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# Analysis of Private R&D Effects in a CGE Model with Capital Varieties: The 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 are 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 labor for capital varieties.*

## 1. Introduction and Objectives

In the strategic document Europe 2020 (EC, 2010), the European Commission proposes a set of measurable targets to steer EU economies out of the ongoing economic and financial crises and bring longer-term prosperity. Particular attention is given to the stimulation of *smart growth*, based on knowledge and innovation, which requires a commitment of the EU countries to invest 3% of their GDP in R&D. In light of this effort, there is a strong call for the development of analytical approaches that help us to understand the contribution of R&D to economic growth and enable governments to allocate resources efficiently.

The Czech Republic is a small, open economy with broad ties to its EU neighbors, 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 expenditure, which has doubled in the last decade (*Figure 1*). R&D carried out by the private sector represents the dominant share of total research expenditure in this period, with the biggest contribution coming from the automotive and machinery industries.

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)

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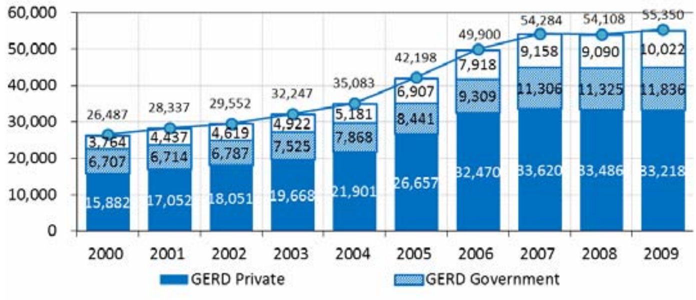
**Figure 1 Overview of Gross R&D Expenditure (GERD) per Performing Sector (CZK m)**




*Source:* Frascati Manual data from CZSO (2011)

model which incorporates the effects of capital varieties and follows Romer's theory of endogenous growth.

The paper elaborates on the hypothesis that standard CGE models do not properly capture R&D effects (as shown, for example, in Kristkova, 2012) 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 study investigates how the results obtained with standard CGE models can be improved by endogenizing R&D-based technological progress in a recursively dynamic CGE model built for the economy of the Czech Republic. This paper draws on the results of Kristkova (2012), who studied the effect of R&D investment on economic growth through knowledge accumulation. The novelty of this paper lies in a modified approach which incorporates a uniform R&D sector producing different capital varieties under imperfect competition into the CGE framework following Romer's theory of endogenous growth.

The paper is structured as follows. In the second section, a review of approaches to modeling R&D investment in CGE models is provided. This is followed in the third section by a description of the methodological approach applied in this paper. The fourth section describes the application of the CGE model in simulations centered on the efficiency of R&D subsidies compared to subsidies allocated to an alternative final goods sector. A section 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

[1] According to Kristkova (2012), the appropriate representation of the R&D sector in the SNA could be underestimated by a factor of 2.5.

capital or labor, 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 of being 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 licenses 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 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 the 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 expenditure 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 valuing 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 the high level of stylization and abstraction, there have been various attempts to implement Romer's endogenous growth theory into applied general equilibrium models. One of the earliest contributions can be found in work dealing with Japan done by Diao, Roe, and Yeldan (1999), in which the authors 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 dynamization, 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.

Ghosh 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 and 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. Detailed documentation of the model and its calibration is presented in Bye, Fæhn, Heggedal, Jacobsen, and Strøm (2008).

Following recent approaches, this paper incorporates R&D effects into a recursively dynamic CGE model built for the economy of the Czech Republic. The need to construct a dynamic CGE model for the Czech economy is supported by the fact that the Czech Republic, as a small open economy, is vulnerable to external shocks, which may have severe long-term repercussions. 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 a planned environmental tax reform, the Czech Ministry of the Environment applied a dynamic CGE model to quantify the impacts of environmental policy on macroeconomic aggregates (Pavel, 2006). The macroeconomic effects of environmental taxation were further analyzed in Ščasný et al. (2009), who applied a structural macroeconometric E3M3 European model adjusted to the Czech economy. R&D investment in the energy sector is incorporated into the structural equations to improve the model's efficiency. Recently, Markandya et al. (2011) analyzed the effects of taxing air pollutants and $CO_2$ in a CGE model, in a study supported by the Czech Ministry of Environment. 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. The topic of fossil fuels and biofuels was also studied by Bruha and Pisa (2010), who investigated the economic effects of biofuel promotion using a CGE model. 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. Further recent CGE applications to the Czech economy deal with the impact of different scenarios of the Common Agricultural Policy reform, in which the authors compare the results of a regional CGE model with a national CGE model called CZNATEC built for agricultural policy simulations (Ratinger and Kristkova, 2012).

Despite the 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 analyzed in the Czech Republic, at least not within the CGE framework. It should be noted, however, that there is an extensive body of research modeling endogenous growth and knowledge accumulation using other approaches—see, for instance, Kejak, Seiter, and Vávra (2004) and Kejak and Vávra (2002), who developed a two-sector endogenous growth model to assess the transitional behavior after EU accession in the CEEC countries, including the Czech Republic.

