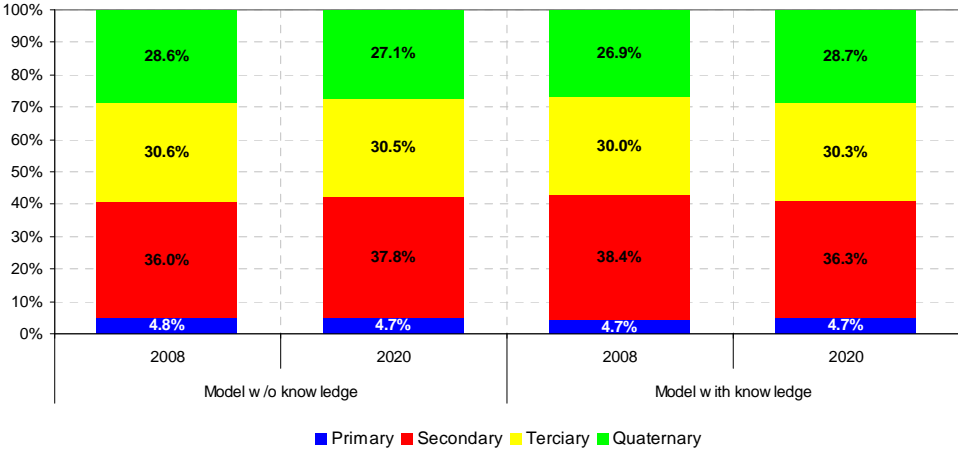
Figure 11: Impact of model dynamisation on GDP components



Source: author's calculations

The impact of different dynamisation forms compared in this paper is also analysed with respect to structure of the economy. In the developed economies, the share of primary sector (agriculture and mining) and secondary sector (processing industry and construction) is less significant compared to the tertiary sector represented by services such as banking and commerce. In the most developed economies, the accent is also put on the quaternary sector, which represents knowledge economy. This sector includes education, health care, research and development and governmental services.

Figure 12: Structural changes in the economy under both types of models



Source: author's calculations

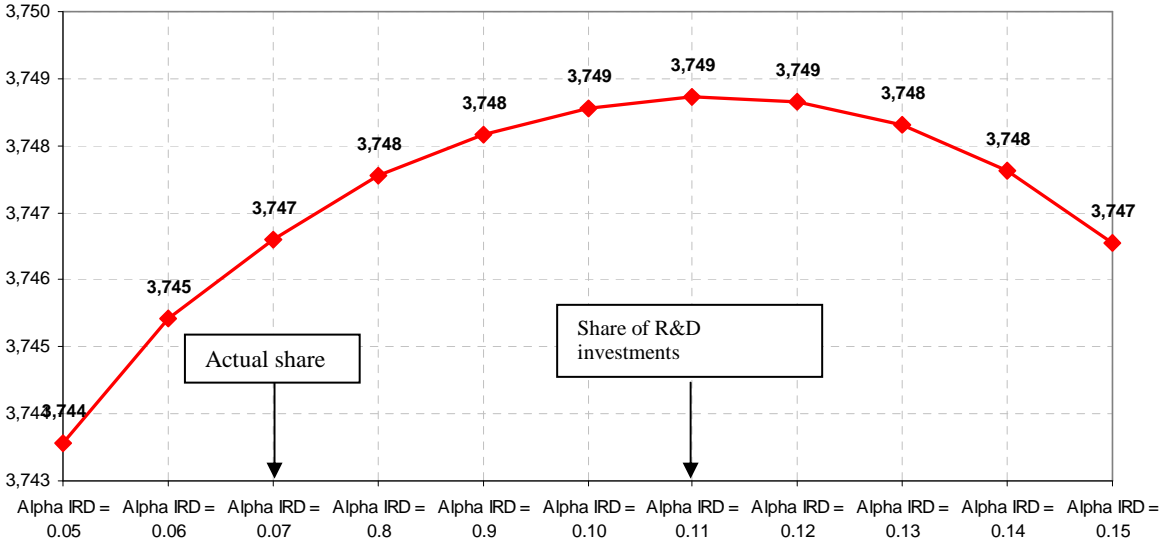
Figure 12 shows how this structure develops over time under the two dynamic models. In case of model without knowledge, the share of quaternary services slightly declines in favour of the secondary sector. This is attributed to high representation of industrial goods in total investments. In particular, the construction sector produces 50% of investment commodities, 23% is produced in the machinery and equipment sector. On the other hand, in the model with knowledge, the tertiary and quaternary

