Analysis of private R&D effects in a CGE model with capital varieties, case of the Czech Republic

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Abstract

In view of the increasing importance of private research in the Czech economy and elsewhere in Europe, this paper attempts to quantify the effect of private R&D on economic growth by applying a Computable General Equilibrium (CGE) model which incorporates the effects of capital varieties following Romer´s theory of endogenous growth.

It was discovered that the dynamics of GDP growth is positively related to the production of capital varieties and the elasticity of substitution between homogenous and variety capital. For the Czech Republic, a small and export-oriented economy, support for private R&D can be particularly beneficial since it stimulates the exports of important industries. However, with regard to households, a policy of stimulating R&D could cause short term adverse effects due to growing unemployment, resulting from the substitution of labour for capital varieties.

By performing scenario analysis in a CGE model with capital varieties as well as a standard CGE model, the paper also argues that the ommission of R&D effects in the CGE model could cause a simulation bias reaching 1% of GDP.

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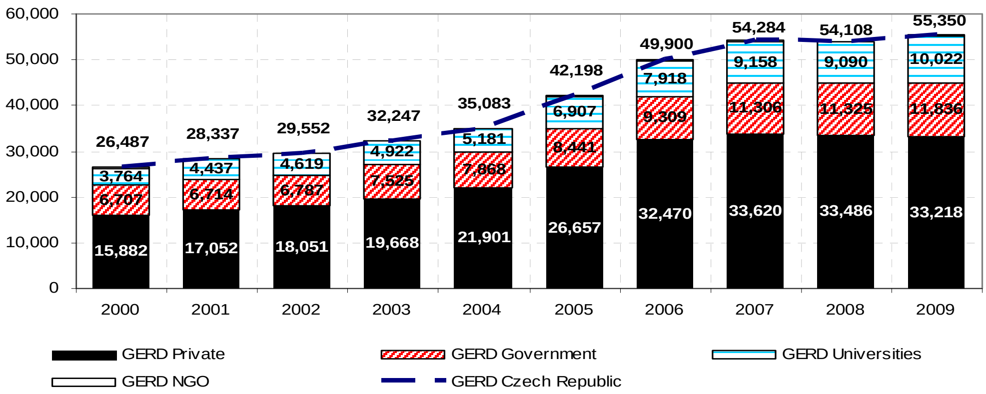
Keywords: research and development, capital varieties, CGE model, economic growth, monopolistic competition, subsidies, Czech Republic

JEL category: C 68, D 58, O3, O4

1. Introduction and objectives

The lack of competitiveness of European economies, together with the increasing attention being given to research and innovation in our society, call for the development of analytical approaches that help us to understand the contribution of R&D to economic growth, and enable governments to efficiently allocate resources. The Czech Republic is a small, open economy with broad ties to its EU neighbours, and has gone through processes of both transition and integration. In the course of these processes, competitiveness in the economy has been established primarily in export-driven industries, which are increasingly dependent on the adoption of new and innovative technologies. This can be easily observed in the evolution of R&D expenditures, which have doubled in the last decade (Figure 1). R&D carried out by the private sector represents the dominant share of total research expenditures in this period, with the biggest contribution coming from the automotive and machinery industries.

Figure 1: Overview of gross R&D expenditures per performing sector (CZK m)



Data source: Frascati Manual data from CSO (2011)

In view of the increasing importance of private research in the Czech economy and elsewhere in Europe, this paper attempts to quantify the effects of private R&D on economic growth by applying a Computable General Equilibrium (CGE) model, which incorporates the effects of capital varieties and follows Romer´s theory of endogenous growth.

The paper elaborates on the hypothesis that in the field of Research and Development, standard CGE models do not properly capture R&D effects (as shown, e.g., in Kristkova, 2011) for several reasons. First of all, until now the

R&D sector has been under-represented in the national accounts[1]. Secondly, standard CGE models usually treat the R&D sector as a final goods sector, and thereby fail to capture its productivity effects and its ability to create public goods.

Given these shortcomings, this paper investigates how the results obtained with standard CGE models can be improved by incorporating the effects of capital varieties produced by the private R&D sector, in a recursively-dynamic CGE model built for the economy of the Czech Republic.

The paper is structured as follows: in the second section, a review of approaches to modelling R&D investments in CGE models is provided, followed by a description of the methodological approach applied in this paper. The fourth chapter includes the results of the simulations. First, the economic growth predicted by a model with capital varieties is compared to a standard CGE model, and the impact is also analysed with respect to different substitution elasticities. Next, the CGE model is applied in various simulations centred on the efficiency of R&D subsidies compared to subsidies allocated to an alternative final goods sector. The chapter containing results is followed by a discussion and conclusion.

2. Endogenous growth theory in CGE models – review of approaches

The original work of Paul Romer (1990), who is considered the main representative of the endogenous growth theory, is based on the assumption that research and development produces innovative ideas that – through the capital goods sector - are converted into new capital varieties. The outstanding feature of Romer's model is that capital varieties, as opposed to other production factors such as homogenous capital or labour, bring increasing returns to scale. This is related to the "public goods" nature of R&D – non-rivalry and partial non-excludability. It follows that the application of a new capital design in one production sector does not limit its chances to be used in another production sector, thereby yielding increased returns. However, as most innovative activity is undertaken by private agents with the expectation of economic gain, the innovative efforts of those private agents must be properly protected (Schmidt, 2003). Patents and licences are concrete examples of this, and they make the results of the R&D sector partially excludable.

According to Romer's model of endogenous growth, new ideas in the form of patents are sold to the capital goods sector, and represent fixed costs for capital goods producers. In the presence of perfect competition, where producer prices are equal to marginal costs, capital goods producers would face a loss, and there

[1] According to Kristkova (2011), the appropriate representation of the R&D sector in SNA could be underestimated by a factor of 2.5.

would be no demand for new ideas. Therefore, the market for capital varieties is characterized by monopolistic competition, where capital goods producers purchase patents for a fixed price, and sell capital varieties for a price higher than their marginal costs. The demand for new capital varieties is represented by a Dixit-Stiglitz ‘love of variety’ function that allows for a certain level of substitution between the varieties.

The assumptions of Romer’s model are highly stylized. First of all, the existence of an intermediate capital goods sector, which easily converts homogenous capital into varieties, provides certain challenges to incorporating such a sector into the CGE model, given that CGE models usually model only final goods sectors. This is also related to their representation in input-output tables and SAM. The second stylization of Romer’s model is based on the assumption that each firm in the capital goods sector converts exactly one design (patent) into a variety. Since production technology is symmetrical for all companies, their productivity and the quantity of each variety produced is equal, which also leads to price equalization across all varieties.

Thirdly, the idea of the existence of a unique R&D sector that is engaged in producing new ideas is rather abstract - for one thing, almost every type of industry carries out its own private R&D activity, so R&D is not actually one single homogenous production sector. In addition, the value of the R&D sector as recorded in national accounts (or recorded in the Frascati database) is based on gross expenditures on R&D, which is not in line with Romer’s evaluation of R&D results according to the production of new ideas that are patented. The problem with the patent approach to valuating R&D is that only those patents that are converted into licenses bring explicit revenues to R&D firms. The value of non-licensed patents must be estimated implicitly.