**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) |

*Notes:* secnrd = non-R&D sectors, secrdic = private R&D sector with imperfect competition, secrdpc = public R&D sector with perfect competition

*Source*: Author's elaboration.

## 3. Description of the Modeling Approach Applied in the Paper

As mentioned above, this paper builds on the results of Kristkova (2012) and presents a modified approach to modeling the effects of R&D. Three novel areas are incorporated into the CGE model: treatment of R&D activity; the market environment, which includes imperfect competition in the private R&D sector; and technological progress based on publicly available accumulation of variety capital. These features are further explained below.

R&D activity is modeled 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 modeling the production of varieties (such as in 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.

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 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.

The modeling approach is described in detail in the following subsection.

### 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 modeled with the use of a *CES I* production function, which employs an accumulated stock of knowledge $HSK_i$ and a bundle of capital-labor $KSKL_i$.

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

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

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

An optimization procedure which minimizes total costs, subject to constraints on production technology, yields conditional demand functions for knowledge, the capital stock, and labor. It is assumed that all companies operating in the private R&D sector employ fixed knowledge and a labor stock component, which is unrelated to the quantity produced. The calculation of fixed costs in the private R&D sector is described in the section 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 modeled 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 R&D variety, and *elasVK* is a functional parameter which indicates the elasticity of substitution between different varieties:

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

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

$$XD_i = NOV^{\frac{elasVK}{(elasVK-1)}} \cdot Xvar \qquad i \in \text{secRDic} \tag{4}$$

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:

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

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 R&D firm are reduced to equation (6), where $tp_i$ represents the subsidy rate per unit of private R&D production:

$$MR = \left(1 - tp_i\right) \cdot Pvar \cdot \left(1 - \frac{1}{elasVK}\right) \qquad i \in \text{secRDic} \tag{6}$$

The functional form of marginal costs is derived from the total costs, which are calculated as the sum of capital, knowledge, and labor inputs derived from the input-demand equations and valued 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):

$$MC_i = \left[\begin{array}{l} PK_i \cdot KSK_i + PL \cdot \left(1 + pldiff_i\right) \cdot \left(LSK_i - NOV \cdot LSKF\right) + \\ + PH_i \cdot \left(HSK_i - NOV \cdot HSKF\right) + DEPRECIATION_i + \sum_i io_{i,j} \cdot XD_i \cdot P_i \end{array}\right] / \, XD_i$$

$$i \in \text{secRDic} \tag{7}$$

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

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

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 labor 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, which is accumulated from investment in physical goods, and variety capital, which is produced by the private R&D sector. There is a nested production structure: on the first level, producers combine a composite capital bundle $KVKSK_i$ with labor to create value added, according to the CES production function (equation (9), *Chart 2—Appendix*):

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

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.

$$KVKSK_i = aKVK \cdot \left( \chi KVK_i \cdot KSK_i^{-\rho KVK_i} + \left(1 - \chi KVK_i\right) \cdot VKSK_i^{-\rho KVK_i} \right)^{-1/\rho KVK_i}$$
$$i \in \text{secnRD} \qquad (10)$$

Based on the optimization, conditional input demand functions are derived for the capital stock, variety capital, and labor. 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 Investment in the Economy

Total investment resources are allocated among three investment groups—homogenous capital goods, investment in capital varieties, and investment 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 the 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 the budget allocated to investment in capital varieties, which is determined from the equation, *VKSKT* is the total stock of variety capital, $\chi_{ivk}$ and *elasIVK* are parameters, and *ROIvk* represents the return on investment for capital varieties. Investment in homogenous capital goods and knowledge is determined analogously, taking into account the respective returns on investment. A schematic representation of investment allocation is displayed in *Chart 3 (Apendix)*.

The return on investment for capital varieties is calculated according to the following formula:

$$ROIVK = \frac{RVKAV \cdot VKSKT}{PINVTVK \cdot INVTVK} \qquad (12)$$

where the numerator represents the product of the average return on variety capital *RVKAV* (calculated as a weighted average of the price of capital variety across the sectors) and the endowment of variety capital in the economy *VKSKT.* The denominator represents the value of investment in variety capital as a product of the investment price *PINVTVK* and quantity *INVTVK*.

The average return on investment in the economy *ROIav* is calculated as the ratio of total capital income (the sum of homogenous, knowledge, and variety capital income) to total investment resources:

$$ROIav = \frac{\sum_i KSK_i \cdot PK_i + \sum_i HSK_i \cdot PH_i + \sum_i VKSK_i \cdot PVK_i}{INVRES} \tag{13}$$

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:

$$KS_{i,t+1} = (1 - sdep_i).KS_{i,t} + IS_{i,t} \tag{14}$$

$$HS_{i,t+1} = (1 - sdepH_i).HS_{i,t} + ISRD_{i,t} \tag{15}$$

$$VKS_{i,t+1} = VKSK_{i,t} + INVTVK_t \tag{16}$$

Equation (14) indicates that the amount of capital stock in the current period is determined by the depreciated amount of capital stock, raised by physical investment, in the previous period. In the same way, the stock of knowledge in the current period can be determined by net R&D investment carried out in the previous period (equation (15)). Equation (16) determines the stock of variety capital endowment per sector, which grows according to the lagged investment in variety capital. To be consistent with the assumption 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 Modeling Labor and the Capital Market

In the CGE model, there is no distinction between skilled and unskilled labor in this stage, and labor can freely move between the sectors in the domestic economy. In addition, the interactions of labor with the EU and the rest of the world are modeled in a fixed proportion (based on the National Accounts in 2008, about 1% of labor was employed abroad).