services increase their share in value added at the expense of the secondary sector. This leads to the conclusion that the CGE models which omit knowledge in their dynamisation slightly overestimate growth of secondary sector over time, at the expense of services.

4.2 The efficiency of R&D investments vs. Physical Investments

The last finding on the positive effect of knowledge accumulation on the structure of the economy leads to investigate another issue which is the efficiency of R&D investments. Hence, would it be more desirable to invest to R&D commodities such as innovations, patents or research papers instead of investing to capital goods such as constructions or machinery? Following simulation examines this issue by varying the Cobb-Douglas parameter that indicates the share of R&D investments in total investment resources. It should be pointed out, that in this exercise the increase of R&D investments is at the expense of physical investments in order to maintain equilibrium between total investment resources and their use. The results of the simulation are provided in Figure 13.

Figure 13: Static effects of different R&D investment shares on GDP (bln. CZK, c.p.)



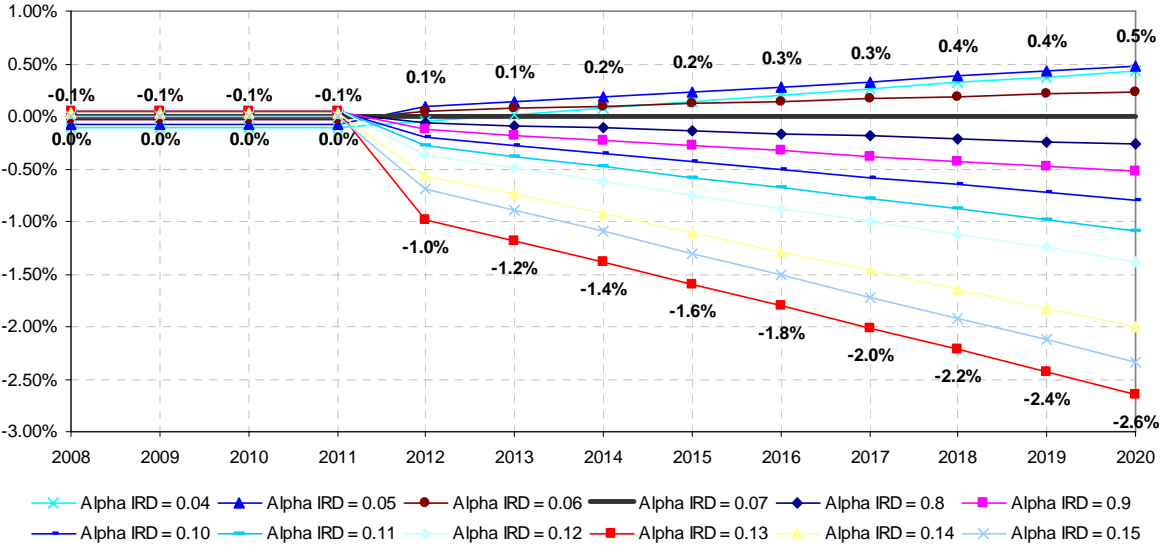
Source: author's calculations

The benchmark GDP level reaches CZK 3,747 bln, corresponding to Alpha IRD equal to 0.07. Figure 13 clearly demonstrates that a small increase of parameter alpha IRD and thus of the share of R&D investments can have a positive effect on GDP. GDP continues to grow until it reaches a peak after which too excessive level of R&D investments can be harmful for the economy. It can be noted that the peak is exactly in the point that corresponds to the OECD level of R&D investments, measured as a percentage of GDD. On the other hand, if the parameter Alpha IRD is reduced, a slight decline in GDP can be expected.