Despite these challenges, various authors have attempted to translate the endogenous growth model into the CGE framework. According to Zürn et al. (2007), CGE models are able to capture 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 CGE models are especially appropriate for the top-down modelling of technical change with a particular focus on investment in R&D (Wang and Chen, 2006; Peace and Weyant, 2008).

One of the earliest contributions on implementing endogenous growth theory into a CGE model can be found in work dealing with Japan done by Diao, Roe and Yeldan (1999), in which they considered monopolistic competition in the variety capital sector, and the effect of international spillovers on the productivity of the R&D sector. The model is based on intertemporal dynamisation, which allows the monopolistic firms to choose the extent of R&D that will maximize their profit.

A more recent version of Diao, Roe and Yeldan´s approach is presented by Madanmohan Ghosh (2007), who studied R&D effects on the Canadian economy. Gosh applies Romer's ideas through the intertemporal dynamic equilibrium model, yet with highly aggregated production sectors.

The most recent application within the CGE framework can be found in Bye, Fæhn and Heggedal (2009), and Bye, Jacobsen (2011), from the Norwegian statistical office. The authors developed a CGE model with one R&D sector, one variety-capital industry, and 16 final goods industries. A detailed documentation of the model and its calibration is presented in Bye, Fæhn, Heggedal, Jacobsen and Strøm (2008).

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 may have severe repercussions in longer time horizons. For this reason, CGE models have gained popularity among policymakers in the Czech Republic, particularly in the field of natural resources and the environment. In conjunction with prepared environmental tax reform, the Czech ministry of the environment has applied a dynamic CGE model for the quantification of environmental policy impact on macroeconomic aggregates (Pavel, 2008). The macroeconomic effects of the environmental taxation were further analysed in Ščasný, Píša, Pollot et al. (2009) who applied structural macroeconometric E3M3 European model adjusted to the Czech economy. In the structural equations, R&D investment in the energy sector is incorporated to improve its efficiency. Another CGE model applied in relation to natural resources is the model developed at the Czech National Bank in cooperation with the Netherlands Bureau of Policy Analysis (Dybczak and van der Windt, 2008) which has been used to predict the effects of oil price shocks on the Czech economy. Concerning fiscal policy, Hurník (2004) applied 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 investment and knowledge formation as related to the endogenous growth theory has not been sufficiently analysed in the Czech Republic, at least not within the CGE framework. It should be noted, however, that there is an extensive body of research modelling the endogenous growth and knowledge accumulation using other approaches, see for instance Kejak, Seiter and Vávra (2004) or Kejak and Vávra (2002), who developed a two-sector endogenous growth model to assess the transitional behaviour after the EU accession in the CEEC countries including the Czech Republic.

3. Description of the modelling approach applied in the paper

The R&D activities are modelled in the form of two specific R&D production sectors – private and public R&D. In line with Romer's idea, it is assumed that the private R&D sector represents the research efforts of private businesses to produce new designs. However, as opposed to the original setting, there is no explicit distinction between the private R&D sector and the variety-capital goods sector. Following the Dixit-Stiglitz approach of modelling the production of varieties (such as Bye et al., cited above), it is assumed that companies involved in private R&D operate in an environment of monopolistic competition – each R&D firm produces a different design and therefore a different variety of capital.

The public R&D sector is not involved in the production of capital varieties, but it does produce general knowledge that subsequently enters the production processes of both public and private R&D as a specific production factor. Thus, public R&D activities directly increase the total factor productivity of the public R&D sector, and they also provide positive spillover into the private R&D sector.

Table 1: List of production sectors included in the CGE model

SAM 2008	OKEČ (NACE)	sectors in SAM	Set
Agriculture, forestry and fishing	01-05	sec1	Secnrd(sec)
Mining	10-14	sec2	Secnrd(sec)
Food processing industry	15-16	sec3	Secnrd(sec)
Chemical and pharmaceutical industry	24	sec4	Secnrd(sec)
Production of machinery and equipment	29-33	sec5	Secnrd(sec)
Automotive industry	34	sec6	Secnrd(sec)
Other processing industries	17-23, 25-28, 35-37	sec7	Secnrd(sec)
Production and distribution of gas and electricity	40-41	sec8	Secnrd(sec)
Construction	45	sec9	Secnrd(sec)
Commerce, accommodation and catering	50-55	sec10	Secnrd(sec)
Transport and storage	60-63	sec11	Secnrd(sec)
Postal services and telecommunication	64	sec12	Secnrd(sec)
Banking and insurance	65-67	sec13	Secnrd(sec)
ICT	72	sec14	Secnrd(sec)
Private R&D	73	sec15	Secrdic(sec)
Public R&D	73	sec16	Secrdpc(sec)
Education	80	sec17	Secnrd(sec)
Health and social care	85	sec18	Secnrd(sec)
Other services	70,71,74,75,90-95	sec19	Secnrd(sec)

Note: *secnrd*=non-R&D sectors, *secrdic*=private R&D sector with imperfect competition, *secrdpc*=R&D sector with perfect competition, *Source: author's elaboration*

Besides the two R&D sectors, there are 17 final production sectors (Table 1), all of which employ the new ideas produced by the private R&D sector and convert them into new varieties. The higher the number of varieties, the higher is the capital stock and total productivity of the final goods sector. Because the new ideas are of a non-rival nature, the available stock of capital varieties is accessible to all production sectors in the economy.

In the following subchapter, the modelling approach is described in detail.

3.1 Production structure of the private and public R&D sectors

The production structure of the private R&D sector (included in the model as sec15) consists of multiple nests, where different production factors are combined to create added value. Value added VA_i is modelled with the use of a *CES I* production function, which employs an accumulated stock of knowledge HSK_i and a bundle of capital-labour $KSKL_i$.

$$VA_i = aH \cdot \left(\chi H_i \cdot HSK_i^{-\rho Hi} + (1-\chi H_i) \cdot KSKL_i^{-\rho Hi}\right)^{-1/\rho Hi} \qquad i \in \text{secRDic} \quad (1)$$

On the second nested level, the capital-labour bundle is further disaggregated between capital stock KSK_i and labour LSK_i (expressed in the number of workers) following the CES II production function:

$$KSKL_i = aF \cdot \left(\chi F_i \cdot KSK_i^{-\rho Fi} + (1-\chi F_i) \cdot LSK_i^{-\rho Fi}\right)^{-1/\rho Fi} \qquad i \in \text{secRDic} \quad (2)$$

An optimization procedure which minimizes total costs, subject to constraints on production technology, yields conditional demand functions for knowledge, capital stock and labour. It is assumed that all companies operating in the private R&D sector employ fixed knowledge and a labour stock component, which is unrelated to the quantity produced. Calculation of fixed costs in the private R&D sector is described in the chapter on calibration.