The total supply of labor in the economy is fixed and a certain proportion of the labor force is unemployed. Unemployment is determined from equation (17), which assumes an inverse relationship between the growth of real wages and the growth of the unemployment rate, following the macroeconomic basis of the Phillips curve:

$$\begin{aligned} &\frac{PL}{PCINDEX} \Big/ \frac{PLZ}{PCINDEXZ} - 1 = \\ &= phillips\left( \frac{UNEMP}{LABORFORCE} \Big/ \frac{UNEMPZ}{LABORFORCEZ} - 1 \right) \end{aligned} \tag{17}$$

where *PL* and *PLZ* are the equilibrium wage rates in the current and base year, *PCINDEX* is the consumer price index, *UNEMP* and *UNEMPZ* represent the number of unemployed persons in the current and base period, and *Phillips* is a parameter taken from the literature, set at –0.45.

The consumer price index used in equation (17) is calculated as a Laspeyres price index measuring the change of the consumer price level with respect to the base year:

$$PCINDEX = \frac{\left( \sum_j \left(1 + tc_j\right) P_j \cdot CZ_j \right)}{\left( \sum_j \left(1 + tc_j\right) PZ_j \cdot CZ_j \right)} \tag{18}$$

where $tc_j$ and $P_j$ are the indirect tax rates and consumer prices charged for commodity $j$ and $CZ_j$ is consumption of commodity $j$ in the base year. Both wages and consumer prices are in fact relative prices compared to a numeraire (in this model, the GDP deflator). Inflation can thus be measured as the deviation of consumer prices with respect to the GDP deflator in the current and base year.

The equilibrium wage rate is determined from the market-clearing equation for labor, in which the total demand for labor in all sectors $i$ meets the total supply reduced by unemployment:

$$\sum_i LSK_i = LABORFORCE - UNEMP \tag{19}$$

Finally, the equilibrium wage rate that is determined in the market-clearing equation is adjusted by multiplying it by a sector-specific wage differential which takes into account wage disparities across industries. The wage differentials were calculated based on labor statistics provided by the Czech Statistical Office.

In the short term, the stock of capital in each production sector is fixed, and in the long term it grows according the growth of net investment, following the recursive type of dynamization. As the investment can be allocated freely among production sectors, the capital is homogenous and there are no capital vintages. Capital stocks defined from the recursive equations 14–16 are employed in the production process, and the demand equations for capital derived from the CES production functions determine the equilibrium price of capital. Subsequently, the rent from all forms of capital is distributed across all institutional sectors based on a fixed share obtained from the calibration procedure. Following the national accounts, there are three institutional domestic sectors distinguished in the CGE model—households, firms, and the government.[2]

### 3.5 Assumptions about Households, the Government, and the Foreign Sector

The behavior of households in the Czech economy is simulated by introducing a representative household, which optimizes its utility subject to a budget constraint.

[2] Whereas households and the government maximize utility, there is no optimization behavior considered in the case of firms—they provide savings that result from the difference between firms' capital income and transfers paid to other institutions. Their separate record in the CGE model is mostly related to accounting.

Whereas microeconomic theory provides numerous suggestions, a standard choice in the field of CGE models is the Stone-Geary Linear Expenditure System (*LES*), which incorporates a subsistence level into the utility function (equation 20).

$$U = \prod_j \left( C_j - \mu Hj \right)^{\alpha HLESj}, \quad \sum_j \alpha HLES_j = 1 \tag{20}$$

where $U$ is the consumer's utility, $C_j$ is the amount of consumption of the $j$-th commodity, $\mu H_j$ represents the subsistence level of consumption of each $j$-th commodity,[3] and $\alpha HLES_j$ is a preferential parameter of the $j$-th commodity in the consumer basket.

The household's consumption budget is determined by the net value of its income after taxation and transfers, reduced by its savings.

In the CGE model, the government is also introduced as an optimizing agent that maximizes utility subject to the disposable budget, derived from income received on the basis of tax collection. Unlike in the case of households, it is not necessary to incorporate the subsistence level into the government's utility function. This enables us to work with the simpler Cobb-Douglas type of utility function:

$$U = \prod_j CG_j^{\alpha CG_j}, \qquad \text{where} \quad \sum_j \alpha CG_j = 1 \tag{21}$$

where $CG_j$ is government consumption of commodity $j$ and $\alpha CG_j$ represents a preferential parameter in the government's consumption basket.