Nevertheless, it is maybe more useful to analyse the efficiency of the R&D investments in the longer run, and see if the static results hold also in the dynamic model. According to Figure 14, any increase

of R&D investment share in the long run causes a decline of GDP. Therefore, there is a certain contradiction between results of static and dynamic model. Whereas in the static model, certain increase of R&D share can be positive for the economy, in the long run, any positive deviation from this share can cause a GDP decline. The extreme case of AlphaIRD parameter reaching 0.15 shows that GDP in 2020 would be 2.6 % points bellow baseline. Another extreme case is considered with Alpha IRD= 0.04 in which the share of R&D investments is reduced⁵. In this case, GDP can reach 0.5% points more than baseline.

Figure 14: Dynamic effects of different R&D investment shares on GDP
Percentage deviation from baseline – AlphaIRD =0.07



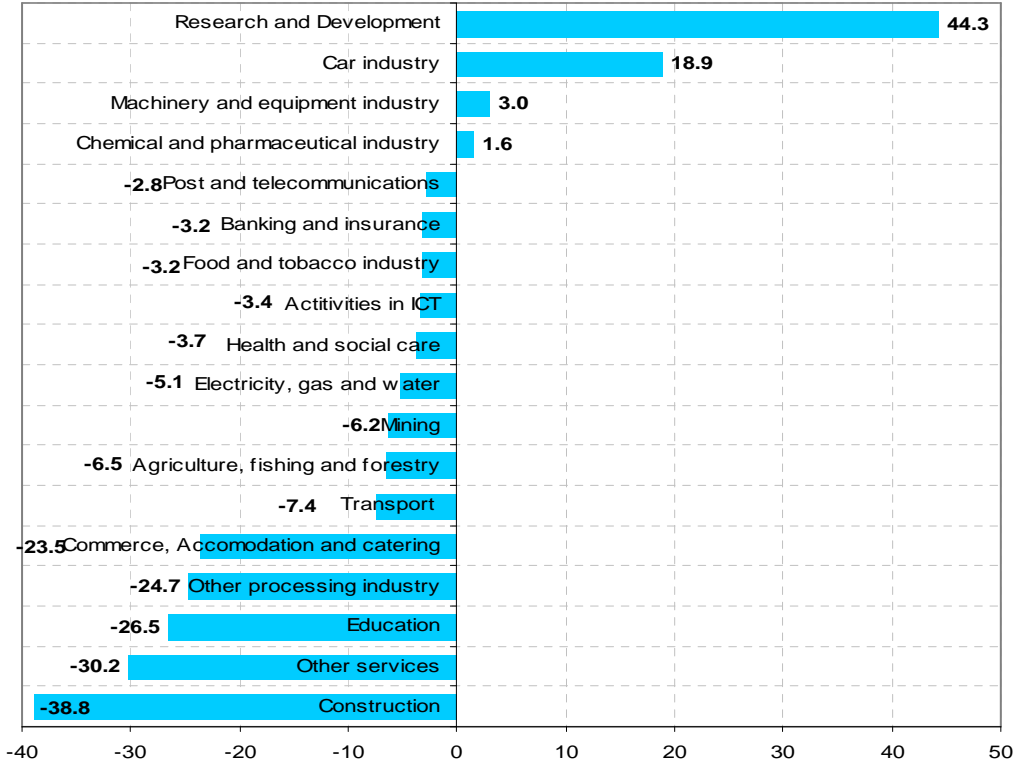
Source: author's calculations

This contradictory finding requires analysing the cause of the GDP decline under changing proportions of investments in favour of R&D. Particularly, the structure of the economy is examined under the two extreme cases, considering R&D investment share 15% and 4%. With the use of the absolute deviations, value added per sector in final year of the analysed period is compared. The results reported in Figure 15 leads to finding that there are substantial structural differences in the economy under both extreme situations. Considering R&D investment share on 15% level, an excessive increase of R&D sector (+44 bln.) and car industry (+19 bln) is reported. Except for the machinery and chemical and pharmaceutical sector which also benefit from higher R&D investment share, all other sectors of the economy have a smaller size compared to the model with lower R&D investments. The strongest decline of value added can be observed in case of the construction sector (-40 bln.) and the sector of other services (-30 bln.). Based on these findings it can be concluded that the stimulation of R&D investments at the expense of the physical investments produces suboptimal allocation of resources. Apparently, the major sectors producing R&D investment commodity such as the R&D sector or the car industry cannot stimulate economic growth at the same extent as the other sectors of the economy, namely the construction, other services or processing industry. One of the