Value added is combined with intermediate consumption following the Leontief function to form the total gross production of the private R&D sector, XD_i, which consists of different designs (varieties). The decomposition of total R&D production into varieties is modelled with a Dixit-Stiglitz 'love of variety' function (equation 3), where *NOV* represents the number of new varieties corresponding to the number of private R&D firms, *Xvar* represents the amount produced per each R&D variety, and *elasVK* is a functional parameter which indicates the elasticity of substitution between different varieties:

$$XD_i = \left[\sum_{r=1}^{NOV} X\text{var}_r^{\frac{elasVK-1}{elasVK}}\right]^{\frac{elasVK}{(elasVK-1)}} \qquad i \in \text{secRDic} \quad (3)$$

Following the standard stylization, it is assumed that all firms in the private R&D sector are symmetric and produce the same amount per each variety. Therefore, equation (3) can be simplified to:

$$XD_i = NOV^{\frac{elasVK}{(elasVK-1)}} \cdot X\,\text{var} \qquad i \in \text{secRDic} \quad (4)$$

Similarly, the relation between the price of each individual variety *Pvar* and the composite producer price of the private R&D sector PD_i is calculated as a true price index:

$$PD_i = NOV^{\frac{1}{(1-elasVK)}} \cdot P\,\text{var} \qquad i \in \text{secRDic} \quad (5)$$

The number of varieties is determined from the optimization rule of marginal costs being equal to marginal revenues. Under monopolistic competition, the elasticity of demand for a capital variety is constant, and therefore the marginal revenues per each R&D firm are reduced to equation (6), where tp_i represents the subsidy rate per unit of private R&D production:

$$MR = (1 - tp_i) \cdot P\,\text{var} \cdot \left(1 - \frac{1}{elasVK}\right) \qquad i \in \text{secRDic} \quad (6)$$

The functional form of marginal costs is derived from the total costs that are calculated as the sum of capital, knowledge and labour inputs derived from the input-demand equations and evaluated at factor prices. Due to the linearity of the cost function, marginal costs coincide with unit costs. Therefore, marginal costs for the aggregate private R&D sector are derived from equation (7):

$$MC_i = [\ PK_i \cdot KSK_i + PL \cdot (1 + pldiff_i) \cdot (LSK_i - NOV \cdot LSKF) + PH_i \cdot (HSK_i - NOV \cdot HSKF)$$
$$+ DEPRECIATION_i + \sum_i io_{i,j} \cdot XD_i \cdot P_i\ ] / XD_i \qquad i \in \text{secRDic} \quad (7)$$

where *LSKF* represents fixed employment in the private R&D sector, *pldiff* reflects the wage differential between wages in the private R&D sector and wages in the national economy *PL*, *HSKF* represents the fixed knowledge stock required for production of capital varieties, and PH_i is a price index of knowledge. The remaining part of the marginal costs equation represents the value of intermediate consumption in the private R&D sector, divided by total production.

Finally, marginal costs per each monopolistic firm are obtained from the following formula (equation 8):

$$MC = MC_i / NOV^{\frac{1}{1-elasVK}} \qquad i \in \text{secRDic} \quad (8)$$

By equating marginal costs with marginal revenues (equations 6 and 8), the optimal number of varieties produced in the private R&D sector can be calculated.

A schematic representation of the production structure in the private R&D sector is displayed in Chart 1 (Appendix).

The production of new ideas is demanded by producers of final goods in the form of investment in variety capital, which increases the total stock of varieties employed in the production process. Similarly as in the private R&D sector, public R&D producers employ knowledge, capital stock and labour to produce a public commodity – knowledge. Unlike the private R&D sector, producers in the public R&D sector face perfect competition, so there is no mark-up above their producer price.

3.2 Production structure of the final goods sectors

Producers of final goods employ two types of capital – homogenous capital that is accumulated from investments in physical goods and variety capital that is produced by the private R&D sector. There is a nested production structure: on the first level, producers combine composite capital bundle $KVKSK_i$ with labour to create value added, according to the CES production function (equation 9, Chart 2 - Appendix):

$$VA_i = aF \cdot \left(\chi F_i \cdot KVKSK_i^{-\rho Fi} + \left(1-\chi F_i\right) \cdot LSK_i^{-\rho Fi}\right)^{-1/\rho Fi} \quad i \in \text{ secnRD } (9)$$

On the second level of the production structure, composite capital is split between homogenous capital and variety capital $VKSK_i$ with the use of the CES II function.

$$KVKSK_i = aKVK \cdot \left(\chi KVK_i \cdot KSK_i^{-\rho KVKi} + \left(1-\chi KVK_i\right) \cdot VKSK_i^{-\rho KVKi}\right)^{-1/\rho KVKi}$$

i ∈ secnRD (10)

Based on the optimization, conditional input demand functions for capital stock, variety capital and labour are derived. The stock of variety capital is determined as the accumulated production of the R&D sector and is fixed in each time period. Therefore, the demand equation for variety capital determines the optimal price of variety capital.

3.3 Allocation of investments in the economy

The macroeconomic closure of savings – investments ensures that investment demand will not exceed investment resources, which are allocated among three investment groups - homogenous capital goods, investments in capital varieties and investments in knowledge. The allocation of total investment resources follows a non-linear function based on the ratio of the return on investment of the respective investment group to an average return in the economy (*ROIav*):

$$\left(\frac{INVTK}{VKSKT}\right) = \chi ivk \cdot \left(\frac{ROIvk}{ROIav}\right)^{elasIVK} \qquad (11)$$

where *INVTVK* represents budget allocated to investments in capital varieties that are determined from the equation, *VKSKT* is the total stock of variety capital, γ_{ivk} and *elasIVK* are parameters and *ROIvk* represents the return on investment for capital varieties. Investments in homogenous capital goods and knowledge are determined analogically, taking into account their respective returns on investment. A schematic representation of investment allocation is displayed in Chart 3.

The modified version of the CGE model contains three equations of motion, which provide a link between the amount of variety capital, homogenous capital, and knowledge stock in the current and subsequent periods:

$$KS_{i,t+1} = (1 - sdep_i).KS_{i,t} + IS_{i,t} \qquad (12)$$

$$HS_{i,t+1} = (1 - sdepH_i).HS_{i,t} + ISRD_{i,t} \qquad (13)$$

$$VKS_{i,t+1} = VKSK_{i,t} + INVTVK_t \qquad (14)$$

Equation 12 indicates that the amount of capital stock in the current period is determined by the depreciated amount of capital stock, raised by physical investments, in the previous period. In the same way, the stock of knowledge in the current period can be determined by net R&D investments carried out in the previous period (equation 13). Equation 14 determines the stock of variety capital endowment per sector, which grows according to the lagged investments in variety capital. To be consistent with the assumptions of non-rivalry of variety capital, equation 14 ensures that all final goods sectors have access to the total stock of capital varieties. Therefore, the capital variety endowments per sector are equal to the total stock of variety capital.

3.4 Closure rules and baseline assumptions

The CGE model applies six closure and factor market assumptions: i) the supply of labour and land is fixed; capital stock grows at the rate of net investments; ii) unemployed labour 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 the 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 endogenous adjustment of exchange rates.

The evolution of exogenous variables follows projections from the Czech Ministry of Finance (April 2012) and European Commission Forecast (Spring 2012). Growth of domestic transfers follows the long-term predicted economic growth of the Czech economy at a rate of 3% annually. Export demand from the EU and the rest of the world is projected to grow 2% in the coming period, followed by more dynamic development, at a rate of 5% annually.

3.5 Calibration of the CGE model with capital varieties

The base year for calibration of the model is 2008 and was determined by the availability of supply-use tables. These tables were used for building the production and commodity accounts of the Social Accounting Matrix (SAM), which arranges data for their consecutive incorporation into the CGE model[2]. Several assumptions, described below, have been adopted in the process of constructing SAM and calibrating the model.

