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The effects of R&D expenditures on economic growth

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Introduction

In this diploma thesis I want to analyze the link between research and development expenditures and economic performance of a country. This means how the research and development expenditures affect the economic growth and on the contrary how the economic growth affects the R&D expenditures. These two main questions of this thesis require building my thesis on the assumptions and models of new (endogenous) growth theory instead of neo-classical (exogenous) growth theory. Consequently, the assumption that people can influence the growth of their economy and technology to some extent plays here an essential role. However, there are some exogenous factors being so complex or big that people cannot (entirely) influence, 'endogenize' them, they can just react to them but not 'interact' with them. I call the set of these exogenous factors as nature.

This thesis basically consists of two main parts: in the first part I will detail the model and its theoretical background and in the second part of this thesis the estimation results will be presented.

As an introduction I would like to explain more detailed the (basic) motivation(s) behind this thesis. Basically I will analyze whether systematic research activities[1] significantly increase the productivity of an economy[2]. I would like to emphasize here that R&D expenditures are special investments in such activities where the effects of outcome on economic performance are very uncertain (zero effect or very high, multiplicative effects) but these (experimental) activities are necessary for development of our life. The (successful) products of R&D activities – I call them R&D products – are inventions and innovations that primarily increase the technological level of an economy and secondarily (after successful distribution (realization) of R&D products in the economy) the productivity of the given economy. However, this improvement in technological level is not directly observable; such improvement in overall technological level can be indirectly observed – e.g. productivity growth of an economy, more efficient products may refer to such improvement in technology. Furthermore (economic) productivity of an economy is expressed in prices and values which may not perfectly reflect the technological change in the total economy. For instance, new technologies may reduce the production costs primarily in the long run that may result in lower prices but more efficient products may cost more money in the short run (cet. par.[3]) – thus the effects of R&D activities on production factors and production processes may offset each other in the short run and hence these effects would not be reflected in prices and values of products – first of all in case of competition. Hence I will analyze in the empirical part whether and how the R&D expenditures and activities influence the economic performance in each year based on nominal data and additionally how useful these observations for economic policy can be.

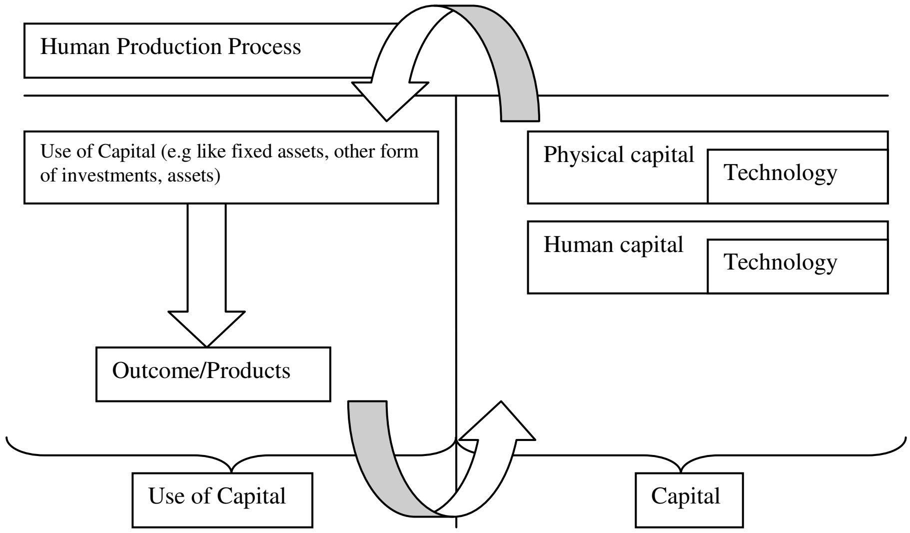
So, R&D expenditures and activities may directly or indirectly affect the overall technological level of an economy through their (realized) products in the given economy. Endogeneity or

[1] R&D activities
[2] Because of data availability the US economy and US R&D expenditures will be analyzed in the empirical part of this thesis.
[3] Ceteris paribus

semi-endogeneity of R&D expenditures and activities in the model play a role to some extent because (i) R&D activities as systematic research activities refer to the use of past experiences, earlier produced goods in a special production process in order to create something new and (ii) these 'new' products also affect the future development of R&D activities; (iii) however, assumption of (entire) exogeneity of technological progress would automatically mean that R&D activities are unnecessary because there would be no systematic activity that would improve the probability of inventions and innovations in an economy because of (entire) exogeneity.

In growth theories the production processes (including R&D activities) in a human economy involve the use of the three basic production factors: technology, physical and human capital – by basic assumption the result(s) of any use of any production factors can be either technology or physical or human capital or any mix of them. However, this ranking of production factors implicitly presumes the existence of mental capital (e.g. mind, knowledge, abilities, skills) as part of human capital and other creatures in the nature that are attached to physical capital. Consequently, the three basic production factors are from my point of view: physical and mental capital and technology – detailed explanation of production factors you will find in the first part. One can assume now that every element of the nature can be ranked into physical or mental capital or technology or mix of them. The quality and quantity of these factors in any production processes determine the overall economic performance of given type (e.g. human economy, ants' economy etc.). From human point of view, in a human economy the physical capital denotes every element of the nature that cannot be attached to human capital, hence every creature other than human is considered as physical element. I want to remark here that generally these factors are called labor input or physical capital input – additionally the physical capital input can be divided into fixed assets and intermediate inputs. So, the change in economic performance between given points of time is a result of the overall quality and quantity of products and factors that have been produced and remained in/after production processes in an economy. Hence, economic performance/growth/decline has basically two main dimensions: quality and quantity. However, the growth of both dimensions may be correlated and may a result of technological progress – e.g. better marketing techniques may lead to higher sales cet. par.; efficient production process may lead to lower costs and prices of goods cet. par. and hence it may lead to higher sales cet. par.; more qualitative goods may attract more people cet. par. and hence they increase the production cet. par. However, the production processes are so complex in an economy that usually common effects of 'used' technologies in the given economy are observable but the different effects cannot be separated from each other. Consequently, prices and values reflect projections of such common effects into nominal data – the aggregate common effect of production factors is generally called as multifactor or total factor productivity (MFP, TFP, respectively). MFP or TFP serves usually as a measure of technological level.

I would like to remark here that technology is not always directly observable; it is hidden in the qualities of production factors and elements of nature. It (technology) can be observable and evaluable if the elements of nature have been used and appropriate conversion system(s) is(are) available. An idea of human production process:



This idea shows that new technologies are/may be the result of using physical and human capital and they (new technologies) should enrich the characteristics of physical and human capital. Hence the technological progress becomes endogenous to some extent. I assume that nature's role cannot be entirely excluded from any production processes and hence technological progress cannot be entirely endogenous. In neoclassic growth models like Solow-Swan model the technological progress is assumed as exogenous. In new growth theories the (semi-)endogeneity of technological progress and economic growth is an issue. Therefore the model I will use and estimate in the empirical part will be close to models of new growth theories.

However, I will build a model based on the idea of separation of state of technology and labor efficiency and separation of qualitative and quantitative features of production factors. The model has a form A^KKA^LL where A^K and A^L denote the overall level of physical and human (or labor) related technologies, respectively, that are attached to given physical capital or acquired by some people in order to improve some or all of their characteristics (efficiency, productivity, ability, etc.). The intuition is that the effects of installed new capital on the given production process depend both on its characteristics (quality like efficiency, productivity, quantity) and on the characteristics of its environment like labor quality and quantity – i.e. it does matter who, when, how long and how much people uses the given physical capital. Our social and education system tends to support the selection/ranking of people into different jobs regarding their qualities but not their quantities - e.g. excess supply of people in given fields of work. In the A^KKA^LL model the state of technology is denoted by A* and the labor efficiency by A. Labor efficiency depends on A* and an additional factor denoted by X. X refers to the knowledge distribution possibilities in the economy. R&D expenditures enter as an external effect into the model that may improve the probability of creating new (successful) designs (i.e. innovation, invention). Further specifications in and explanation of the model and variables can be found in the next chapter (Theoretical Part).

In the empirical part you will find the analysis of aggregate US economic performance and aggregate US R&D expenditures as well as their effects on each other. I will use yearly nominal data in order to use Fisher Price and Ideal Quantity Indices in the regressions.

1. Theoretical Part

In the opening section of the theoretical part I will briefly discuss the basic aggregate production functions and growth models. This section serves as a contribution to the better understanding of evolution of growth theories and to the better comprehension of my model. This section focuses on the advantages and drawbacks of exogenous and endogenous growth models and on that how for the drawbacks of these models can be corrected. The main intuition behind these growth models is to build a model that can capture as good as possible the effects of production factors and external effects on aggregate production and economic growth and additionally this model should serve as a good tool for influencing, controlling the economic activities, growth, especially in the long-run. In other words these models try to explain the economic growth through accumulation of production factors, exogenous or endogenous technological progress, population growth and different assumptions on return to scales in the model. However, despite of different assumptions on economic growth the production factors are the same in each model. The three basic type of production factors are the following: capital (K), labor (L) and technology (F* and A). Later I will exactly define the basic production factors that are essential for production processes.