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 the producer to find the most profitable combination of supply between foreign and domestic markets, modeled with a Constant Elasticity of Transformation *(CET)* function, and second, the intention of the consumer to find the optimal combination of imported and domestically produced commodities, modeled with a *CES Armington* function. The optimum export supply derived from the CET function meets with foreign export demand and the equilibrium export price is determined (a schematic representation of foreign trade flows is provided in *Chart 4* in *Appendix*). An extension to the foreign market equations has been carried out in order to model trade and financial flows on a disaggregated level comprising the EU foreign sector and the Rest of the World (RoW).

### 3.6 Closure Rules and Baseline Assumptions

CGE models typically include three macroeconomic balances: the government balance, the external balance (the current account of the balance of payments, which includes the trade balance), and the savings-investment balance (Lofgren, Lee, and Robinson, 2002).

In this CGE model, closure of the government account is arranged by fixing the ratio of government consumption to GDP. Government savings are thus adjusted to the difference between government income and expenditure.

[3] If $\mu H = 0$, the *LES* utility function is reduced to the Cobb-Douglas utility function.

Concerning the external balance, foreign savings are set exogenously and equilibrium in the current account is achieved by an endogenous exchange rate, which is in line with the floating regime adopted in the Czech Republic.

The savings-investment balance is necessary to ensure the condition of Walras' law and the absence of leakages in the economy.[4] This condition requires total investment resources, which are represented by domestic and foreign savings and the depreciation of capital, to be spent on investment in capital goods. In this model, the adopted closure is savings-driven, which requires the value of investment to adjust to total savings (an alternative option is investment-driven closure, where savings adjust and the level of investment is determined from total savings).

Finally, the assumption of a small country case is applied in the model. This requires world import and export prices to be fixed.

The evolution of exogenous variables follows the projections of the Czech Ministry of Finance (April 2012) and the 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 at a rate of 2% in the coming period and then accelerate to 5% annually.

### 3.7 Calibration of the CGE Model with Capital Varieties

The base year for the 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.[5] Several assumptions, described below, were adopted in the process of constructing the SAM and calibrating the model.

#### 3.7.1 Assumptions Concerning Production Factor Remuneration

Frascati Manual statistics on GERD (CZSO, 2011a,b) were used to obtain the labor 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 (CZSO, 2011b). It is assumed that the share of variety capital in total capital remuneration is approximately 15%, which corresponds to the share of gross R&D expenditure in the 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 remuneration.

[4] In the case of multi-country CGE models such as GTAP, the macroeconomic closure of savings-investment does not need to hold for an individual country, but does need to hold for the region as whole. However, as the aim of this research is to model a single economy, this closure rule must hold on the country level. Endogenizing the EU foreign sector and the Rest of the World in the CGE model was beyond the scope of this exercise.

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

### 3.7.2 Calibration of Stock Variables

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

$$VKSKT = \frac{YKVT}{growth\_privateRD} \tag{22}$$

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 expenditure (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*:

$$PKV_i = \frac{YKV_i}{VKSKT} \tag{23}$$

### 3.7.3 Calibration of the Private R&D Sector with Monopolistic Competition

The 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 Bye et al. (2008):

$$FCOST = \left(1 - tp_i\right) \cdot PD_i \cdot XD_i \cdot \left(\frac{1}{elasVK * NOV}\right), \qquad i \in \text{secRDic} \tag{24}$$

where $tp_i$ is the subsidy rate of the private R&D sector, $PD_i$ is the 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 are CZK 8 billion, which represents 20% of the sector's total costs.

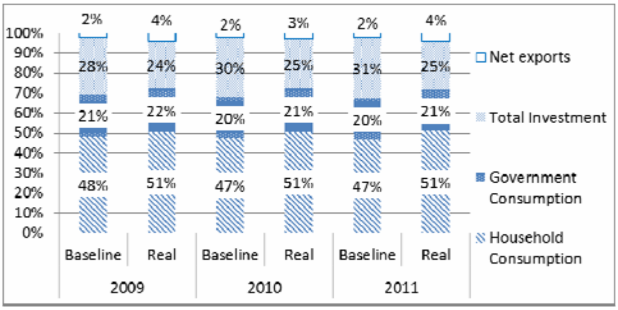
It is assumed that the fixed costs arise from the employment of labor and knowledge, which form an important part of the added value of private R&D firms. Fixed labor costs are calculated from the share of researchers employed in the R&D

**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 | 1,825 |
| Total fixed costs in the private R&D sector (bln CZK) | 8.57 |
| Share of fixed costs in total costs | 20% |
| Fixed costs of labor in the private R&D sector (bln CZK) | 2.38 |
| Share of fixed labor 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.

**Figure 2 Comparison of the Baseline and Real Structure of GDP Expenditure**




*Sources:* Author's calculation and CZSO data (2013a).