Assumptions concerning production factor remunerations

Frascati Manual statistics on the GERD (CSO, 2011a,b) were used to obtain the labour and capital costs of the private and public R&D sectors. Employment of capital in the public R&D sector was derived from the profitability rate of the private R&D sector. The sector-specific wage in the public R&D sector was calculated from the number of employees specified by the publically available Frascati data survey from the Czech Statistical Office; employment in the private R&D sector was calculated from a purchased database of private R&D companies (CSO 2011 b). It is assumed that the share of variety capital in total capital remuneration reaches approximately 15%, which corresponds to the share of gross R&D expenditures in total capital stock, as reported from a survey of private R&D companies. The distribution of knowledge and variety capital gains among households, firms, and government was approximated from the structure of physical capital remunerations.

Calibration of stock variables

The growth of variety capital stock was approximated from the average compound growth rate, which reached 10%, of private R&D investments in the period 2000-2009. The total stock of variety capital VKSKT was calculated based on the steady-state condition:

$$VKSKT = \frac{YKVT}{growth\_privateRD}, \tag{15}$$

where $YKVT$ is total remuneration from variety capital in the base year.
Similarly, the total stock of knowledge was estimated based on the growth rate of public R&D expenditures (about 8.5% annually).

After calibration of the stock of variety capital, the price of variety capital PKV_i (i.e. the return on variety capital) was calculated by dividing the remuneration from variety capital per sector YKV_i by the stock of capital variety $VKSKT$:

[2] The final SAM, uploaded to GAMS, is a matrix of size 56x56 and is available from the author upon request.

$$PKV_i = \frac{YKV_i}{VKSKT} \quad (16)$$

Calibration of the private R&D sector with monopolistic competition

Fixed costs of the private R&D sector (*FCOST*) were calculated from the elasticity of substitution between varieties (*elasVK)*, which is equivalent to the perceived demand elasticity for variety and set to 5.0 according to Brita Bye et al. (2008):

$$FCOST = (1 - tp_i) \cdot PD_i \cdot XD_i \cdot \left(\frac{1}{elasVK * NOV} \right), \quad \text{i} \in \text{ secRDic} \quad (17)$$

where tp_i is the subsidy rate of the private R&D sector, PD_i is producer price, XD_i is the quantity produced by the private R&D sector, and *NOV* is the number of new varieties, which corresponds to the number of private R&D companies in the sector. According to Table 2, the total fixed costs of the private R&D sector reach CZK 8 billion, which represents a 20% share of the sector's total costs.

It is assumed that the fixed costs arise from the employment of labour and knowledge, which form an important part of the added value of private R&D firms. Fixed labour costs are calculated from the share of researchers employed in the R&D process in the total number of employees. Based on the Frascati survey, this share reaches about 21%. Labour costs for researchers were calculated using publicly available statistics on wages in research – in 2008, average wages in research reached about 29,000 CZK. The fixed costs of knowledge were derived as a remaining component of the total fixed costs after subtracting labour costs.

Table 2: Calibration of fixed costs in the private R&D sector

Indicator	Value
Elasticity of substitution between varieties	5.00
Number of R&D companies	1825
Total fixed costs in the private R&D sector (bln CZK)	8.57
Share of fixed costs in total costs	20%
Fixed costs of labour in the private R&D sector (bln CZK)	2.38
Share of fixed labour costs in total labour costs	20%
Fixed costs of knowledge in the private R&D sector (bln CZK)	6.19
Share of fixed costs of knowledge in total knowledge costs	55%

Source: author's calculation

4. Results

4.1 Definition of scenarios

The incorporation of capital varieties into the CGE model allows for analysis of the following research questions:

- *What is the impact of the incorporation of capital varieties on predicted economic growth in the Czech Republic?*
- *What is the efficiency of governmental support for private R&D compared to subsidizing other sectors?*

Concerning the first research question, the predicted economic growth obtained from the CGE model with capital varieties is compared to the economic growth estimated from the standard CGE model, and the differences in outcomes are compared. The results of this simulation enable to estimate the magnitude of the impacts that the R&D sector can have on economic growth.

Regarding the second research question, the CGE model with capital varieties is applied to assess the efficiency of governmental support. In this simulation, different scenarios are considered that compare the effect of subsidies allocated to the private R&D sector, with that of subsidies allocated to the final goods sector with the highest subsidy rate.

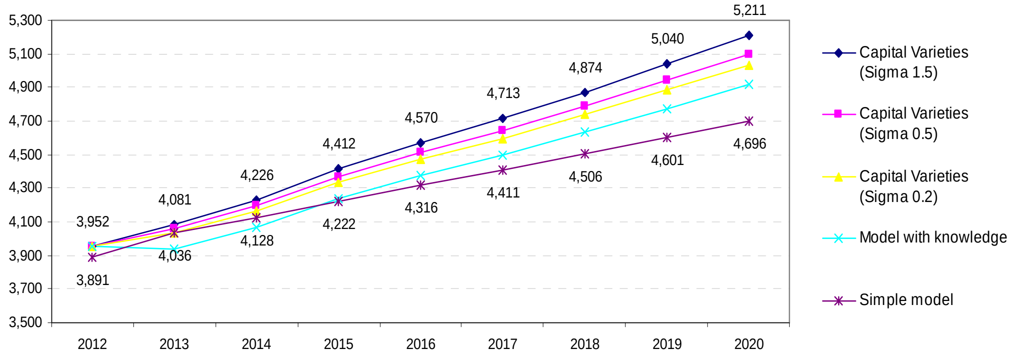
4.2 The impact of capital varieties on predicted economic growth – comparison of baselines

In this chapter, the effects of incorporating capital varieties into the CGE model are investigated. In order to capture the importance of substitution elasticity between the capital varieties and homogenous capital, the model is run under different elasticity options.

The results of the simulation are displayed in Figure 2. It was discovered that the CGE model with capital varieties predicts higher GDP values than the standard CGE model. Moreover, with increasing substitution elasticity, predicted economic growth is higher. This result indicates that the greater the ability of the economy to convert homogenous capital goods to variety capital, the higher the achieved economic growth.

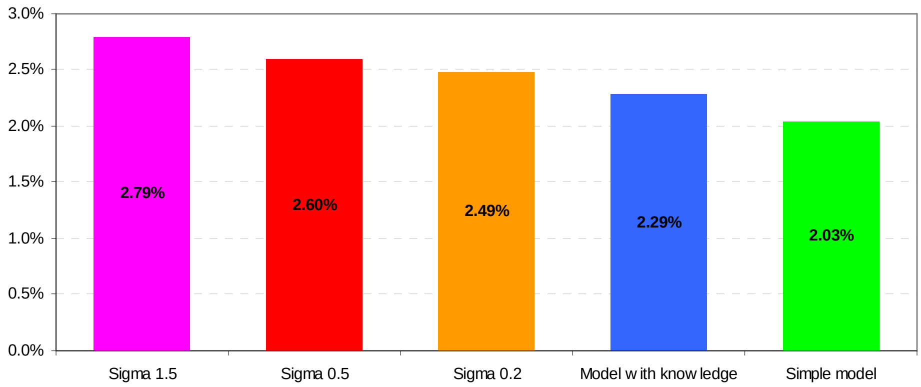
Due to slightly different base year values, it is more consistent to compare the behaviour of both models according to their growth rates and not their nominal GDP values. Figure 3 shows that the effects of capital varieties on the dynamics of economic growth range from + 0.45 to + 0.75 percentage points. This result can be interpreted from both a methodological and empirical perspective. The former reveals that baseline growth rates in the standard CGE model are usually moderately underestimated due to the omission of R&D effects. The latter shows that the production of capital varieties can stimulate economic growth by nearly 1%, which is not a negligible effect in the current context of economic crisis.