1.1. A brief overview of production functions and growth models:

1.1.1. Exogenous growth theory:

First of all I would like to present the initial aggregate production function for the sake of better comprehension and comparison of different growth models:

$Y(t) = F^*(K(t), L(t), t)$

Y(t) denotes the products (‘produced goods[4]’) in period t;
K(t) denotes the capital stock in period t;
L(t) denotes the labor force in period t;

And F*: $\Re^3_+ \mapsto \Re_+$ is a production function (technology) that expresses the basic production process: a single output good is produced from two inputs. Thus F* is a technology that is responsible for (good or bad) combination (use) of production factors. F* may vary with respect to time because technological change is possible. It is obvious that this model does not take (explicitly) into account the technology affiliated to production factors. Consequently in this model the technological progress is inconsistent with the balanced growth path. The Harrod-neutral technological progress is the only form of technological progress that is consistent with a balanced growth path and the aggregate production function has the form and satisfies the following condition:

$Y(t) = F(K(t), A(t)L(t)) = F^*(K(t), L(t), t)$ and $Y(t) = K(t)^{\alpha}[A(t)L(t)]^{\beta}$

A(t) denotes the state of technology or set of technologies or labor efficiency in period t. A(t)L(t) denotes the effective labor force. F exhibits constant returns to scale if $\alpha+\beta=1$.

[4] Goods refer to ’goods and services’.

Remark: A(t)K(t) would mean the effective physical capital and hence A(t) the physical capital efficiency. Such representation of the model would be interesting if somebody wants to analyze how the physical capital efficiency differs across different types of creatures. In this case the aggregate effects of all technology in the given production process would be attached to physical capital instead of labor. The type of addition of technology to factor capital or factor labor changes only the interpretation of estimated values but not the estimated values. However, it shall be noted that measuring of efficiency of any given production factor requires the use of production factors and the use of production factors means a particular production process. It will be detailed later.

Furthermore the technology affiliated to production factors determines the quality (efficiency) of production factors, by assumption. Let the (labor) efficiency be called as an observable quality of the (total or aggregate) production process of an economy in a given period of time. Usually the value added in a given production process reflects this efficiency. It is obvious that the (aggregate) efficiency depends on (i.e. positively related to) the "amount" of quality of production factors – i.e. 2 units of a same production factor may produce more value added than 1 unit of the same factor ceteris paribus - and on the way how (often) these production factors have been combined (used) with each other. In section 1.2 of this thesis A^K, A^L and 'x' denotes the quality of physical, human capital and the way of production, respectively. Consequently function F determines the output if the aggregate quality and amount of production factors and the way of production are given. This shall be increasing with all of these factors – for instance the way of production "increases" if the efficiency of production methods increases. However, it is very complicated to analyze on aggregate level which variables induced the economic growth because what we can observe is only the change of efficiency affiliated to a given production factor – this affiliated efficiency depends not on the factor itself but on 'x' and other variables that have impact on the efficiency of this factor. In the following I work with A(t).

If the production function exhibits constant returns to scale[5] (i.e. F is linearly homogenous), the following transformations can be made:

y(t) = Y(t)/[A(t)L(t)] denotes the output per unit of effective labor;
k(t) = K(t)/[A(t)L(t)] denotes the capital stock per unit of effective labor;

and y(t) = F(K(t), A(t)L(t))/[A(t)L(t)] = F(k(t), 1) = f(k(t))[6].

f is a continuous function and its first two derivatives f'(k) and f''(k) exist and are continuous for all k>0. Furthermore: f'(k)>0, f''(k)<0 and f(0)=0 for all k>0. It satisfies additionally the Inada conditions: $\lim_{k\to 0} f'(k) = +\infty$, $\lim_{k\to +\infty} f'(k) = 0$.

(Simple) Dynamics of capital accumulation in the Solow-Swan model framework (1956):
$Y(t) = F(K(t), A(t)L(t)) = K(t)^{\alpha}[A(t)L(t)]^{1-\alpha}$
$dA(t) = gA(t)$, $A(0) = A_0$
$dL(t) = nL(t)$, $L(0) = L_0$
S(t) = I(t) = sY(t)
Y(t) = C(t) + I(t)
C(t) = (1-s)Y(t)

[5] It means: F(ßK, ßAL) = ßF(K, AL)
[6] f: $\Re_+ \mapsto \Re_+$

$dK(t) + \delta K(t) = I(t), K(0) = K_0$

This is an aggregate production process in closed economy with constant returns to scale and exogenous population growth (n), technological progress (g), saving rate (s), A_0, L_0, K_0, F and δ (depreciation rate). Further assumptions: $0<\alpha<1$, $n+\delta+g>0$, $0<s<1$, $A_0>0$, $L_0>0$, $K_0>0$.
The steady state k* is determined by the equation: $sf(k^*) = (n+\delta+g)k^*$.
The balanced growth path is characterized by the following equations:

$K(t) = k(t)A(t)L(t) = A_0L_0k^*e^{(n+g)t}$
$Y(t) = f(k(t))A(t)L(t) = A_0L_0f(k^*)e^{(n+g)t}$
$k'(t) = K(t)/L(t) = A_0k^*e^{gt}$
$y'(t) = Y(t)/L(t) = A_0f(k^*)e^{gt}$
$c'(t) = C(t)/L(t) = (1-s)A_0f(k^*)e^{gt}$

Based on these equations, the only exogenous variable that affects the technological progress is the rate of technological progress g because the long-run growth rate is $\lim_{t\to+\infty}\gamma_{y'}(t) = g$.

1.1.2. Solow-Swan model with human capital – Mankiw, Romer, Weil (1992):

Historically this is not the next growth model after the Solow-Swan model but I think it is better to represent now this model.

$Y(t) = F(K(t), H(t), A(t)L(t)) = K(t)^\alpha H(t)^\beta [A(t)L(t)]^{1-\alpha-\beta}$
$dA(t) = gA(t), A(0) = A_0$
$dL(t) = nL(t), L(0) = L_0$
$dK(t) = s_KY(t) – \delta K(t)$
$dH(t) = s_HY(t) – \delta H(t)$

All variables have the same interpretation as in the above model. H(t) denotes the human capital in period t that depreciates at the same rate like physical capital. Technological progress remained exogenous but human capital accumulation is explained in the model.

Human capital in economics means the acquired skills like teaching skills, learning skills, awareness skills, memory skills, driving skills etc. Remark: learning skills are important for the existence of both types of human capital accumulation (learning-by doing and education type of accumulation); the existence of knowledge requires in my opinion the existence of learning and memory skills. So, knowledge is based on the existence of skills. Knowledge is non-rival and excludable because of the existence or lack of some skills or other artificial barriers like patents, secrecy.
However, I call human capital the mix of human related physical and mental capital like body (physical) and knowledge, skills (mental). Consequently, the accumulation of this human capital implies/involves the accumulation of skills and knowledge. In my opinion the accumulation of skills and knowledge play important and necessary condition for technological progress. However, the simple quantitative accumulation of skills and knowledge is not sufficient for technological progress. Qualitative improvement of skills and knowledge is essential for the increase of state of technology.
Quantitative accumulation means the accumulation of existing skills and knowledge available in the world. Qualitative accumulation means the more efficient use of skills and knowledge. Both are essential for technological progress. Experience means something new that enrich the mental capital of people. Arrow, Lundberg and Verdoorn connect the 'learning-by doing'

effects (i.e. using the production factors more efficient) to quantitative accumulation of experiences. It means more experienced people are expected to use more efficient the given products and expected to be more productive. I agree with this assumption but it shall be noted that this statement is not true for all types of jobs, working activities. For instance elder athletes are expected to know how to use more efficient "themselves" in order to reach higher level of sport performance but they are restricted by their "old" body. However, they can give suggestions to younger athletes whose performance (efficiency) can be improved in this way. Consequently, the time, the age of people restricts partly the human capital efficiency. Remark - Efficiency: I call efficiency or inefficiency a (relative) characteristic, quality of a given factor in a given application range. In order to measure it (efficiency, inefficiency of a factor) there is a need for the use of at least two factors of fixed type and in fixed application range. It means the efficiency or inefficiency of factors in a given application range or type of use depends on the performance of more factors in the given application range. If an outcome of using a factor lies over the average outcome in the given application range then this factor is efficient. If an outcome of using a factor lies below the average outcome in the given application range then this factor is inefficient.

Assumptions in the model: $0<\alpha$, $0<\beta$, $\alpha + \beta <1$, $0<s_K$, $0<s_H$, $s_K + s_H <1$, $\delta \geq 0$ and technological progress is exogenous.
The steady state is determined by (k*, h*) as follows:

$$k^* = \left(\frac{s_K^{1-\beta} s_H^{\beta}}{n+\delta+g} \right)^{\frac{1}{1-\alpha-\beta}} \quad , \; h^* = \left(\frac{s_K^{\alpha} s_H^{1-\alpha}}{n+\delta+g} \right)^{\frac{1}{1-\alpha-\beta}}$$

Empirical estimations showed that the standard Solow-Swan model cannot explain the data as good as the extended model with human capital.

1.1.3. The Ramsey-Cass-Koopmans model (1965):

The fundamentals of this model trace back to Ramsey's paper (1928) in which he determined the optimal saving rate of an economy subject to maximizing the future utility over successive generations. He used intertemporal maximization and optimization of collective and individual utility by applying techniques of dynamic optimization. Unlike the Solow-Swan model in Ramsey's growth model the saving rate of households is endogenously determined. David Cass (1965) considered additionally the case where consumers prefer consumption today to consumption tomorrow and the total of discounted utility of consumption per capita is relevant for maximization of the social welfare. This feature of Cass's work makes the major difference to Ramsey's growth model.