⁵ The model cannot be run with simulations lower than alphaIRD=0.04.

reasons is a high specialization of particular sectors on production of capital goods for which even a small decline in investment demand may negatively affect their production results. According to the situation in 2008, such sector is for instance construction, where more than 50% of production is designated for investment goods.

Figure 15: Absolute difference of value added in 2020 (bln. CZK, s.p.2008)
Alpha IRD=0.15 vs. Alpha IRD =0.04



Source: author's calculations

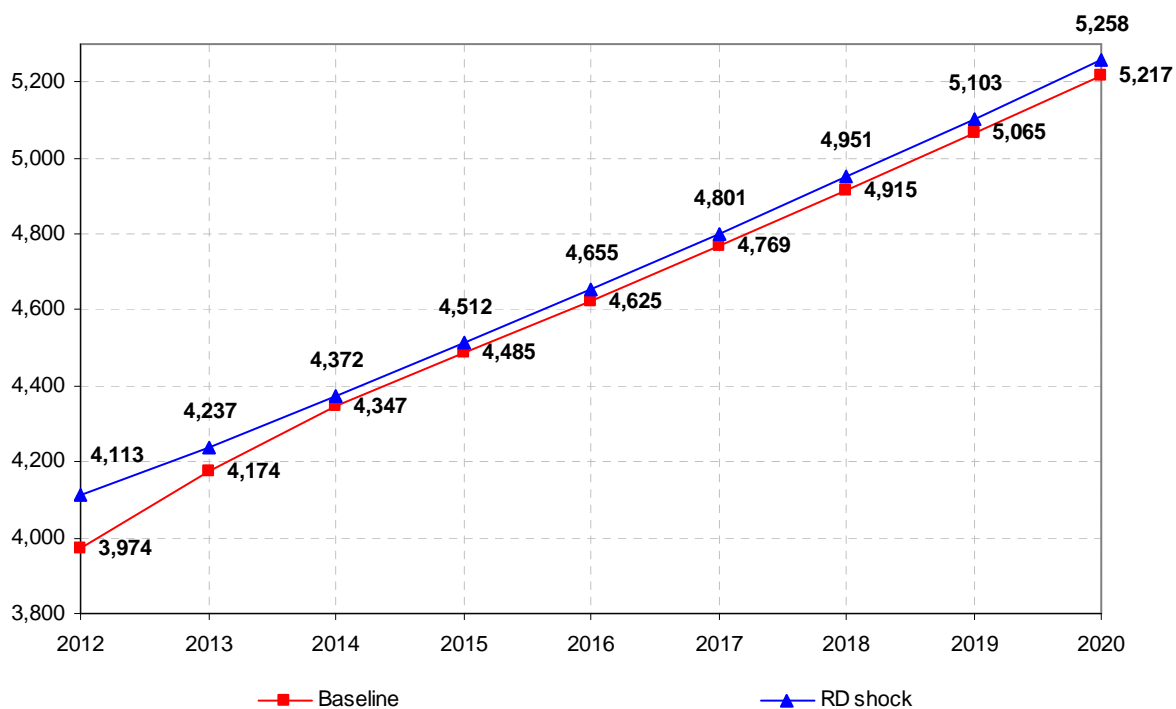
4.3 Impact of R&D stimulating shock on the economy