Figure 2: Comparison of nominal GDP (CZK bln., c.p.) in models with and without capital varieties



Source: author's calculation

Figure 3: Comparison of nominal GDP (CZK bln., c.p.) in models with and without capital varieties



Source: author's calculation

4.3 The efficiency of governmental support for the private R&D sector

Under the current economic crisis, governments are even more pressured to justify their budgets. Moreover, there is a common consensus that EU policies should be more oriented towards research and innovation to stimulate the competitiveness of the European economy. On the other hand, certain EU policies such as the Common Agricultural Policy are facing increasing criticism on the part of tax payers, due to the extensive subsidization of EU farmers. Strong EU agricultural support is also reflected at the national level – in the Czech Republic, agriculture receives the highest production subsidy rate across all production sectors. In light of this fact, this chapter investigates possible economic effects induced by the government's reallocation of support from agriculture to the private R&D sector, in line with the EU's strategy of smart and sustainable growth.

The analysis is performed in three scenarios which are described in Table 3. The baseline scenario is the status quo, and indicates that the private R&D sector receives a subsidy rate of about 8.5% of its gross production, whereas the agricultural sector enjoys an 11% subsidy rate. Scenario 1 simulates a situation in which the subsidy rate of private R&D goes up to 11%, and thus answers the question "*what happens if the private R&D sector receives the same proportion of governmental support for its production as agriculture does"?* Scenario 2 takes into account the volume of subsidies that are distributed to agriculture (about CZK 24 billion in 2014) and answers the question "*what happens if the private R&D sector receives the same volume of governmental support as agriculture"*? This scenario thus models a situation in which a 40% subsidy rate is applied to the R&D sector. Finally, Scenario 3 considers a complete reallocation of governmental subsidies from agriculture to private research and thereby responds to the question "*what happens if government shifts all support from agriculture to the private R&D sector"?*

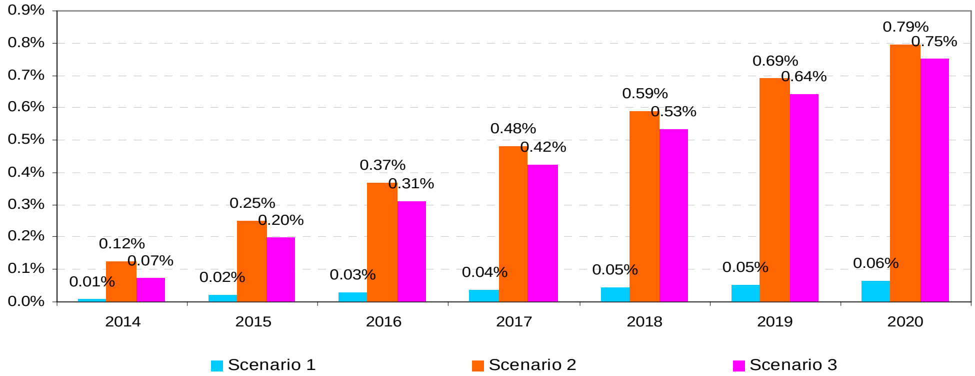
Table 3: Scenario definition

Production sector	Subsidy rate (share of gross production)			
	Baseline (2008-2020)	Scenario 1 (from 2014 on)	Scenario 2 (from 2014 on)	Scenario 3 (from 2014 on)
Agriculture, fisheries, forestry	10.5%	10.5%	10.5%	0.0%
Private R&D sector	8.5%	10.5%	39.4%	39.4%

The impact of the considered scenarios on real GDP is illustrated in Figure 4. In Scenario 1, the GDP effects are small, as the simulated subsidy rate increases by only 2 percentage points. Stronger GDP effects reaching + 0.8% deviation from the baseline are found in the case of Scenario 2. Scenario 3 reports a slightly lower effect compared to Scenario 2, due to the removal of subsidies to agriculture, which will be explained further.

Due to the fact that Scenarios 1-3 are asymmetric and are applied from 2014, which gives the model only a short time to adjust, additional simulations were carried out to obtain a comprehensive overview of the GDP effects under different subsidy options. The scenarios described in Table 4 aim to compare three situations – *there are no agricultural subsidies from 2010 on* (Scenario 3_2010), *there are both agricultural and R&D subsidies* (Scenario 4_2010), and *there are no R&D subsidies* (Scenario 5_2010). In this way, it is possible to compare what is more costly for the economy – to fully remove subsidies to agriculture, or to fully remove subsidies to the R&D sector.

Figure 4: Effects on real GDP - deviation of scenarios from the baseline



Source: author's calculation

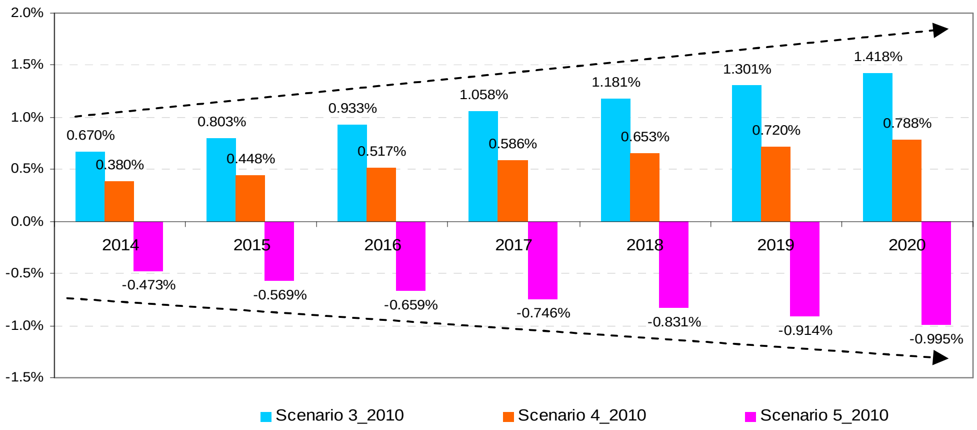
Table 4: Scenario definition 2

Production sector	Subsidy rate (share of gross production)			
	Baseline (2008-2020)	Scenario 3_2010 (from **2010** on)	Scenario 4_2010 (from **2010** on)	Scenario 5_2010 (from **2010** on)
Agriculture, fisheries, forestry	10.5%	0%	39.5%	39.5%
Private R&D sector	8.5%	39.5%	39.4%	0%

The results of this simulation are displayed in Figure 5. The dashed arrows can be understood as a band in which GDP can oscillate depending on governmental choices. If subsidies are fully reallocated from agriculture to private research, then GDP can be stimulated over the long term by 1.4% compared to the baseline; however, if the government decides to support only agriculture, then GDP would be one percentage point lower, compared to the baseline. The analysis also shows that the positive effects of subsidization are even more pronounced over the long term.