**Table 3 Comparison of Baseline and Real Structure of the Net Value Added (in %)**

| | 2009 | | 2010 | | 2011 | |
|---|---|---|---|---|---|---|
| | **Baseline** | **Real** | **Baseline** | **Real** | **Baseline** | **Real** |
| Primary | 4 | 3 | 5 | 3 | 5 | 3 |
| Secondary | 36 | 37 | 37 | 37 | 37 | 37 |
| Tertiary | 59 | 60 | 58 | 60 | 58 | 60 |

*Sources:* Author's calculation and and CSO data (2013b).

process in the total number of employees. Based on the Frascati survey, this share is about 21%. Labor costs for researchers were calculated using publicly available statistics on wages in research—in 2008, the average wage in research was about CZK 29,000. The fixed costs of knowledge were derived as the remaining component of the total fixed costs after subtracting labor costs.

### 3.8 Verification of the Constructed CGE Model

The presented CGE model was verified by following standard verification procedures. First of all, the ability to correctly replicate the economy was checked by removing all infeasibilities in the benchmark equilibrium. The second procedure tested whether Walras' law holds in the case of an exogenous shock brought to the model. For this purpose, the balancing equation of the labor market was excluded from the system of equations in order to verify if the labor market equilibrium still holds. The third check tested the homogeneity of degree zero in prices by multiplying the *numeraire* by a chosen constant and controlling whether the real quantities remain unchanged. All tests proved the correctness of the CGE model.

Although CGE models are designed primarily for scenario analyses rather than for prognostic purposes, it is possible to assess the predictability of the model by comparing its outcomes with real historical values. Since in the ex-post period, GDP is set exogenously in order to copy its real development, it is only possible to assess the differences in the baseline structure of GDP and the real GDP structure. *Figure 2* shows that the structure of GDP expenditure in the period 2008–2011 predicted by the model is closely comparable to the structure of GDP expenditure observed in this period.

Another comparison can be done with respect to the structure of value added. *Table 3* shows that the baseline of the model is comparable to the real figures for the participation of the primary, secondary, and tertiary sectors in the total net value added.

## 4. Results

The incorporation of capital varieties into the CGE model allows us to assess the efficiency of government support in various simulations. Specifically, 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.

### 4.1 The Efficiency of Government Support for the Private R&D Sector

In 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 toward 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 taxpayers, 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 of all production sectors. In light of this fact, this section 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.

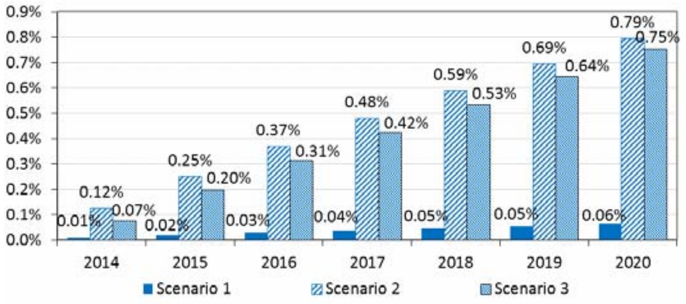
Before introducing the scenarios, it should be noted that in this exercise, the agricultural sector is modeled as a private sector without market failures (attempts to incorporate public goods features in agriculture into the CGE model are complicated by a lack of empirical evidence, as shown in Kristkova et al., 2011).

The analysis is performed in three scenarios, which are described in *Table 4*. The baseline scenario is the status quo. It 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 government 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 government 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 government subsidies from agriculture to private

**Table 4 Scenario Definition (in %)**

| 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 |

**Figure 3 Effects on Real GDP—Deviation of Scenarios from the Baseline**




*Sources:* Author's calculation.

research and thereby responds to the question "*What happens if the government shifts all support from agriculture to the private R&D sector?*"

It should be noted that all the scenarios considered affect government income (subsidies charged to producers are recorded in the government income equation as negative taxes). Increased subsidization of the R&D sector will result in lower government income, which will be reflected in reduced government savings (for this reduction there is no compensation by increased income tax).

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

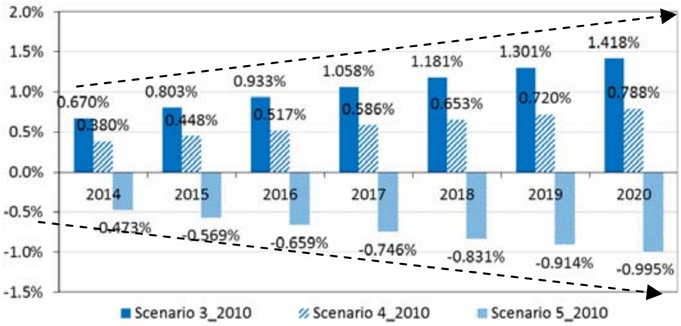
Due to the fact that Scenarios 1–3 are asymmetric and are applied as from 2014, which gives the model only a short time to adjust, additional simulations were carried out to obtain a comprehensive overview of the GDP effects under different subsidy options. The scenarios described in *Table 5* aim to compare three situations—*no agricultural subsidies from 2010 on* (Scenario 3_2010), *both agricultural and R&D subsidies* (Scenario 4_2010), and *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.