As the results of the previous chapter show, it is not possible to expect positive impact of R&D investments if these are stimulated at the expense of the physical investments. Even though in short term this might be beneficial, in the long term this trade off can decelerate the economic growth. Therefore, in the last simulation, an exogenous R&D shock that directly increases the investment resources for R&D goods is incorporated in the model and its impact on the economic growth is calculated. In this exercise, it is assumed that in compliance with the EU Strategy 2020, there is an inflow of the EU support to the Czech economy, which is directed to investment resources in R&D. This simulation is produced in the benchmark period, and its short and long-term impacts are analysed. In the simulation, the R&D investment resources increase by 25 bln. CZK, which raises the total R&D investments in the Czech Republic to the OECD level, measured in terms of the share in GDP. Furthermore, it is approximately the same amount as the total subsidies distributed to Czech farmers from the EU Common Agricultural Policy budget. This gives the idea about the size of the

simulation, which is comparable to a size devoted to the support of a specific resort of the national economy.

Figure 16 shows changes in GDP produced by the simulation. It can be noted that increasing foreign investment resources for R&D can lead to a higher GDP level at the end of the analysed period (1% increase)⁶.

Figure 16: Impact of R&D stimulating shock on GDP (bln. CZK, c.p. 2008)



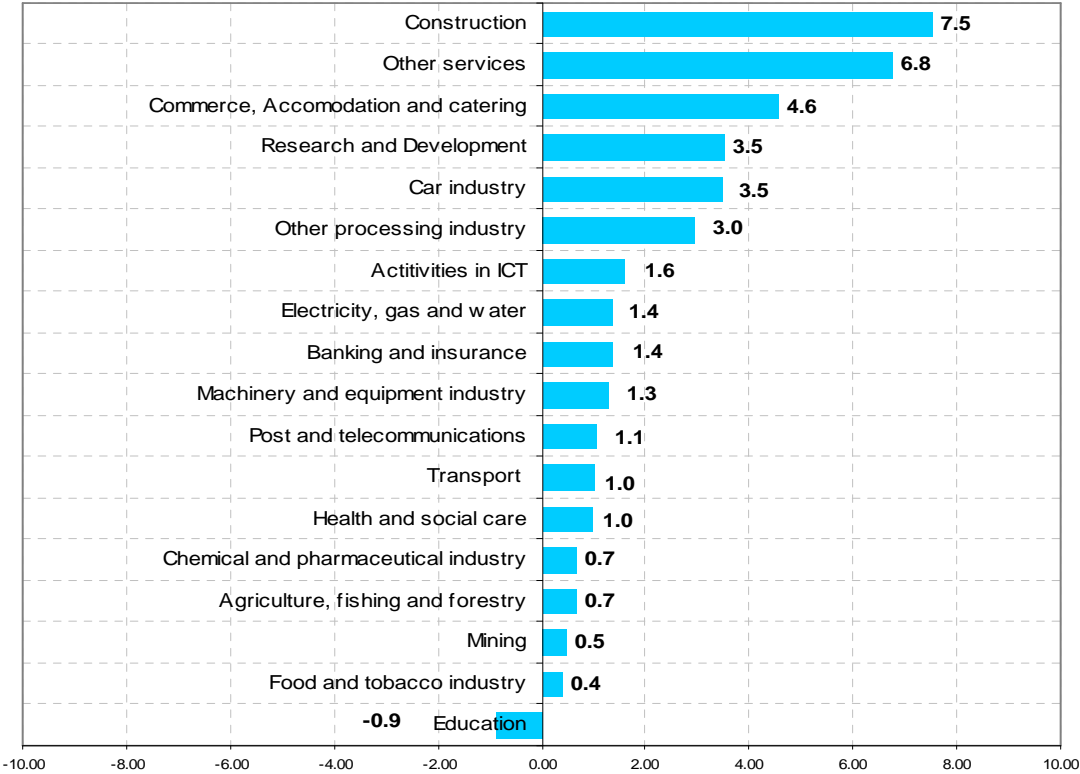
Source: author's calculations

Despite such a small impact on growth, for some particular sectors, the increase of R&D investment resources can be important. As seen in Figure 17, production across all sectors of the economy is stimulated, except for education. Sectors of construction and other services, which include also real estate and recreation increase gross value added by 7% with respect to baseline, which are the sectors with high capital stock accumulation. Notable stimulation of value added (+4% vs. baseline) is also reached in sectors of R&D and car industry, which is explained by a high share of knowledge in their value added. The remaining sectors are also better-off, particularly other services sectors, the primary sectors such as mining and agriculture also to a lesser extent. Surprisingly, the sector of education seems to be negatively hit by the R&D induced shock. This is explained by the fact that the R&D stimulating shock leads to an increased demand for public and private