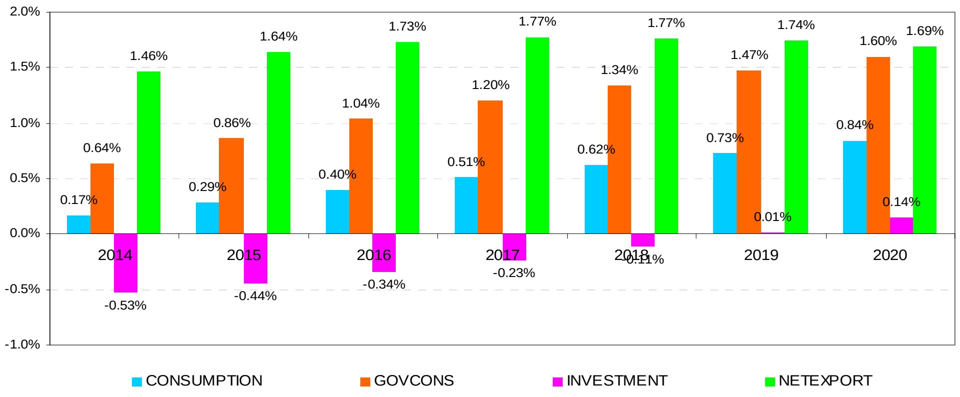
The investigated positive effects of GDP can be further decomposed into particular sources of growth. Figure 6 focuses on changes in household consumption, investments and net exports induced by the removal of agricultural subsidies in 2014 (Scenario 3). It is apparent that GDP is mainly driven by the growth of net exports, and in particular by the growth of industrial exports and services. This can be explained by the fact that the agricultural sector has a rather low export orientation, and therefore reducing its share in the economy can stimulate the exports of other industries. It is important to note that the effect on investments is positive only over the long term; in the short term, there is a slight decline due to a reduction in governmental and firms´ savings. In the case of governmental savings, Scenario 3 imposes greater pressure on the government's budget, which leads to a decline in savings (the closure rule implies that governmental savings adjust to the difference between governmental income and expenditures). The negative reaction of firms´ savings is caused by a sharp decline in returns on capital in agriculture, which is then transmitted to the capital remuneration of firms. Effects on consumption are positive but not so significant, since stimulation of the R&D sector through governmental policies does not directly affect households. Finally, the evolution of governmental consumption is positive and parallels GDP growth, which is determined by the closure rule (fixed governmental consumption as a proportion of GDP).

Figure 5: Effects on real GDP - deviation of scenarios from the baseline



Source: author's calculation

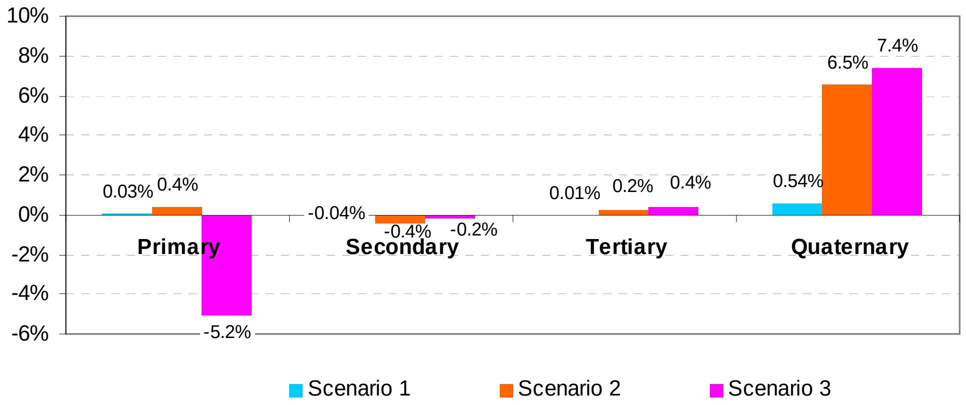
Figure 6: Deviation of GDP components from the baseline in Scenario 3



Source: author's calculation

It is also possible to analyze structural changes in the economy produced by the considered scenarios. Figure 7 indicates that the participation of the primary sector would decrease in favour of the tertiary and quaternary sectors, which are directly influenced by R&D policies. Therefore, growth in GDP in the case of stimulated subsidies to R&D can be attributed mainly to the growth of the quaternary sector of the economy. Small but positive changes can also be noted in the case of the tertiary sector of the economy. The secondary sector responds neutrally and in Scenario 3 slightly decreases, which is related to the backward linkages of industry with agriculture.

Figure 7: Deviation of value added from the baseline



Source: author's calculation

The increase in the quaternary sector can be further analysed with a special focus on the situation in the private R&D sector. Due to the fact that the reallocation of support to R&D is modelled through production subsidies (negative net taxes), the chain of reactions is driven by price changes. The higher the producer's subsidy, the lower the price that the producer may charge to cover his costs. In the case of the private R&D sector, a producer may offer R&D varieties at a lower price, which stimulates investment demand and increases the number of varieties produced. These series of changes are displayed in Table 5, which indicates percentage changes vs. the baseline at the end of the observed period. The results indicate that the prices of capital varieties decline by 16% if subsidies are reallocated to the private R&D sector, which leads to an expansion in the number of private R&D firms in the sector. Table 5 also shows that as a result of the governmental policy, investments to variety capital increase substantially. Moreover, due to the ties between the private and public R&D sectors, investments in knowledge are also stimulated.

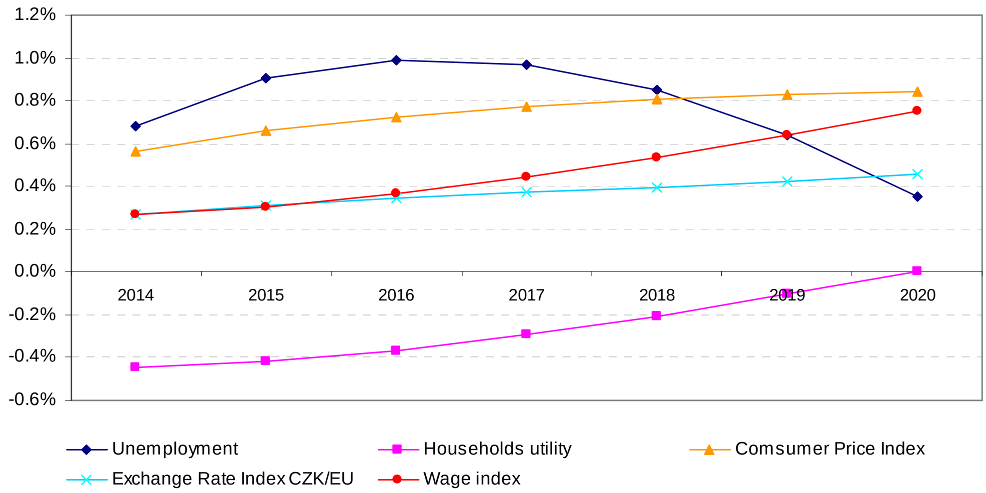
Table 5: Impact of Scenario 3 on the private R&D sector (year 2020)

	Baseline	Scenario 3	% Change vs. Baseline
price of R&D variety	6.6	5.5	-16.2%
no. of varieties and no. of private R&D firms	2216.7	2398.8	8.2%
investments in variety capital	99.4	126.8	27.5%
investments in knowledge	81.6	92.9	13.8%

Source: author's calculation

Finally, it remains to be discussed what repercussions the reallocation of governmental support might have on the labor market and other macroeconomic variables (Figure 8). In this case, more adverse effects can be observed.