The results of this simulation are displayed in *Figure 4*. The dashed arrows can be understood as a band in which GDP can oscillate depending on government choices. If subsidies are fully reallocated from agriculture to private research, then

**Table 5 Scenario Definition 2 (in %)**

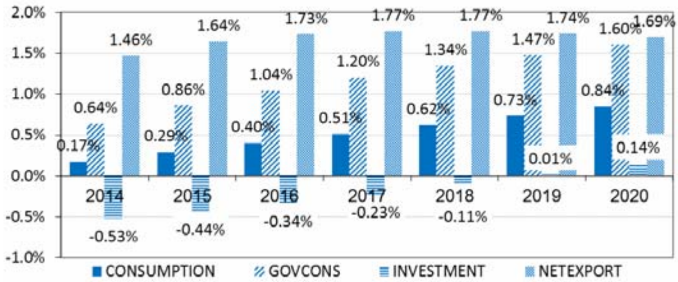
| Production sector | Subsidy rate (share of gross production) | | | |
|---|---|---|---|---|
| | Baseline (2008–2020) | Scenario 3_2010 (from 2010 on) | Scenario 4_2010 (from 2010 on) | Scenario 5_2010 (from 2010 on) |
| Agriculture, fisheries, forestry | 10.5 | 0.0 | 39.5 | 39.5 |
| Private R&D sector | 8.5 | 39.5 | 39.5 | 0.0 |

**Figure 4 Effects on Real GDP—Deviation of Scenarios from the Baseline**




*Sources:* author's calculation

**Figure 5 Deviation of GDP Components from the Baseline in Scenario 3**

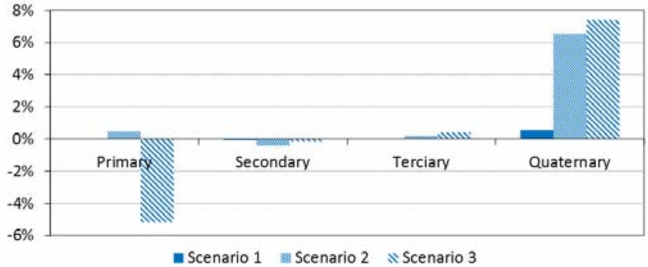



*Sources:* Author's calculation.

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 on GDP can be further decomposed into particular sources of growth. *Figure 5* focuses on changes in household consumption, investment, 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 investment is positive only over the long term; in the short term, there is a slight decline due to a reduction in government and firms' savings. In the case of government savings, Scenario 3 imposes greater pressure on the government's budget, which leads to a decline in savings (the closure rule implies that government savings adjust to the difference between government income and expenditure). 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. The effects on final consumption become more positive in the longer term, when households recover from the in-

**Figure 6 Deviation of Value Added from the Baseline**




*Sources:* Author's calculation.

creased prices and the temporary growth of unemployment, as explained below. Finally, the evolution of government consumption is positive and parallels GDP growth. This is determined by the closure rule (fixed government consumption as a proportion of GDP).

It is also possible to analyze the structural changes in the economy produced by the scenarios considered. *Figure 6* indicates that the participation of the primary sector would decrease in favor 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 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. This is related to the backward linkages of industry with agriculture.

The increase in the quaternary sector can be further analyzed 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 modeled 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 6*, which shows the percentage changes versus 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. This leads to an expansion in the number of private R&D firms in the sector.

**Table 6 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.

**Table 7 Deviation of Macroeconomic Variables from the Baseline in Scenario 3 (in %)**

| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|
| Unemployment | 0.68 | 0.91 | 0.99 | 0.97 | 0.85 | 0.64 | 0.36 |
| Comsumer Price Index | 0.56 | 0.66 | 0.73 | 0.77 | 0.81 | 0.83 | 0.84 |
| Exchange Rate Index CZK/EU | 0.27 | 0.31 | 0.34 | 0.37 | 0.40 | 0.43 | 0.46 |
| Wage index | 0.27 | 0.31 | 0.37 | 0.44 | 0.54 | 0.64 | 0.75 |
| Equivalent Variation | -4.89 | -3.17 | -2.21 | -1.50 | -0.88 | -0.36 | 0.06 |

*Source*: Author's calculation.

*Table 6* also shows that as a result of the government policy, investment in variety capital increases substantially. Moreover, due to the ties between the private and public R&D sectors, investment in knowledge is also stimulated.

Finally, it remains to be discussed what repercussions the reallocation of government support might have on the labor market and other macroeconomic variables (*Table 7*). In this case, more adverse effects can be observed.

First of all, the unemployment rate could go up in the short run as a consequence of the contraction of agriculture, which is more labor 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 government 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 labor to be scarcer. This is further transmitted to the current account balance, which suffers from higher payments to labor 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 the welfare of households is negative (the equivalent variation immediately falls by 5%). This 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.