In the Ramsey-Cass-Koopmans model the firms rent capital and hire labor in competitive factor markets and they maximize profits. Households live infinitely, own production factors and maximize the utility. In this model framework a welfare analysis is possible. Further assumptions: perfect competition, rational expectations, and complete markets, saving rate is endogenously determined. Consequently, a dynamic general equilibrium model can be built on this model where goods, labor and capital markets dynamics are involved. The model:

A representative firm maximizes at each point of time $Y(t) - q(t)K(t) - w(t)L(t)$ subject to $Y(t) = F(K(t), A(t)L(t))$ and $K(t) \geq 0$, $L(t) \geq 0$. q(t) is the price of renting capital, w(t) denotes the wage rate, A(t) is the state of the technology (labor efficiency) – firm takes all of these as given and maximizes with respect to Y(t), K(t) and L(t).

First-order conditions: $q(t) = F_1(K(t), A(t)L(t))$
$w(t) = A(t)F_2(K(t), A(t)L(t))$
Optimality conditions: $y(t) = f(k(t))$, $y(t) = Y(t)/[A(t)L(t)]$, $k(t) = K(t)/[A(t)L(t)]$
$q(t) = f'(k(t))$
$w(t) = A(t)[f(k(t) - k(t)f'(k(t))]$

Technological progress is exogenous and given by dA(t) = gA(t). The return to capital (real interest rate) is r(t) = q(t) – δ.

In this model there is H identical infinitely-lived households and dL(t) = nL(t) – exogenous population growth. The aggregate consumption of households is denoted by C(t) and every household consumes C(t)/H. Each household maximizes $(1-\theta)^{-1}\int_{t=0}^{+\infty} e^{-\beta t}c(t)^{1-\theta}dt$ subject to dk(t) = w(t)/A(t) + [r(t) – (n+g)]k(t) – c(t) and $\lim_{t\to+\infty} e^{-R(t)}e^{(n+g)t}k(t) = 0$ and c(t) ≥ 0. <u>Remark</u>: This is the case for θ ≠ 1. Further specifications in the model: $R(t) = \int_0^t r(\tau)d\tau$, c(t) = C(t)/[A(t)L(t)], β = ρ – n- (1-θ)g > 0 where ρ is the time-preference rate (discount rate) – it means this parameter measures how much weight is given to future consumption relative to present consumption. The parameter θ determines how strongly a household reacts to intertemporal price differences. The elasticity of intertemporal substitution is equal to 1/θ.

<u>Equilibrium and balanced growth in the model</u>:

Equilibrium is given by the following conditions:
$dk(t) = f(k(t)) - (n+g+\delta)k(t) - c(t)$
$dc(t) = c(t)[f'(k(t)) - \rho-\delta-\theta g]/\theta$
$k(0) = k_0$
$\lim_{t\to+\infty} e^{-R(t)}e^{(n+g)t}k(t) = 0$

The balanced growth path is similar to that of the standard Solow-Swan model:

$K(t) = k(t)A(t)L(t) = A_0L_0k^*e^{(n+g)t}$
$Y(t) = f(k(t))A(t)L(t) = A_0L_0f(k^*)e^{(n+g)t}$
$k'(t) = K(t)/L(t) = A_0k^*e^{gt}$
$y'(t) = Y(t)/L(t) = A_0f(k^*)e^{gt}$
$c'(t) = C(t)/L(t) = A_0[f(k^*) - (n+\delta+g)k^*]e^{gt}$

The only parameter that has a long-run growth effect is g. Difference to the Solow-Swan model is that saving rate of households is endogenously determined.

One can show in a decentralized market economy where agents are coordinated by market prices the market equilibrium is Pareto-optimal.

1.1.4. Diamond model (1965):

The main differences of the Diamond model to the Ramsey-Cass-Koopmans model are that households live finitely many periods (two periods) but there are infinitely many overlapping generations of households. The time formulation of this model is discrete, every household lives for two periods and the equilibrium is inefficient because a social planner can carry out redistributions that are impossible in the market economy.

In the Diamond model the production and technological progress are described as in the Ramsey-Cass-Koopmans model and the parameters have the same interpretation as in the previous model, n>-1, g>-1 and 0<δ<1. A household of generation t maximizes $\frac{[(1-s_t)w_t]^{1-\theta}-1}{1-\theta}+\frac{[(1+r_{t+1})s_t w_t]^{1-\theta}-1}{(1+\rho)(1-\theta)}$ where s_t denotes the saving rate of the household and $s_t = (w_t - C_{t,t})/w_t$, $C_{t,t}$ denotes the consumption of a household of generation t in period t. The optimal saving rate is independent of w_t and so it can be expressed as $s_t = s(r_{t+1})$. The optimal saving rate s(r) is an increasing or decreasing with respect to r depending on the value of parameter θ: if θ>1 the income effect dominates, if θ<1 the substitution effect dominates, if θ=1 $s_t = 1/(2+\rho)$.

Capital accumulation in the Diamond model can be expressed as follows: $k_{t+1}=\frac{[f(k(t))-k(t)f'(k(t))]s(f'(k(t+1))-\delta)}{(1+n)(1+g)}$ and every sequence $(k(t))_{t=0,+\infty}$ which satisfies the difference equation and the initial condition for k_0 is an equilibrium. A constant sequence corresponds to a balanced growth path.

The Ramsey-Cass-Koopmans model and Diamond model are important contributions to macroeconomic analysis. The determination of the endogenous (optimal) saving rate as well as dynamic optimization techniques and capital accumulation make the use of these models more advantageous then standard Solow-Swan model. Petr Duczynski (2002) introduced technological diffusion in the neoclassic growth model. He showed that the Ramsey model with technological diffusion is tractable and this model with the two negative eigenvalues appear to be better approximation of the real world than the dynamics of the standard Ramsey model. A drawback of his model is the exogenous technological progress. However, this paper is an important contribution to how the technology behaves in the Ramsey model framework.

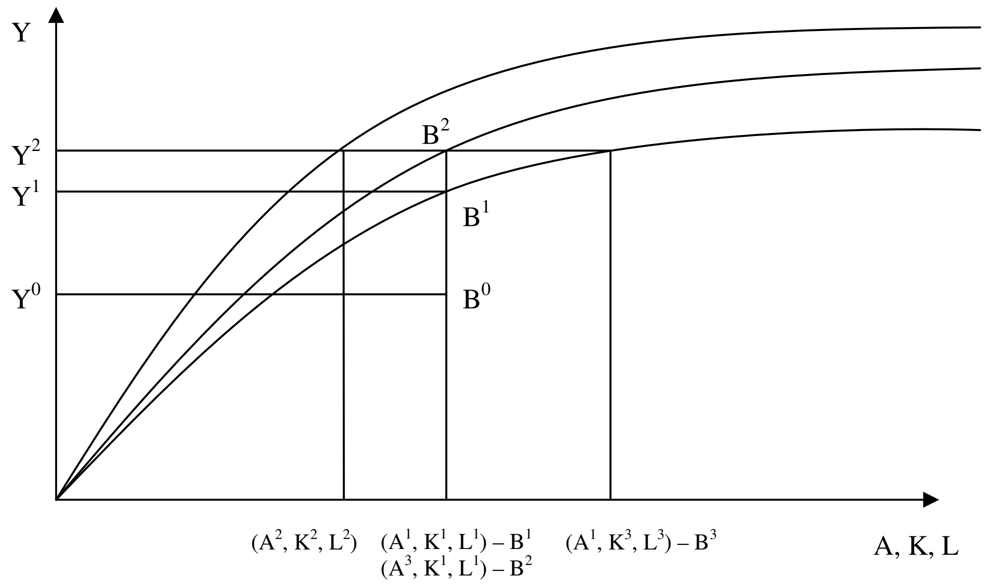
The main contributions of neoclassical growth models to the growth theories are the dynamics of factor accumulation (including physical capital, human capital and technology) and convergence of economic growth. The main drawback is the assumption of (entirely) exogenous technological progress. Optimal saving rate and capital accumulation are very important but not sufficient conditions for technological progress and long-run growth. They are important because the financing of different investment projects (including R&D projects) depends on the savings in an economy. Insufficient because accumulation of capital, technology may not lead alone to technological progress. Technology by (my) assumption is a part of physical and human capital. Accumulation of technology occurs if human and physical capital accumulate over periods but the fact of accumulation is not sufficient condition for technological progress. Technological progress is a result of different combination (use) of given production factors, by assumption. Hence it is a particular production process where the outcome is an invention or innovation, new or more efficient production factors. Hence, the endogenous change in aggregate technology shall be explained in the model in order to ‘endogenize’ the technological progress to some extent. The (new) endogenous growth theories (try to) explain the technological progress as an endogenous process. In my opinion, both types of growth theories are correct to some extent. Endogenous growth theory is right if it assumes endogenous technological progress because technological progress is a product (or by-product) of human activity. Assume two types of technological progress: natural (evolution) and artificial (e.g. human technological progress). Evolution is a result of adaption of world’s elements to the given environment in each period of time determined solely by nature – it is a very slow process relative to human one. Artificial technological progress can be generated only by production activities of creatures (they are elements of the world that possess mental and physical capital). They combine or use variously the different production factors and some of these combinations result in new technologies (e.g. new physical capital or new ideas, skills). Artificial technological progress is faster than the natural one and its speed can be influenced by supporting more or less physical capital or researchers. So, if there were no human activities, no human technological progress would then exist. Partly exogenous feature of technological progress can be assumed because it is almost unpredictable when a new technology will be created that would be actually important, necessary.

As mentioned in the Introduction, traditional neo-classical (exogenous) growth models without technological progress rules out the long-run growth of per-capita GDP because of decreasing marginal returns of capital. Consequently, a balanced growth path with a positive growth rate of per-capita GDP can only exist if (i) the technology F has constant returns to scale and all production factors are accumulable or (ii) the technology F has increasing returns to scale.