Figure 8: Deviation of macroeconomic variables from the baseline in Scenario 3

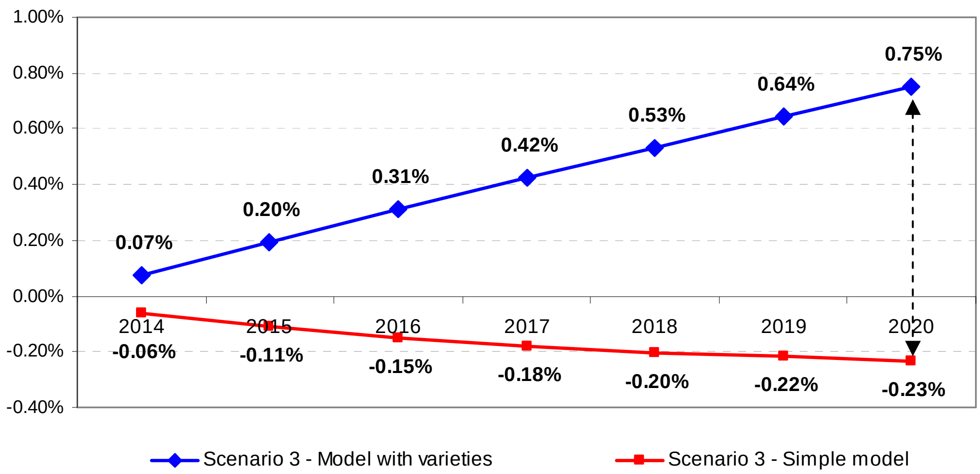


Source: author's calculation

First of all, the unemployment rate could go up in the short run as a consequence of the contraction of agriculture, which is more labour intensive. The absence of subsidies means that producer prices would correspond to full production costs, and this would be reflected in higher food prices and overall inflation. Regardless of which sector suffers from the removal of subsidies, an increase in governmental support for the private R&D sector will always lead to a relative increase in wages, since an expansion of the stock of variety capital causes labour to be relatively more scarce. This is further transmitted to the current account balance, which suffers from higher payments to labour abroad, and consequently leads to currency depreciation (due to the closure rule, the exchange rate balances the current account in the presence of fixed foreign savings). Finally, the impact of Scenario 3 on household utility is negative, which is related to the previously-mentioned decline in unemployment and growth in consumer prices. Over the long term, the economy is able to adjust to the new situation and unemployment converges to the baseline.

To summarize, the series of reactions caused by the reallocation of governmental support leads to positive effects for net exports, total GDP, and the private R&D sector, but also negative effects for households. These findings were further contrasted with the results obtained from a standard CGE model that omits the R&D effects. Figure 9 illustrates the percentage deviations of real GDP from the baseline, in models with and without variety capital. Whereas the reallocation of subsidies from agriculture to private research leads to a positive GDP effect (+0.07%) in the model with capital varieties, in the standard model that omits the R&D effects, the immediate GDP effect is negative (-0.06%). Moreover, these differences become more pronounced over time, when the model with capital varieties diverges quicker from the baseline in the positive direction. These results confirm the preliminary hypothesis that the standard CGE model underestimates R&D effects and could produce biased estimates. According to Figure 9, the simulation bias can reach up to 1% of GDP, which is not a negligible error.

Figure 9: Deviation of GDP from the baseline in Scenario 3, in models with and w/o capital varieties



Source: author's calculation

5. Discussion

The results of this paper are to a large extent determined by the choice of methodology and the representation of R&D in the CGE model. It is necessary to point out that in this paper, only domestically produced R&D effects are considered, and these effects are channeled through the production of capital varieties which have a public goods nature. This is Romer´s idea of economic growth, driven by R&D companies operating in a market with monopolistic competition.

There could be a lengthy discussion about the plausibility of some of Romer´s assumptions, such as the symmetry of capital varieties. Furthermore, it should be noted that R&D effects are produced in large interactions with foreign R&D; this has been analysed in various works, such as Lejour and Rojas-Romagosa (2008). Moreover, in practice, private and public R&D are not distinguishable and can act together in synergies. This feature has been partially captured in the CGE model by the knowledge links between the public and private R&D sectors. Table 5 showed that with increasing support for the private R&D sector, the public R&D sector would also see higher investments, due to the present spillover between the two sectors.

There are several fields in which this methodological approach can be further extended. First of all, the notion of capital variety depreciation has not yet been considered, due to a lack of empirical evidence. Secondly, the dynamics of the CGE model follow myopic expectations, which are certainly more realistic than perfect foresight. However, intertemporal CGE models with perfect foresight can be used to assess the optimal allocation of R&D investments over longer time horizons, and they can reveal interesting findings. Another important extension to the present CGE model is the incorporation of human capital. As the results in Figure 8 indicated, investments in R&D can reduce the demand for labour because the economy becomes more capitally intensive (capital varieties replace labour). In reality, the invention of new designs that are converted to varieties requires human capital, and therefore the adverse effects on the labour market might be smaller.

Finally, it should be highlighted that the scenarios concerning the complete removal of agricultural subsidies are used for an illustrative comparison with the R&D sector, and that agriculture is understood to be the final goods sector with the highest subsidy rate. However, it can be argued that in the same way as the R&D sector, agriculture can also be considered a sector which produces public goods. Especially within the European Union, the distribution of large direct payments to EU farmers is mainly justified by the farmers’ contributions to landscape, biodiversity, and food security, which all have the nature of public goods.

6. Conclusion

This paper analysed the role of research and development in the economy with the use of a CGE model that incorporates the effects of capital varieties produced by the private R&D sector.