### 4.2 Sensitivity Analysis—the Effect of the Substitution Elasticity of Variety Capital

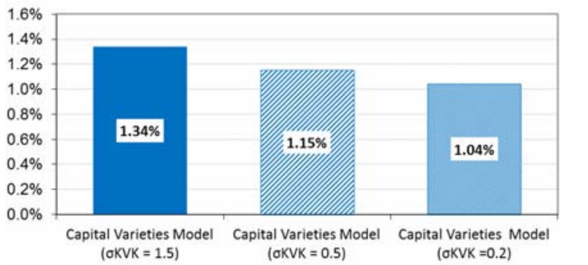
In this section, the robustness of the results is checked by performing a sensitivity analysis with respect to the elasticity of substitution between variety capital and homogenous capital. The elasticity of substitution $\sigma_{KVK}$ is related to the parameter $\sigma KVK$ in the CES function (equation (10)) according to the formula:

$$\sigma KVK = \frac{1}{1+\rho KVK} \tag{25}$$

At first, the sensitivity analysis focused on the differences in baselines under different substitution elasticities. The results are provided in *Figure 7*. It can be concluded that the greater is the ability of the economy to convert homogenous capital goods to variety capital, the higher is the economic growth achieved.

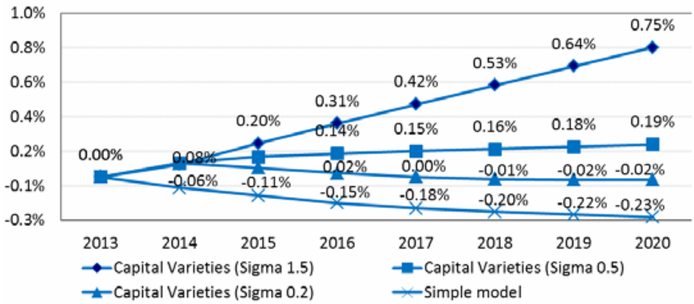
Given that the different values of substitution elasticity affect the projections of baseline growth rates, they might also affect the behavior of the model in

**Figure 7 Baseline Growth Rates of Real GDP (2008–2020)**




*Source*: Author's calculation.

**Figure 8 Deviation of Real GDP in Scenario 3 from the Baseline—Sensitivity Analysis**




*Source*: Author's calculation.

the scenarios considered (in this case, Scenario 3 is used, as it is the most radical). *Figure 8* shows that in the short run, GDP in Scenario 3 positively deviates from the baseline under all elasticity alternatives, although in the longer term the results diverge. It can be observed that with higher substitution elasticity, the shifts of government support from agriculture to the private R&D sector yield noticeably higher positive effects. When there is limited substitution between the two types of capital, the shock produced by removing the subsidy in agriculture is not compensated by stimulated productivity of capital. Finally, the case of a simple CGE model without R&D-driven production of variety capital is shown here to illustrate the difference in the response to the policy shock—the reallocation of subsidies from agriculture to R&D in the simple CGE model generates an immediate negative effect on GDP, as the model does not capture properly the positive effects of the R&D sector in the economy.

The sensitivity analysis thus revealed that the reallocation of subsidies from agriculture to private research leads to a positive GDP effect in the model with the highest substitution elasticity between capital varieties (+0.75% in 2020), whereas in the standard model, which omits R&D effects, the GDP effect is negative (–0.23% in 2020). These results confirm the preliminary hypothesis that the standard CGE models underestimate the R&D effects and could produce biased estimates. According to *Figure 8*, the simulation bias can be as high as 1% of GDP, which is not a negligible error.

## 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 strong interaction with foreign R&D; this has been analyzed in various studies, such as Lejour and Rojas-Romagosa (2008). Moreover, in practice, private and public R&D are not distinguishable and can act together in synergy. This feature has been partially captured in the CGE model by the knowledge links between the public and private R&D sectors. *Table 6* showed that with increasing support for the private R&D sector, the public R&D sector would also see higher investment, due to spillover between the two sectors.

There are several directions in which this methodological approach can be 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 investment over longer time horizons, and they may reveal interesting findings. Another important extension to the present CGE model is the incorporation of human capital, following the idea of Lucas (1988), who showed that human capital formed by education has positive effect on economic growth. As the results in *Table 7* indicated, investment in R&D can reduce the demand for labor because the economy becomes more capital intensive (capital varieties replace labor). This is in line with the findings of Yungchang et al. (2010), who simulated the impact of increased public R&D investment in Taiwan in their CGE model and found an adverse effect on unemployment due to advances in technology. As a solution, the authors advise the government to enhance vocational and technical training in order to upgrade the labor force. The role of human capital is thus important to enable the economy to benefit from R&D-stimulating government policy. As the inventions of new designs that are converted to varieties require human capital, the adverse effects on the labor market might be smaller. This notion should thus be better captured in the present CGE model. A possible way to introduce the linkage of R&D with human capital would be to incorporate the supply of high-skilled labor that can be employed in the R&D sector and model it as a complement to variety capital, following the arrangements of Rojas-Romagosa (2010) in the World Scan model.

Finally, it should be emphasized that the scenarios concerning the complete removal of agricultural subsidies are used for 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 agriculture—like the R&D sector—can 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 farmers' contributions to the landscape, biodiversity, and food security, which all have the nature of public goods.