R&D commodity, raising their respective prices. Because public R&D commodity is partially produced by the education sector, this price inflation is transmitted to other commodities produced by the education sector as well, which is mainly the education commodity itself. As the education is predominantly consumed by government, following the Cobb-Douglas consumption function, there is an immediate decrease of governmental consumption and proportional reduction of the total aggregate demand for education. To summarize

⁶ Simulations concerning a parallel removal of subsidies in agriculture corresponding to the value of additional investment R&D resources showed no impact on the economic growth.

these effects, the decline of value added in education is a result of two contradictory forces, first the R&D investment demand stimulating education sector in the production of research commodity, second the decline of governmental demand reducing the outcome of education sector, which overweighs the positive effect⁷.

Figure 16: Impact of R&D stimulating shock on Gross Value Added (c.p. 2008)
Absolute difference in bln. CZK



Source: author's calculations

Changes are also produced concerning the structure of GDP expenditures. Table 3 reports the aggregate consumption, investments, exports and imports in the baseline and R&D shock scenario. Values are reported in 2020 both in current prices and also in percentage and absolute differences. The stimulation of R&D investments has the highest impact on investments which are directly linked to the performed simulation. However, it can be also observed that the R&D simulation produces a notable growth of imports, which acts negatively on the GDP. When analysing the import structure it is found out, that the increase of imports is driven predominantly by five investment commodities, which are the machinery and equipment, automobiles and other industrial goods, to a lesser extent the R&D private commodity and the pharmaceuticals (Figure 17). This finding is closely linked to a high share of imported commodities in total investment goods. Thus, any increase of investment demand is going to require more imported commodities and will offset the positive effect on the GDP.

⁷ In 2020, 84% of total commodity production in the education sector is attributed to education; the remaining 14% is the R&D commodity. 75% of education services are consumed directly by government in 2020.

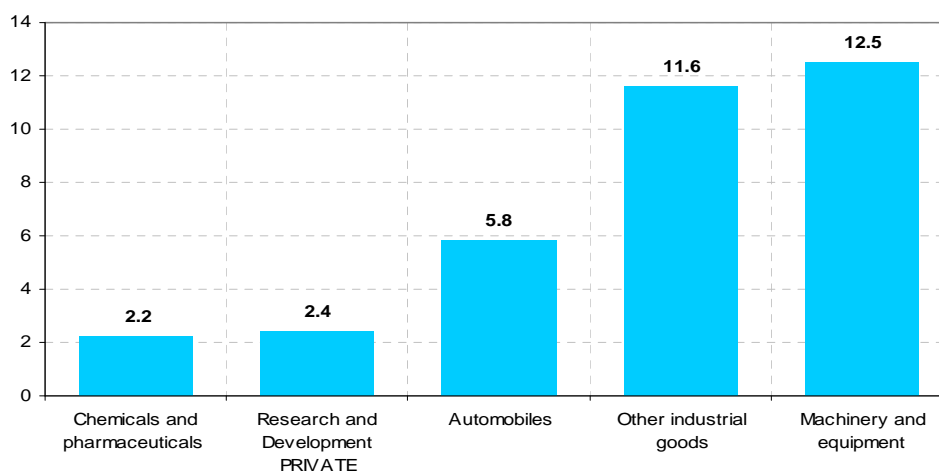
Regarding aggregate consumption and exports, the changes produced by the R&D simulation are comparable and both are positive.