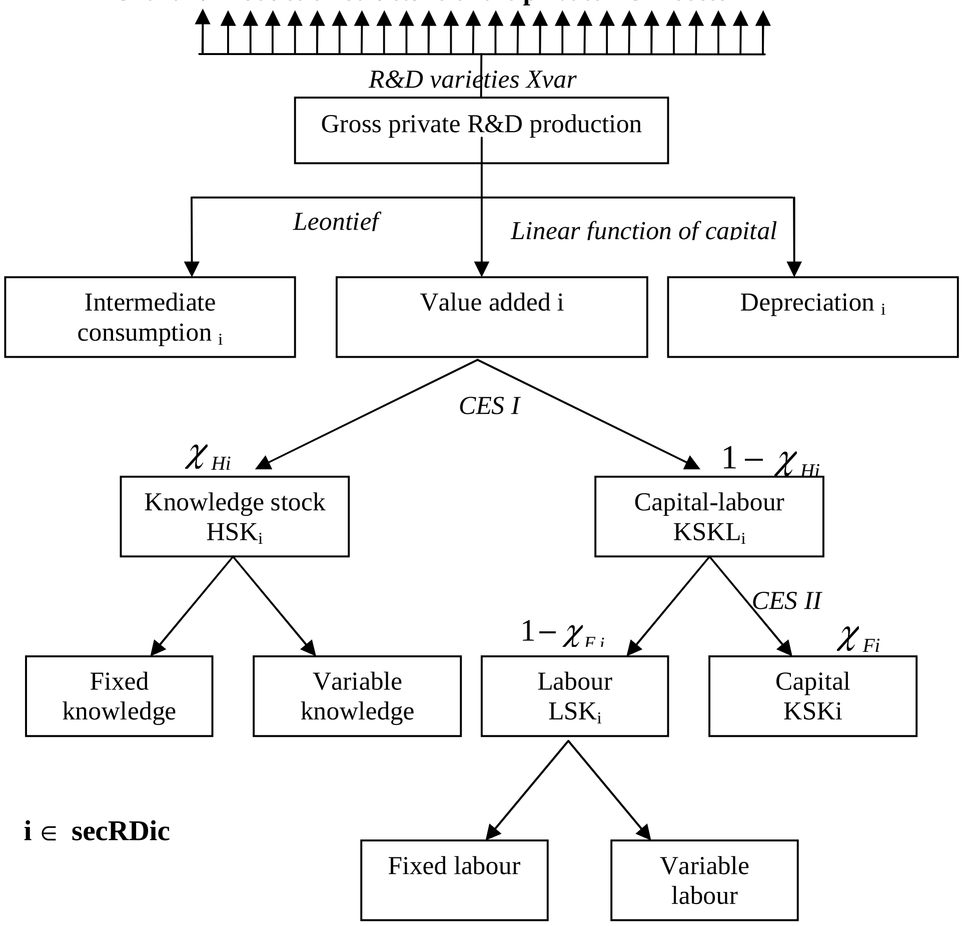
By performing scenario analysis in a CGE model with capital varieties as well as a standard CGE model, the paper argues that the ommission of R&D effects in the CGE model could cause a simulation bias. In the example of agricultural subsidies reallocation, this simulation bias could reach 1% of GDP and might produce conflicting results. This finding is extremely important if the CGE model is used to analyse the efficiency of governmental subsidies.

Furthermore, the CGE analysis showed some interesting results concerning the role of research and development in the economy. It was discovered that the dynamics of GDP growth is positively related to the production of capital varieties and the elasticity of substitution between homogenous and variety capital. Due to this fact, if government allocates more subsidies to the private R&D sector, the economy can be stimulated, even at the expense of a final goods sector – as demonstrated in the example of agriculture. For the Czech Republic, a small and export-oriented economy, support for private R&D can be particularly beneficial since it stimulates the exports of important industries. However, with regard to households, a policy of stimulating R&D could cause short term adverse effects due to growing unemployment, resulting from the substitution of labour for capital varieties.

The methodological approach presented can be further extended to incorporate links between R&D sectors and human capital, and thereby reduce the adverse effects on labour markets. Furthermore, the CGE model could also be applied to investigate the role of international R&D spillovers, which are certainly relevant in a small open economy such as the Czech Republic.

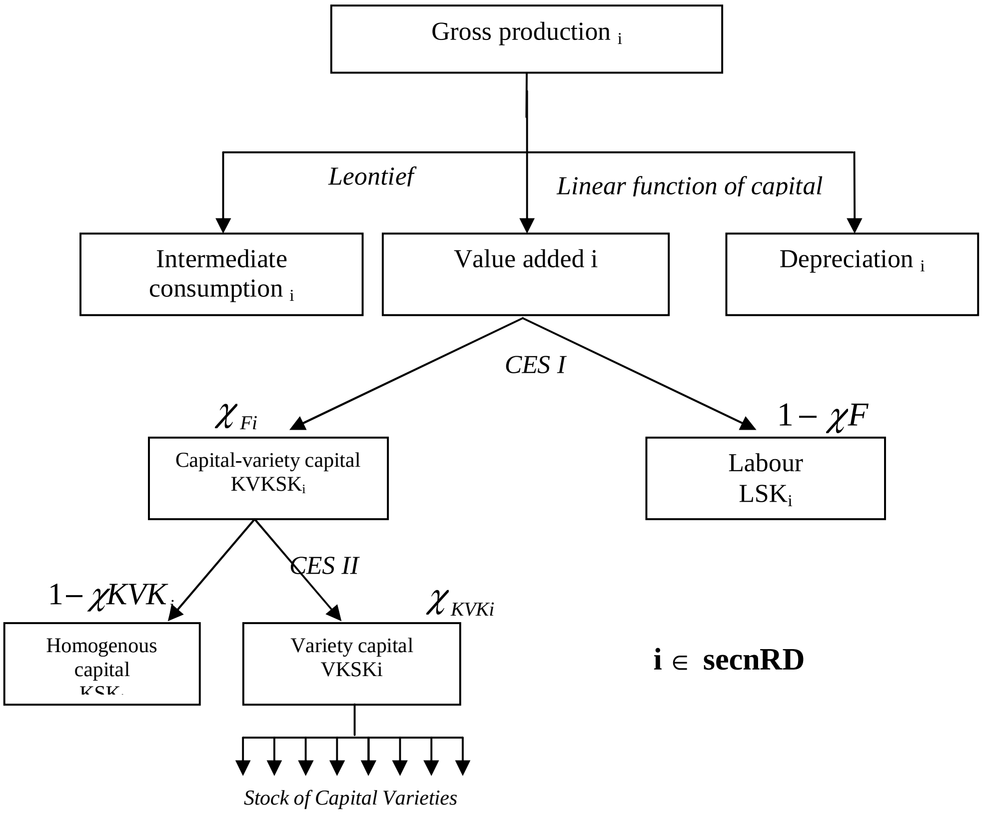
Appendix

Chart 1: Production structure of the private R&D sector



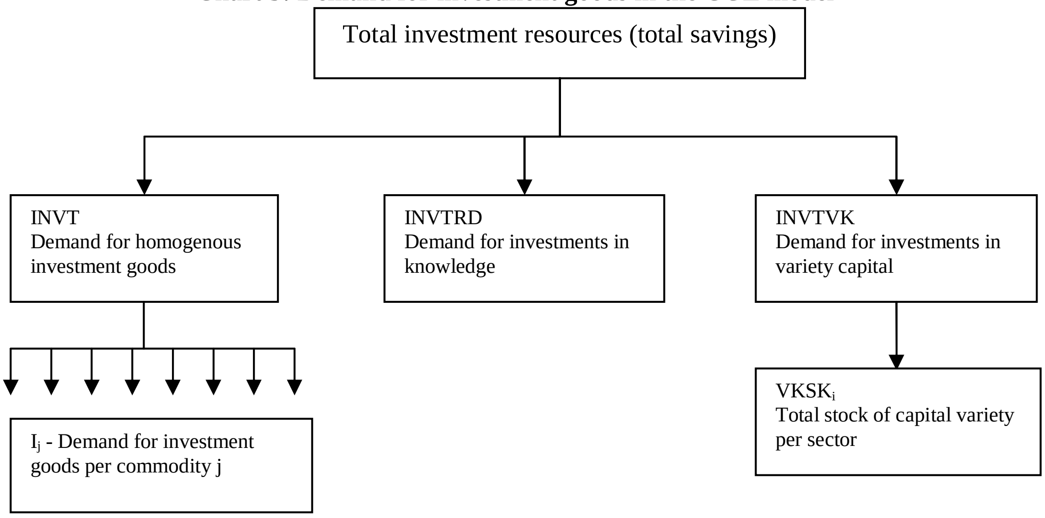
Source: author's elaboration

Chart 2: Production structure of the final goods sector



Source: author's elaboration

Chart 3: Demand for investment goods in the CGE model



Source: author's elaboration

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