1.1.5. Endogenous growth theory:

In the following I will briefly discuss the endogenous growth theory and the model that is important for my model.

The fundamentals of endogenous growth theory trace back to Lundberg, Verdoorn (1956), Arrow and Romer. The recent trends in this growth theory are mainly determined by the papers of Romer (1986, 1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Jones (1995, 1997), Segerstrom (1998), and Young (1998). Erik Lundberg’s study (1959) about the Horndal iron works in Sweden showed that although no new investment is made the production of the firm increases on the average 2% p.a. Arrow (1962) referred to this study and he made a formal analysis of this example of learning by doing (acquisition of knowledge). He introduced an endogenous theory of changes in knowledge to explain the differences between production curves/functions of different countries. Learning, from Arrow’s point of view, is a product of experience that takes place during activity since it usually occurs through the attempt to solve a problem. Arrow takes cumulative gross investment as an index of experience, because he claims that only gross investment can capture the productivity of capital – new products, factors used in production process change the environment and through this gives new incentives to adaption to changing environment. Verdoorn (1956), opposed to Arrow, relates current output to cumulative output in order to explain learning by doing. Barro and Sala-i-Martin (1995) summarizes Arrow’s two crucial assumptions as follows: first, learning by doing works through each firm’s investment and an increase on a firm’s capital stock leads to a parallel increase in its stock of knowledge. Second, knowledge is a public good that any other firm can access at zero cost. However, the outcome is not Pareto optimal. Remark: for instance patents, secrecy may be barriers for knowledge diffusion over some periods of time. Under these assumptions, the production function yields increasing returns to scale in gross investment and labor used. This result relies on the fact the each new input is used more effectively than the old one. Digression – Production curves and efficiency of aggregate production process:



The three curves in the diagram represent three different (efficient) aggregate production functions with decreasing returns to scale – analogously to constant and increasing returns to scale. These curves represent the maximum aggregate output under given input combination. All points under these curves represent a possible output – input combination but the points on the curve represent the most efficient combination of inputs. Technology F is responsible, by assumption, for the good, efficient use, combination of inputs, so for instance B^0 represent a bad or less efficient combination of inputs relative to B^1 or B^2 because the same input combination result in less output in case of B^0 relative to the outputs in case of B^1 or B^2. It is, however, very complicated to determine whether an economy is on the most efficient production curve or below it. The existence of good and efficient technologies is not a guarantee for the good and efficient use of production factors. (Temporary) Barriers for maximal efficiency can be the (temporary) barriers for knowledge/technology diffusion. Remark: temporary barriers are mentioned because knowledge is assumed as partly excludable good.

In each aggregate production function the technology (A) is fixed. On the vertical axis the possible outputs are represented, on the horizontal axis the possible input combinations. This figure shows that a given output Y^2 can be achieved with different combinations of inputs. The initial case is Y^1 where the economy uses the inputs A^1, K^1, L^1. If the economy wants to reach the level of Y^2 in the next period, it can reach it in 3 different ways: (i) by simple input variation - A^1, K^3, L^3; (ii) by increasing the technological level and reducing the capital and labor input – A^2, K^2, L^2; or (iii) by increasing the technological level and letting the capital and labor input at constant level. The intuition behind the investments in R&D activities is that the resulting effect of R&D activities may lead to case (ii) or (iii). It means R&D activities should increase the technological level and productivity of an economy. However, the exact look of such curves of production possibilities in each period of time is unknown and an increase in technological level is not a guarantee for more efficient production. It is namely unknown that the economy is on the efficient aggregate production curve or below that if the technological level (A) is fixed. Using Arrows idea of learning by doing, one can say that at the point of technological progress (e.g. A^1 to A^3) the economy uses the production factors not efficient any more – point B^1. Through learning by doing economy can reach the point B^2 where the production factors are used at most efficient level if the technological level is A^3. Consequently, increasing returns to scale in an aggregate production function can also occur if the efficient aggregate production function exhibits decreasing returns to scale. Decreasing returns to scale are evidence for insufficient level of technology, productivity for constant level of economic growth.

Investments in quality (case (ii) and (iii)) (improvement) of production factors (physical and human capital) may increase the relative efficiency of aggregate production – technological progress. Remark: increase of relative efficiency of aggregate production in period t means an improvement of efficiency relative to period t; example: economy moves from B^0 to B^1 after A^1 moves to A^3. Absolute increase of efficiency occurs if e.g. the distance between B^2 and B^1 (distance between efficient aggregate production curves after technological progress under given input combinations) is smaller than the distance B^0 and B^1 (distance between observed outputs under fixed input combination). Investments in quantity (case (i)) should be seen as increase of aggregate production by simple input variation – using more but not more efficient inputs. Optimal or efficient choice of quality and quantity: it means the allocation (X^i) or choice of quality and quantity of products, production factors are Pareto optimal or Pareto efficient subject to the current (economic and natural) environment.

Subjective optimality or efficiency of allocation of quality and quantity:
Let U_t denote the environment or state of the world in period t and let $E_t(U_{t+1})$ denote the environment in period t+1, expected from period t. Furthermore let me define the environment if an allocation X^i has been chosen: $U_t|X^i$. Analogously: $E_t(U_{t+1}|X^i)$ denotes the environment in period t+1, expected from period t, if in period t an allocation X^i has been chosen. Remark: Expectations need not to be rational. Let $S_{t,\ t+k}(X^i)$ denote the sequence of environments conditional on allocation X^i as follows: $S_{t,\ t+k}(X^i) \equiv (U_t|X^i, E_t(U_{t+1}|X^i), E_t(U_{t+2}|X^i), \ldots, E_t(U_{t+k}|X^i))$ – k is any positive integer. Remark: One can assume more complicated determination of the sequence like $E_{t+1}(E_t(U_{t+1}|X^i))$. Let $Y_t(X^i)$ denote the aggregate output in period t if an allocation X^i. Furthermore let $E_t(Y_{t+1}(X^i))$ the aggregate output in period t expected from period t, if in period t an allocation X^i has been chosen. Let $P_{t,\ t+k}(X^i)$ denote the sequence of aggregate outputs conditional on allocation X^i as follows: $P_{t,\ t+k}(X^i) \equiv (Y_t(X^i), E_t(Y_{t+1}(X^i)), E_t(Y_{t+2}(X^i)), \ldots, E_t(Y_{t+k}(X^i))$. Remark: One can assume more complicated determination of the sequence like $E_{t+1}(E_t(Y_{t+1}(X^i))$. Using these definitions, an allocation X^i (consisting of quality and quantity of factors) is subjective optimal relative to X^j if the sequence $S_{t,\ t+k}(X^i)$ weakly or strictly dominates any other sequence $S_{t,\ t+k}(X^j)$, and the sequence $P_{t,\ t+k}(X^i)$ weakly or strictly dominates any other sequence $P_{t,\ t+k}(X^j)$, and $j \neq i$, i,j are natural numbers. Remark: $S_{t,\ t+k}(X^i)$ weakly dominates another sequence $S_{t,\ t+k}(X^j)$ if there exists at least one period in the possible time range [t, t+∞[where the given (expected) environment determined by X^i is preferred by people relative to the (expected) environment determined by X^j in the same period and in any other periods the possible (expected) environments are equally preferred by people. $S_{t,\ t+k}(X^i)$ strictly dominates another sequence $S_{t,\ t+k}(X^j)$ if in all periods of the time range [t, t+k[the given (expected) environment determined by X^i is preferred by people relative to the (expected) environment determined by X^j. $P_{t,\ t+k}(X^i)$ weakly dominates another sequence $P_{t,\ t+k}(X^j)$ if there exists at least one period in the possible time range [t, t+k[where the given (expected) aggregate output determined by X^i is higher than the (expected) aggregate output determined by X^j in the same period and in any other periods the possible (expected) aggregate outputs are equal. $P_{t,\ t+k}(X^i)$ strictly dominates another sequence $P_{t,\ t+k}(X^j)$

if in all periods of the time range [t, t+k[the given (expected) aggregate output determined by X^i is higher than the (expected) aggregate output determined by X^j.
Objective optimality or efficiency of quality and quantity can be controlled only by ex-post analysis of an economy, hence the definition is: an allocation X^i of quality and quantity was objective optimal in period t-n - subject to the given sequence of current and past environment and aggregate output - observed from period t if $S_{t-n,\ t}(X^i)$ weakly or strictly dominates any other sequence $S_{t-n,\ t}(X^j)$, and the sequence $P_{t-n,\ t}(X^i)$ weakly or strictly dominates any other sequence $P_{t-n,\ t}(X^j)$, and $j \neq i$, i,j,n are natural numbers.
If a given allocation X^i is objective and subjective optimal, X^i can be seen as optimal decision or choice in the given period and under given circumstances. If objective and subjective optimal allocations are different, the decision or choice was suboptimal. However, optimal corrections for suboptimal decisions are very complicated because of the complexity of processes. An optimal correction for suboptimal decision(s) leads to optimal decision(s).

However, investments in quantity and quality cannot be separated from each other but quantity-driven or quality-driven investments exist. Quantity-driven investments mean the quantity of factors is prior, the quality of those factors is subordinate, lower order of importance. Quality-driven investments are investments where the quality of products is prior, the quantity is negligible. However, most investments are subject to budget constraints and hence investors optimize usually simultaneously the quality and quantity of production factors.

In my opinion, Lundberg stated in his study the existence of 'skill to use production factors more efficient' over time and Arrow stated the existence of 'skill to learning by doing'. These are different skills because learning something new does not mean learning the efficient use of production factors. The combination of these observations gives the result that people are able to update their skills and knowledge, and through this they are able to improve their efficiency. As a follow-up of increased labor efficiency the productivity of an economy increases. In some growth models this feature of production and investment is represented as external effects. If it is so one should distinguish between the individual and aggregate production function.