Table 3: Impact of R&D shock on GDP components (2020)

GDP components 2020	Baseline R&D CZK bln. (c.p.)	R&D shock CZK bln. (c.p.)	% Difference vs. Baseline	Absolute Diff. Vs. Baseline
CONSUMPTION	2,486	2,491	0.2%	5
GOVCONS	895	900	0.6%	5
INVESTMENT	1,561	1,615	3.4%	54
EXPORTS	3,927	3,932	0.1%	5
IMPORTS	3,652	3,680	0.8%	28

Source: author's calculations

**Figure 17: Five imported commodities with highest absolute increase vs. Baseline
(bln. CZK, c.p. 2008)**



Source: author's calculations

Finally, the impact on the situation of households is investigated (Table 4). It can be noted that the stimulation of R&D investments can lead to a positive effect on labour market, the unemployment rate decreases by 1.2%. Furthermore, the welfare of households measured by equivalent variation is increased by 1.5% compared to baseline.

Table 4: Impact of R&D stimulating shock on households in 2020 (bln. CZK)

	Baseline R&D	R&D shock	% Difference vs. Baseline
Unemployment (thous of workers)	273	270	-1.2%
Household Income (CZK bln.)	3774	3782	0.2%
Equivalent Variation (CZK bln.)	712	723	1.5%

Source: author's calculations

5. Discussion and conclusions

This paper investigated the effect of R&D investments on the economic growth from two perspectives, the methodological perspective and the economic perspective. From the methodological perspective, the aim was to assess what would be the impact on results of a CGE model with R&D investments and knowledge accumulation, compared to results of a CGE model without knowledge. From the economic perspective, the aim was to analyse the role that R&D plays in the Czech economy and to derive corresponding conclusions. In order to gain satisfactory insights, the R&D investments were analysed with respect to their impact on GDP and other macroeconomic variables, furthermore with respect to their efficiency compared to physical investments. Finally, the R&D effects were examined in a scenario which leads to an increase of R&D investments to reach the OECD level.

With respect to the role of knowledge in the dynamisation of the CGE model, the paper showed that there are only minor effects on the GDP compared to results of the model that excludes knowledge. This finding is of course influenced by the length of the analysed period. In this paper, the model provides solutions until 2020, if this period is extended the impacts could be more pronounced, as for instance in Zürn et al. (2007) who derive 1.2% GDP effects in 2020 and 1.8% in 2030. Additional analysis further showed that higher initial knowledge endowment can increase the role of knowledge in the economic growth. Nevertheless, the importance of knowledge inclusion does not necessarily lay in the dynamics of economic growth but rather in its effect on the structure of the economy. The analysis showed that CGE model without knowledge overestimated the secondary sector in the longer run, at the expense of services.

Regarding the efficiency of the R&D investments, it was concluded that investing more to R&D on account of capital goods can bring positive effects only temporarily. From the longer run, the CGE model shows that R&D investments are less efficient in producing value added compared to investments to capital goods. This finding suggests that the effects of R&D are still not properly captured in the presented CGE format and it confirms the necessity to carry out more thorough research with the use of the firm-level data. Particularly, the econometric estimates would enable to assess the effect of R&D investments on the companies' Total Factor Productivity and determine the type of technological progress. Furthermore, it seems that the model should also incorporate R&D spill-over effects from abroad, which in case of the Czech Republic being a small opened economy with a considerable share of FDI investments might be very relevant, as further analysed in Lejour and Rojas-Romagosa (2008).

Despite its rather simplistic approach, the CGE model revealed some interesting insights into the role of R&D investments in the Czech economy. It was found out that if R&D investments are stimulated as a result of the EU efforts for smart and sustainable growth, positive effects on all GDP components can be expected. Furthermore, these positive effects are translated across most of industries and services. The negative impact on trade balance as a consequence of increased demand for imported capital goods is offset by a reduced unemployment rate and higher consumer welfare.

Acknowledgement

The results of this paper are part of a research grant of the Czech Science Foundation “ Evaluation of Research and Development Effects on the Economic Growth of the Czech Republic with the Use of a Computable General Equilibrium model“.

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