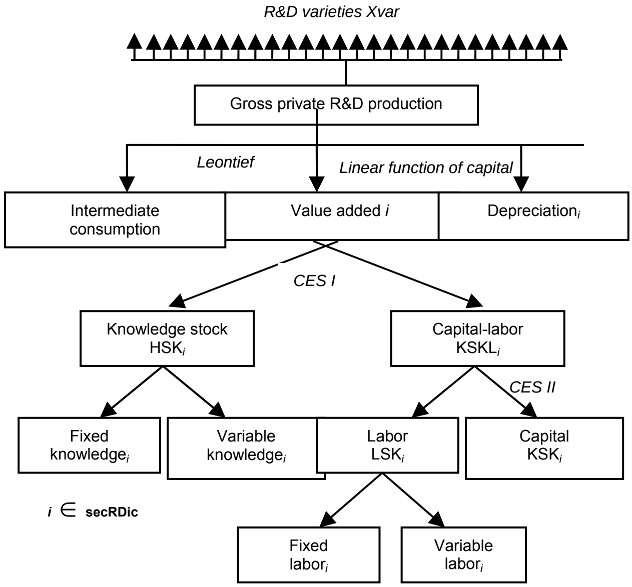
## 6. Conclusion

This paper analyzed 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. It was discovered that the dynamics of GDP growth are positively related to the production of capital varieties and the elasticity of substitution between homogenous and variety capital. Due to this fact, if the government allocates more subsidies to the private R&D sector, the economy can be stimulated, even at the expense of the final goods sector—as demonstrated on 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 labor for capital varieties.

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

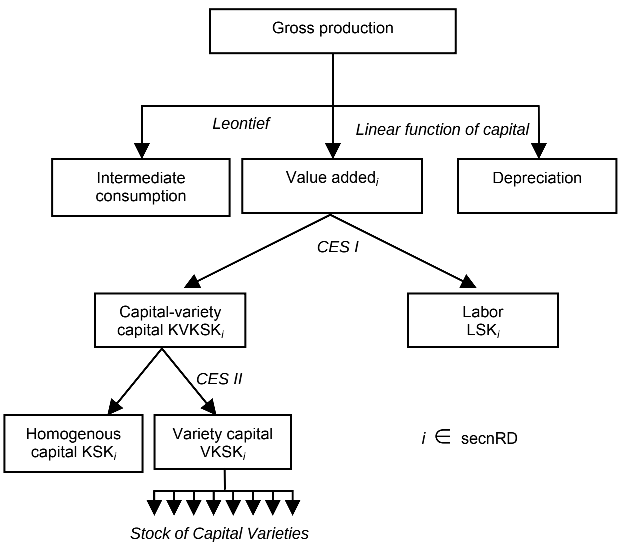
# APPENDIX

## Chart 1 Production Structure of the Private R&D Sector



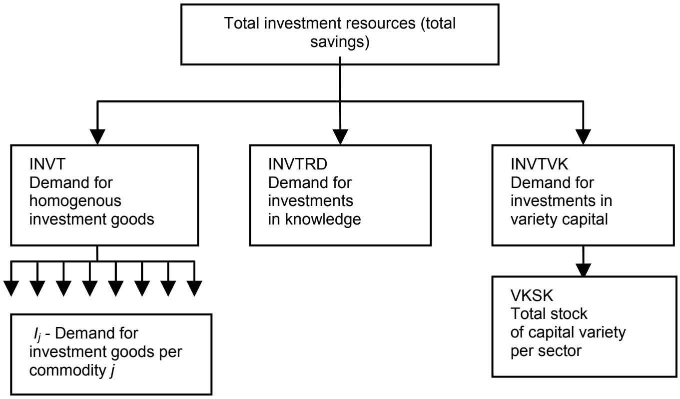

*Source:* Author's elaboration.

## Chart 2 Production Structure of the Final Goods Sector



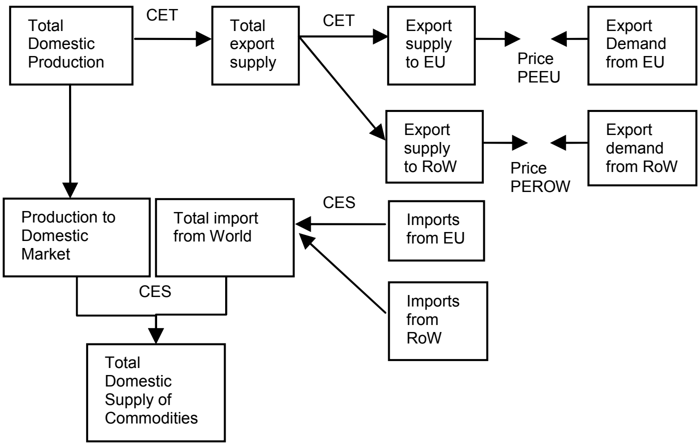

*Source:* Author's elaboration.

**Chart 3 Demand for Investment Goods in the CGE Model**




*Source:* Author's elaboration.

**Chart 4 Incorporation of the Foreign Sector into the CGE Model**




*Source:* Author's elaboration.

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