$Y_i(t) = F[K_i(t), A(t)L_i(t)] = K_i(t)^{\alpha}[A(t)L_i(t)]^{1-\alpha}$, $0<\alpha<1$, $0\leq i\leq 1$. This is an individual production function where every single firm takes A(t) as given.

Romer (1986) set up an equilibrium model of endogenous technological change in which the long run growth is driven primarily by accumulation of knowledge by forward looking, profit-maximizing agents. Further assumption is that knowledge has its own production function with some inputs and decreasing returns to scale. The externality comes from the non- or partly excludable and non-rival property of knowledge. <u>Remark</u>: in endogenous growth models experience, acquisition of knowledge are outcomes of particular production processes where the outcome enriches the mental capital of people. Experience and efficiency is a function of capital stock because people use usually (the same) physical capital (i.e. physical factors) of same type and quantity in more identical production processes to produce some outputs and during these production processes they 'learning by doing'. Presuming that every skill, knowledge of people based on experiences with physical capital, one can use the following function for development of efficiency of individuals: $A_i = K_i^{\varphi i}$ where A_i denotes the efficiency of human i and K_i denotes the total stock of physical capital this human i ever 'used' in his/her life, φ_i denotes the effect of physical capital i's efficiency. It is possible that more people used the same physical capital in order to acquire knowledge, experiences. Hence, on aggregate level $A = K^{\varphi}$. This model or idea emphasizes that the aggregate labor efficiency is important for economic growth. <u>Remark</u>: The effects of K on labor efficiency depend on the quality, skills and knowledge of labor. Consequently, φ has higher value if labor has a higher average level of skills and knowledge and lower if the labor is not so skilled, qualitative. So, this idea can be represented as follows: $A = KA^L$ where A^L denotes the 'quality' of labor.

Lucas (1988) focused on the average level of human capital or labor efficiency in the economy and not on aggregate human capital stock or aggregate human efficiency. Based on this idea, Barro and Sala-i-Martin (1995) defines $A_i = K/L$. In my opinion both the aggregate and average level of labor efficiency is important for the determination of knowledge diffusion or distribution possibilities in a given economy. Knowledge diffusion or distribution will de detailed in section 1.2.

However, $A_t = K_t^{\varphi}$ can be interpreted as the current aggregate efficiency of labor which is a function of until period t available physical capital. So, it can be used in the model. Embedding this idea into the Solow-Swan framework:

$Y(t) = K(t)^{\alpha}[A(t)L(t)]^{1-\alpha} = K(t)^{\alpha+\varphi(1-\alpha)}L(t)^{1-\alpha}$
$dK(t) = sY(t) – \delta K(t)$
$dL(t) = nL(t)$

The parameter values n and φ determines the structure of equilibria. Possible cases:

- if $\varphi>1$ or $\varphi=0$ and $n>1$ one gets explosive growth:

Romer (1986, 1990), Grossman and Helpman (1991), Aghion and Howitt (1992) used the special and important property of knowledge (i.e. knowledge is a non-rival good) in their models which leads to scale effects. Consequently, larger economies grow faster than smaller economies. However, this is inconsistent with empirical facts over the last 40-50 years.

- if $\varphi=1$ and $n=0$ it leads to the single production factor model (AK-model) with $A = sL^{1-\alpha}$ and $n = 0$;
- if $\varphi<1$ one gets semi-endogenous growth (no scale effects)

1.1.6. The AK-model:

$Y(t) = AK(t)$
$dK(t) = sY(t) - \delta K(t)$
$dL(t) = nL(t)$

Defining $k(t) = K(t)/L(t)$ and $y(t) = Y(t)/L(t)$ the growth rate of k and y are the same: $\gamma_k(t) = \gamma_y(t) = sA-\delta-n$ and increasing with respect to s and A and decreasing with respect to δ and n. Economic policy which affects s has long-run growth effects. Every solution of the model is a balanced growth path.
Let $A = sL^{1-\alpha}$ and $n = 0$ in the model, one gets $dK(t) = sL^{1-\alpha}K(t) - \delta K(t)$ and $\gamma_K(t) = \gamma_Y(t) = \gamma_k(t) = \gamma_y(t) = sL_0^{1-\alpha} – \delta$. The growth rate depends positively on the population size. However, this scale effect contradicts empirical observations.

Model with semi-endogenous growth ($\varphi<1$):

One can show that the economy converges towards a balanced growth path with:
$K(t) = [k^*L(t)]^{1/(1-\varphi)}$

$\gamma_K(t) = \gamma_Y(t) = n/(1-\varphi)$, $\gamma_A(t) = \gamma_y(t) = n\varphi/(1-\varphi)$

where $k(t) = K(t)/[A(t)L(t)] = K(t)^{1-\varphi}/L(t)$ and $\lim_{t\to+\infty} k(t) = k^* = \left[\frac{(1-\varphi)s}{n+\delta(1-\varphi)}\right]^{\frac{1}{1-\alpha}}$.

In this model the growth rate of the economy is proportional to the population growth rate and positive growth of per capita GDP is only possible if there is positive population growth.

The above mentioned models cannot explain very well the long-run economic growth because the main/real sources of technological progress in an economy remained unexplained. Productivity growth through learning by doing and education can be explained. However, productivity can be improved in the long-run only if technological progress exists. Otherwise an economy would reach in some periods of time a marginal situation (point on efficient aggregate production curve) where economic productivity depends only on simple input variation of capital and labor. The following model (with R&D) tries to explain the technological progress through R&D activities. The basic idea behind this model is that researchers create new knowledge (inventions, innovations, product designs). Researchers (L_A) are special part of labor that are not belonging to workers ($L_W = L-L_A$). Researchers participate in particular production processes where the outcome is an invention or innovation (new knowledge, new product). Workers participate in any other type of production processes. The only input to create knowledge is labor. Remark: this assumption is true but the efficiency, success of knowledge creation processes can be improved by physical capital – for instance in economic sectors where output is primarily physical good (like car industry, chemistry) and experiments are very sensitive to physical capital, the support of appropriate amount of physical capital (for experiment, R&D activities) are of higher-order of importance relative to less capital sensitive and intensive sectors.

A(t) denotes the number of designs available in period t. Every researcher produces B(t) new designs in each period of time. Hence the production function for designs is therefore:

$dA(t) = B(t)L_A(t)$.

Workers produce final output from capital and knowledge. Consequently the aggregate production function of an economy has the following form:

$Y(t) = F(K(t), A(t)L_W(t))$.

Assumption in this model: $\gamma_L(t) = \gamma_{Lw}(t) = \gamma_{La}(t) = n$ and $\gamma_y(t) = \gamma_A(t) = g$ where $\gamma_A(t)$ is endogenously determined. To do that, in the first step the researchers' efficiency, productivity B(t) shall be explained. A general specification is

$B(t) = \beta L_A(t)^\lambda A(t)^\eta$

- if $\lambda = \eta = 0$, there is no external effects;
- if $\eta < 0$, there exists a negative effects of the number of existing designs on the research productivity (fishing-out effect);
- if $\eta > 0$, there exists a positive effect of A(t) on B(t) – existing designs support 'knowledge creation';
- if $-1< \lambda < 0$, there exists a negative effect of the number of researchers on their productivity (e.g. duplication effect);

- if $\lambda > 0$, there exists a positive effect of researchers on existing designs (e.g. communication effect).

The application of the idea of Arrow to this model as follows:

$B(t) = \beta L_A(t)^{\lambda} A(t)^{\eta} R(t)^{\psi}$ or $B(t) = \beta L_A(t)^{\lambda} R(t)^{\psi}$ where R(t) denotes the R&D expenditures in period t. Remark: Similarly to Arrow's idea, I assume here that researchers' efficiency, productivity can be increased only by new invested capital in R&D projects. So, we can make the same interpretation of parameters as above:

- if $\psi = 0$ R&D, expenditures have no external effect on designs;
- $\psi < 0$, R&D expenditures have negative effects on designs;
- $\psi > 0$, R&D expenditures have positive effects on designs.

If we insert these models into the initial model of endogenous technological progress, we get:

$dA(t) = B(t)L_A(t) = \beta L_A(t)^{1+\lambda} A(t)^{\eta}$ or
$dA(t) = \beta L_A(t)^{1+\lambda} A(t)^{\eta} R(t)^{\psi}$ or
$dA(t) = \beta L_A(t)^{1+\lambda} R(t)^{\psi}$

The choice of model specification depends on which factor(s) or variable(s) might have an impact on technological progress – such factors or variables enter as external effects into the model. Empirically it (i.e. the model) is however not verifiable because of lack of data on B(t), A(t).

Further consequences of the model with $dA(t) = B(t)L_A(t) = \beta L_A(t)^{1+\lambda} A(t)^{\eta}$:

- if the parameters (including n>0) are larger than 1, one gets explosive growth;
- if $n = 0$ and $\eta = 0$ the $\gamma_A(t) = \beta L_A(0)^{1+\lambda}$ for all t, i.e. the growth rate is proportional to the number of researchers. This assumption is empirically not verifiable but theoretically seems to be wrong. Premises like efficient education system, selection of researchers, and efficient production of researchers are necessary conditions for the correctness of this idea;
- if $n > 0$ and $0 < \eta < 1$ one gets semi-endogenous growth and $\gamma_A(t) = \gamma_y(t) = n(1+\lambda)/(1-\eta)$. The long-run growth rate is proportional to the population growth and depends on external effects λ and η.

1.2. The $A^K KA^L L$ model:

The above mentioned model has a main drawback: technological progress or labor efficiency depends "only" on researchers. In this sense L_A consists not only of people who are "called" and "employed" as researcher but of people who has invented, innovated at any point of time. Otherwise technological progress would have other sources than researchers and then the model would be incorrect. It means that a researcher is not the person who is "employed" as researcher, it is a person who is able to invent and innovate under given circumstances. However, not all researchers are efficient. Requirements on the person of a researcher from my point of view:

Researchers (i.e. R&D staff) should be such person who can invent/innovate with high(est) probability and in addition these people have (the) large(st) marginal product with respect to one additional unit of physical capital in the human population and their products (invention, innovation) can be distributed, applied in the most efficient way in the human population, economy. People with lower probability to innovate and lower innovation elasticity should be employed as worker and not as R&D staff.

$\text{Prob}(I \mid T_R) \geq \text{Prob}(I \mid T_W)$ where I denotes the innovation or invention;
T_R denotes the researchers' type
T_W denotes the workers' (not researchers) type

$\partial[\text{Prob}(I \mid T_R)]/\partial K \geq \partial[\text{Prob}(I \mid T_W)]/\partial K$ means that researchers invent or innovate with higher probability than workers if they get an additional unit of capital K.

In the first step, make the following specification: A denotes the labor efficiency and not the state of technology (A*), then knowledge diffusion and quality of labor (limited skills, other barriers in labor[7]) play important role in increase of labor efficiency besides the technological progress. Consequently, state of technology and labor efficiency is not the same. State of technology is a list of every (different) innovation and invention created by people. Labor efficiency depends on the state of technology and on the knowledge distribution or diffusion possibilities (X(t)) in the economy. In my opinion, several endogenous and R&D based growth models emphasize the quantitative growth of production factors but they lack the quality change of production factors. Quality of production factors play essential role for instance in distribution of knowledge (including new technologies). The quality of human capital determines the 'speed' of knowledge diffusion, distribution. However, analyses of quality change of production factors (especially that of the human capital) are very complex. Experience and education level of labor, or evolution of average and marginal of firms' cost curves over years are usual proxies for aggregate labor 'quality'. State of technology can be improved like $dA^*(t) = \beta_0 L_A(t)^{1+\lambda} A^*(t)^{\eta} R(t)^{\psi}$ but the increase of labor efficiency depends on other variables, external effects.

Further remarks on invention and innovation:

Both can be vertical or horizontal. Horizontal invention or innovation creates completely new product. A vertical invention or innovation improves the quality of an existing product. In my model these types of invention and innovation are embedded in the following way: invention and innovation may represent (i) new characteristics or (ii) new combination of characteristics or (iii) both compared to existing characteristics and combination of characteristics. A quality is a combination of different characteristics. Consequently, there is a set consisting of all possible characteristics of physical and mental elements and combinations of them. So, each element of the world is a special combination constructed from this set by some functions. Consequently, different qualities imply (i) different combination of same characteristics or (ii) combination of different characteristics or (iii) both. These characteristics determine the material and immaterial qualities (characteristics) of the elements. So, the state of technology is a list of characteristics and combination of characteristics that are different and recorded in a systematic way and they can be attached to physical or human (mental) elements of the world through different processes, mechanisms. Through implementation, realization of these characteristics in the economy (including production processes) they may be embedded within material or immaterial products that can be observed, evaluated, copied, learned by different techniques. So, physical or mental elements are the 'carrier' of (new) technologies (knowledge), characteristics.

[7] Labor quality cannot be improved to the „infinity".

(Labor) efficiency depends on the state of available technology (i.e. available physical and mental related technology) to production factors as follows: A(t) = A*(t)X(t). Current state of technology: $A^*(t)=A^*(A^{K^*}(t), A^{L^*}(t), \text{'x'}(A^{L^*}(t)))$. $A^{L^*}(t)$ denotes the "labor (L(t)) related technology" (i.e. human mental capital contains knowledge, skills) in period t and $A^{K^*}(t)$ denotes the technology related to physical capital K(t) in period t and technology 'x'*(t) = $\text{'x'}(A^{L^*}(t))$[8] is responsible for the use and combination of production factors. The available A^{L^*} and A^{K^*}, denoted by A^L and A^K, respectively, to labor and in physical capital determine the quality of these production factors, L and K, respectively. L and K denote the amount, size of respective production factors. X(t) = X(K(t), L(t), A(t)) where X(t) depends on the available technology A(t), physical and human capital or in other words X(t) depends on the quality and quantity of production factors and processes in an economy. 0≤X(t) (if X(t) is a scalar) can be seen as a measure of the state of infrastructure for technology distribution. If A(t) denotes the average level of technology (i.e. technology per capital stock and labor) then 0≤X(t)≤1 because neither capital nor a human can possess more technology than the existing technologies in a given period, by assumption. If A(t) denotes the aggregate level of technology then 0≤X(t) because different physical elements and different humans may possess the same (existing) technology in a given period of time, by assumption. X(t) = 1 implies that there is no two different physical element or people whop would possess the same technology. Homogenous elements are here different if (i) they would be produced in different times or (ii) in different production process (methods) or (iii) in different places.

<u>Matrix notation for the state of technology and labor efficiency</u>:

$$A^*(t) = \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} \bullet \begin{pmatrix} n_1 \\ n_2 \\ \vdots \\ n_j \end{pmatrix} = \begin{pmatrix} 1n_1 \\ 1n_2 \\ \vdots \\ 1n_j \end{pmatrix}$$

where n_i denotes the i^{th} innovation or invention among all new designs until period t. This is called a Hadamard product.

$$(A(t))^t = \underbrace{\underbrace{\begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{k1} & x_{k2} & \cdots & x_{kj} \end{pmatrix}}_{kxj}}_{X(t)} \underbrace{\underbrace{\begin{pmatrix} n_1 \\ n_2 \\ \vdots \\ n_j \end{pmatrix}}_{jx1}}_{A^*(t)}$$

where x_{kj} determines an "amount" of technology j available to individual k in period t and $(A(t))^t$ is the transpose of A(t).

$$X(t) = \gamma A(t)^{\alpha 1} L(t)^{\alpha 2} K(t)^{\alpha 3} = \gamma A^L(t)^{\beta 1} L(t)^{\beta 2} A^K(t)^{\beta 3} K(t)^{\beta 4}$$

- if $\alpha_1, \alpha_2, \alpha_3 < 0$, the current state of technology, capital and labor does not support the knowledge distribution;
- if $\alpha_1, \alpha_2, \alpha_3 > 0$, the current state of technology, capital and labor supports the knowledge distribution;

[8] Assumption: only people can combine, use production factors, hence people's mental capital influence, determine the way of use and combination.

- if $\alpha_1 = \alpha_2 = \alpha_3 = 0$, the current state of technology, capital and labor have no effects on knowledge distribution.

Analogously to βs:

- if $\beta_1, \beta_2, \beta_3, \beta_4 < 0$, currently available mental capital of labor, number of labor, physical capital related technology, amount of physical capital does not support the knowledge distribution;
- if $\beta_1, \beta_2, \beta_3, \beta_4 > 0$, currently available mental capital of labor, number of labor, physical capital related technology, amount of physical capital supports the knowledge distribution;
- if $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$, currently available mental capital of labor, number of labor, physical capital related technology, amount of physical capital have no effects on knowledge distribution;

Consequently, if the parameters are negative, the value of X(t) is low. Consequently, A(t) is also low based on the equation A(t) = A*(t)X(t). If the parameters are positive, the value of X(t) is high and A(t) becomes also larger.

Using this idea, let $A^{La}(t)$ denote the available mental capital to researchers that depends also on the knowledge distribution possibilities to researchers ($X_A(t)$) as follows: $A^{La}(t) = A^*(t)X_A(t)$. So, $dA^*(t) = \beta_0 L_A(t)^{1+\lambda} A^{La}(t)^{1+\eta} R(t)^{\psi}$ where $B(t) = \beta_0 L_A(t)^{\lambda} A^{La}(t)^{\eta} R(t)^{\psi}$. It means the number and quality of new designs depends on the number and quality of researchers and on the R&D expenditures. Hence, the technological progress (increase of the state of technology) depends on the quality and quantity of new designs by researcher of given number and quality.

The increase in labor efficiency depends on two factors as follows: $dA(t) = B(t)^{\beta}X(t)$ – increase in labor efficiency depends on availability of technology embedded in production factors and new designs B(t) where $B(t) = \beta_0 L_A(t)^{\lambda} A^{La}(t)^{\eta} R(t)^{\psi}$. The parameter β denotes the effects of 'successful' designs that have been realized (distributed) in the economy in period t, $\beta \leq 1$. $\beta<0$ refers to negligible effects of new designs on labor efficiency.

Remark: A researcher j is efficient if $B_j(t) > 0$ and β is close to 1 in $dA(t) = B_j(t)^{\beta}X(t)$.

The growth path of technology - discrete time framework:

$A^{K*}(0) = A_0^{K*}$ denotes the (initial) list of physical capital related technologies;
$A^L(0) = A_0^L$ denotes the (initial) mental capital of people;
$'x'(0) = 'x'(A^L(0))$;
$A^K(0) = A_0^K$ denotes the (aggregate) initial technological level of physical capital;
$A^L(0) = A_0^L$ denotes the (aggregate) initial mental capital of humans;
$'x'(0) = 'x'(A^L(0))$;
$A^*(0) = (A^{K*}(0), A^{L*}(0), 'x'^*(0))$ and $A^*(t) = (A^{K*}(t), A^{L*}(t), 'x'^*(t))$;
$A(0) = (A^K(0), A^L(0), 'x'(0))$ and $A(t) = (A^K(t), A^L(t), 'x'(t))$;
$dA(t) = A(t) – A(t-1) = A^K(t)–A^K(t-1) + A^L(t)-A^L(t-1) + 'x'(t)-'x'(t-1) = dA^K(t)+dA^L(t)+d'x'(t)$ - denotes the increase of labor efficiency in period t.

$A^*(t) = A^*(0)e^{dA^*(1)+dA^*(2)+\ldots+dA^*(t)}$
$A(t) = A(0)e^{dA(1)+dA(2)+\ldots+dA(t)}$

Furthermore let me assume that the initial technological level of the world denoted by A*(0) and initial labor efficiency A(0) were determined solely by nature. Based on the idea of overlapping generations, each generation's initial mental capital and efficiency are determined by solely or partly by nature. Consequently, nature brings some initial and continuous exogeneity in the model that cannot be (entirely) excluded.

Consequently, using this endogenous model of growth the endogeneity of technological progress and increase of labor efficiency have been clarified. There are some critics on endogenous growth theory, namely the endogenous growth models cannot explain so good the evolution of the world income distribution like neoclassical (exogenous) growth theory with appropriate modifications[9]. Additionally, spatial application of endogenous growth theory is criticized[10]. In my point of view there are countries, regions where there is no own technological progress (because (i) financing the R&D projects is impossible because of lack of capital and (ii) researchers are not "available" or researchers' productivity is negligible) and the main sources of technological progress and increase of labor efficiency in such countries and regions are the knowledge spillover and other external sources of knowledge and technology. Such countries and regions take the technology or knowledge as given, consequently the neoclassical growth models with appropriate modifications may better explain the economic performance and growth - however, knowledge diffusion possibilities are endogenously determined. The main shortcoming of application of endogenous theory to a given (spatial or whole) economy without the existence of researchers and the existence of not negligible productivity of researchers ('not negligible' means: $B(t) > 0$, $\beta > 0$ in the equation $dA(t) = B(t)^{\beta}X(t)$) and R&D is that in this economy technological progress and increase of labor efficiency is endogenously excluded. However, through knowledge spillover technological progress and increase of labor efficiency can be improved in such countries and regions. Consequently, the technological progress and increase of labor efficiency in these cases depend on the technological progress in other countries and regions. This problem of the endogenous growth model can be eliminated as follows (variables and parameters with same interpretation as above):

<u>Notes on accumulation of factors</u>: It is based on the capital accumulation process in the Solow-Swan model (with human capital) because this type of factor (capital) accumulation turned out to be the most useful of all types of factor accumulation models – based on empirical studies like Parente (2001) and Roberts and Setterfield (2007). Consequently this is a dynamic model that describes the endogenous growth through saving and investment processes.

$dA^L(t)L(t) = dA^L(t) + dL(t) = A^L(t)-A^L(t-1) + nL(t) = \lambda_R R(t) + \lambda_I I(t) + nL(t)$
$L(0) = L_0$

This process describes the accumulation of 'labor efficiency'. The process can be divided into two processes: (i) labor growth (quantitative) and (ii) growth of labor quality (qualitative). Quantitative growth of labor is exogenous and denoted by $nL(t)$. Qualitative growth of labor is endogenous and determined by the process: $dA^L(t) = s_{AI}Y(t) - \delta_L A^L(t)$ (like in the Solow-Swan model with human capital H: $dH(t) = s_H Y(t) - \delta H(t)$) and $dA^L(t) - \delta_L A^L(t) = \lambda_R R(t) + \lambda_I I(t)$. It means knowledge may depreciate at rate δ_L. Based on these equations two types of investments are necessary in order to maintain and improve the quality of labor and (or) improve the quality of labor by new products (e.g. schools, educational services, new medicine, pills etc.): $\lambda_R R(t)$ includes investments that have the main goal to discover new products to improve labor

[9] Parente, Stephen L. The Failure of Endogenous Growth. University of Illinois at Urbana-Campaign, 2001.
[10] Mark Roberts and Mark Setterfield. Endogenous regional growth: a critical survey. June 2007.

quality; $\lambda_I I(t)$ includes all other investments that may maintain or improve labor qualities. Furthermore investments are determined by savings in an economy. Thus $\lambda_R R(t) + \lambda_I I(t) = s_{Al} Y(t)$.
Investments in technology 'x' – $\chi R(t) + \chi_I I(t)$ – can be seen as a part of $\lambda_R R(t) + \lambda_I I(t)$ because technology 'x' is a part of A^L, by assumption. Hence investments in A^L may improve technology 'x', so the relevant part of such investments (in A^L) can be seen as investments in technology 'x'. The emphasis of technology 'x' is important for the interpretation of the problem of missing skills. It means people know how to do something (e.g. a project) but they have not got the necessary skills to realize the project.
Analogously, the accumulation of physical capital can be divided into a quantitative and qualitative accumulation process as follows:

$dA^K(t)K(t) = dA^K(t) + dK(t) + \delta K(t) = A^K(t)-A^K(t-1) + dK(t) + \delta K(t) = \kappa_R R(t) + \kappa_I I(t) + dK(t) + \delta K(t) = \kappa_R R(t) + \kappa_I I(t) + I_K(t)$
$K(0) = K_0$

Quantitative growth of capital is given by $dK(t) = I_K(t) - \delta K(t) = s_K Y(t) - \delta K(t)$ – quantity-driven capital investments minus quantitative capital depreciation. Qualitative growth of capital is endogenous and determined by the process: $dA^K(t) = s_{Ak} Y(t) - \delta_K A^K(t)$ and $dA^K(t) - \delta_K A^K(t) = \kappa_R R(t) + \kappa_I I(t)$. Hence the quality of capital may depreciate at rate δ_K. Again, investments in relevant R&D projects - $\kappa R(t)$ – and investments in maintenance and improvement of capital quality - $\kappa_I I(t)$ – are necessary for positive and not decreasing $dA^K(t)$ in current and future periods. Savings influence the amount of money to be invested in such (quality-driven) projects: $\kappa_R R(t) + \kappa_I I(t) = s_{Ak} Y(t)$.

Finally, the overall level of savings - $sY(t)$ - depends on the aggregate level of consumption – $C(t)$ - in an economy as follows:

$C(t) = (1-s)Y(t)$ and
$S(t) = sY(t) = s_{Al} Y(t) + s_{Ak} Y(t) + s_{'x'} Y(t) + s_K Y(t) = \lambda_R R(t) + \lambda_I I(t) + \kappa_R R(t) + \kappa_I I(t) + I_K(t)$

$I(t)$ denotes investments excluding R&D-type of investments. $R(t)$ denotes the R&D expenditures. s_{Al}, s_{Ak} and $s_{'x'}$ denote the 'saved quality' of labor, physical capital and 'saved technology' of combination (use) of production factors. It means the 'saved factors' can be used in (future) production of new products – 'new' means here not only the inventions and innovations but the reproduction of still existing or existed products. Currently consumed factors are used in current production of products. It implies that current economic performance depends on current consumption and investments (or savings):

$Y(t) = C(t) + S(t) = C(t) + I(t) + R(t)$

where $\lambda_R R(t) + \kappa_R R(t) = R(t)$ and
$\lambda_I I(t) + \kappa_I I(t) + I_K(t) = I(t)$.

The following models represent different types of technological growth and growth of labor efficiency. The quantitative and qualitative accumulation of factors is secondary now, the role of factors are of primary interest in these models.

<u>Endogenous technological growth and labor efficiency of economy i if there is (only) own technological progress</u>:

$dA_i(t) = B_i(t)^{\beta}X_i(t) = \beta_0^{\beta}L_{Ai}(t)^{\lambda\beta}A_i^{La}(t)^{\eta\beta}R_i(t)^{\psi\beta}X_i(t)$
$dA^*_i(t) = \beta_0 L_{Ai}(t)^{1+\lambda}A_i^{La}(t)^{1+\eta}R_i(t)^{\psi}$

Endogenous technological growth and labor efficiency of economy i if there is no own (i.e. external) technological progress:

$dA_i(t) = B_{-i}(t)^{\beta}X_i(t) = \beta_0^{\beta}L_{A-i}(t)^{\lambda\beta}A_{-i}^{La}(t)^{\eta\beta}R_{-i}(t)^{\psi\beta}X_i(t)$
$dA^*_i(t) = \beta_0 L_{A-i}(t)^{1+\lambda}A_{-i}^{La}(t)^{1+\eta}R_{-i}(t)^{\psi}$

where $B_{-i}(t)$ denotes the external sources of knowledge and $X_i(t)$ denotes the knowledge ($B_{-i}(t)$) spillover possibilities in economy i. Premise: such sources of knowledge are accessible for economy i.

Endogenous technological growth and labor efficiency of economy i if there is own and external technological progress:

$dA_i(t) = B_{-i}(t)^{\beta 1}B_i(t)^{\beta 2}X_i(t) =$
$\beta_0^{\beta 1}L_{A-i}(t)^{\lambda 1\beta 1}A_{-i}^{La}(t)^{\eta 1\beta 1}R_{-i}(t)^{\psi 1\beta 1}\beta_0^{\beta 2}L_{Ai}(t)^{\lambda 2\beta 2}A_i^{La}(t)^{\eta 2\beta 2}R_i(t)^{\psi 2\beta 2}X_i(t)$

$dA^*_i(t) = (\beta_1 L_{Ai}(t)^{1+\lambda 1}A_i^{La}(t)^{1+\eta 1}R_i(t)^{\psi 1})^{\zeta 1}(\beta_2 L_{A-i}(t)^{1+\lambda 2}A_{-i}^{La}(t)^{1+\eta 2}R_{-i}(t)^{\psi 2})^{\zeta 2}$

Digression - Individual ‘technological progress’ and increase of individual efficiency:

An individual can “gather” only knowledge and skills. However, these knowledge and skills may relate to physical capital or use of physical capital.

$dA_i^L(t) = B_{-i}(t)^{\beta 1}B_i(t)^{\beta 2}X_i(t) =$
$\beta_0^{\beta 1}L_{A-i}(t)^{\lambda 1\beta 1}A_{-i}^{La}(t)^{\eta 1\beta 1}R_{-i}(t)^{\psi 1\beta 1}\beta_0^{\beta 2}L_i(t)^{\lambda 2\beta 2}A_i^{La}(t)^{\eta 2\beta 2}R_i(t)^{\psi 2\beta 2}X_i(t)$

$dA^{L*}_i(t) = (\beta_1 L_i(t)^{1+\lambda 1}A_i^{La}(t)^{1+\eta 1}R_i(t)^{\psi 1})^{\zeta 1}(\beta_2 L_{A-i}(t)^{1+\lambda 2}A_{-i}^{La}(t)^{1+\eta 2}R_{-i}(t)^{\psi 2})^{\zeta 2}$

Similar to ‘Endogenous growth of economy i if there is own and external technological progress’, an individual may create new designs (that exist but are unknown to i) and may learn, acquire but i denotes the individual i and –i denotes the set of people excluding individual i. L_i denotes individual i who is worker and researcher together. $X_i(t)$ denotes the learning skills of individual i. The coefficients need not to be the same like in the ‘Endogenous growth of economy i if there is own and external technological progress’.

An economy with (only) own technological progress:

$X(t) = \gamma A^*(t)^{\alpha 1}L(t)^{\alpha 2}K(t)^{\alpha 3} = \gamma A^L(t)^{\beta 1}L(t)^{\beta 2}A^K(t)^{\beta 3}K(t)^{\beta 4}$
$B(t) = \beta_0 L_A(t)^{\lambda}A^{La}(t)^{\eta}R(t)^{\psi}$
$dA(t) = B(t)^{\beta}X(t)$
$dA(t) = \beta_0^{\beta}L_A(t)^{\lambda\beta}A^{La}(t)^{\eta\beta}R(t)^{\psi\beta}\gamma A^L(t)^{\beta 1}L(t)^{\beta 2}A^K(t)^{\beta 3}K(t)^{\beta 4}$

Let define $L(t) = L_W(t)$ as workers and $L_W(t)+L_A(t)$ denotes the total labor force; K(t) denotes every physical capital other than R(t). Labor efficiency together with researchers’ efficiency constitutes the total efficiency of human society.

Specifications in $dA(t) = \beta_0^{\beta} L_A(t)^{\lambda\beta} A^{La}(t)^{\eta\beta} R(t)^{\psi\beta} \gamma A^L(t)^{\beta 1} L(t)^{\beta 2} A^K(t)^{\beta 3} K(t)^{\beta 4}$:

$\beta_0^{\beta}\gamma = \tilde{\alpha}$
$A^K(t)^{\beta 3} = \tilde{A}^K(t)^A$
$K(t)^{\beta 4} = \tilde{K}(t)^B$
$A^{La}(t)^{\eta\beta} A^L(t)^{\beta 1} = \tilde{A}^L(t)^C$ - $\tilde{A}^L$ aggregate labor quality (including workers and researchers)
$L_A(t)^{\lambda\beta} L_W(t)^{\beta 2} = \tilde{L}(t)^D$ -$\tilde{L}$ aggregate labor force size (including workers and researchers)
$R(t)^{\psi\beta} = \tilde{R}(t)^E$

Consequently:

$$dA(t) = \tilde{\alpha}\tilde{A}^K(t)^A \tilde{K}(t)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t)^E$$

This model shows that an increase of labor efficiency in an economy in period t is an outcome of a special production process $Y_A = \tilde{\alpha}\tilde{A}^K(t)^A \tilde{K}(t)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t)^E$ where different production factors have been variously combined with each other to create a special output (invention or innovation) and to distribute this output among other people, economic agents. Intuition behind this idea is to divide the aggregate production process of an economy into two sub-processes: production of output and distribution, allocation of output in the markets. Knowledge distribution, allocation is a part of the aggregate distribution, allocation mechanisms in an economy. At this point the aggregate production of output and (aggregate) knowledge distribution, allocation are separated from each other – and not the whole distribution, allocation mechanisms. $X^D(t) = \delta A^L(t)^{\delta 1} L(t)^{\delta 2} A^K(t)^{\delta 3} K(t)^{\delta 4}$ can be interpreted as an aggregate function of knowledge distribution, allocation mechanisms where people characteristics and physical capital characteristics determine the choice of knowledge distribution, allocation mechanisms. The choice is optimal if $X(t) = X^D(t)$, i.e. supplying more knowledge to the economy than the economy can demand is suboptimal ("wasting" knowledge) and supplying less knowledge to the economy than required is also suboptimal (it probably leads to loss of market power on international level as a result of knowledge "withholding"). I presume that generally the condition $X(t) = X^D(t)$ holds and therefore I use $X(t) = \gamma A^L(t)^{\beta 1} L(t)^{\beta 2} A^K(t)^{\beta 3} K(t)^{\beta 4}$ instead of $X^D(t) = \delta A^L(t)^{\delta 1} L(t)^{\delta 2} A^K(t)^{\delta 3} K(t)^{\delta 4}$.

Aggregate production function – R&D expenditures explicitly represented:

$$Y(t) = F[K(t), A(t), L(t), R(t)] = G[\tilde{A}^K(t), \tilde{K}(t), \tilde{A}^L(t), \tilde{L}(t), \tilde{R}(t)] = \tilde{\alpha}\tilde{A}^K(t)^{G1} \tilde{K}(t)^{G2} \tilde{A}^L(t)^{G3} \tilde{L}(t)^{G4} \tilde{R}(t)^{G5}$$

where $A(t) = A^*(t)X(t)$ and

$$\tilde{\alpha}\tilde{A}^K(t)^{G1} \tilde{K}(t)^{G2} \tilde{A}^L(t)^{G3} \tilde{L}(t)^{G4} \tilde{R}(t)^{G5} = [\tilde{\alpha}\tilde{A}^K(t)^A \tilde{K}(t)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t)^E]^{w1} [\tilde{\alpha}\tilde{A}^K(t)^{H1} \tilde{K}(t)^{H2} \tilde{A}^L(t)^{H3} \tilde{L}(t)^{H4} \tilde{R}(t)^{H5}]^{w2}$$

where $dA(t) = \tilde{\alpha}\tilde{A}^K(t)^A \tilde{K}(t)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t)^E$ denotes the "produced" labor efficiency increase in an economy and $\tilde{\alpha}\tilde{A}^K(t)^{H1} \tilde{K}(t)^{H2} \tilde{A}^L(t)^{H3} \tilde{L}(t)^{H4} \tilde{R}(t)^{H5}$ contains other products of economic performance that contribute to economic growth, stagnancy or decline. The weighted effects of these processes determine the path of overall economic progress. Remark: $\tilde{R}(t)^E$ denotes the effects of R&D expenditures on labor efficiency, technological progress and $\tilde{R}(t)^{H5}$ denotes the effects of R&D expenditures on demand and price of some factors – like R&D equipment, research tools, etc. w_1 and w_2 are "weights" and $w_1 + w_2 = 1$. These parameters determine how much % of the aggregate production process accounts for R&D activities and how much % for non-R&D activities. For instance $w_1 = 0.05$ means that R&D activities accounts for 5% of the aggregate production process.

<u>Economy i with own and external technological progress</u>:

$$X_i(t) = \gamma A_i^*(t)^{\alpha 1} L_i(t)^{\alpha 2} K_i(t)^{\alpha 3} = \gamma A_i^L(t)^{\beta 1} L_i(t)^{\beta 2} A_i^K(t)^{\beta 3} K_i(t)^{\beta 4}$$
$$B_i(t) = \beta_0 L_{Ai}(t)^{\lambda 2} A_i^{La}(t)^{\eta 2} R_i(t)^{\psi 2}$$
$$B_{-i}(t) = \beta_0 L_{A\text{-}i}(t)^{\lambda 1} A_{-i}^{La}(t)^{\eta 1} R_{-i}(t)^{\psi 1}$$
$$dA_i(t) = B_{-i}(t)^{\beta 1} B_i(t)^{\beta 2} X_i(t) =$$
$$\beta_0^{\beta 1} L_{A\text{-}i}(t)^{\lambda 1\beta 1} A_{-i}^{La}(t)^{\eta 1\beta 1} R_{-i}(t)^{\psi 1\beta 1} \beta_0^{\beta 2} L_{Ai}(t)^{\lambda 2\beta 2} A_i^{La}(t)^{\eta 2\beta 2} R_i(t)^{\psi 2\beta 2} X_i(t) =$$
$$[\beta_0 L_{A\text{-}i}(t)^{\lambda 1} A_{-i}^{La}(t)^{\eta 1} R_{-i}(t)^{\psi 1}]^{\beta 1} [\beta_0 L_{Ai}(t)^{\lambda 2} A_i^{La}(t)^{\eta 2} R_i(t)^{\psi 2}]^{\beta 2} \gamma A_i^L(t)^{\beta 1} L_i(t)^{\beta 2} A_i^K(t)^{\beta 3} K_i(t)^{\beta 4}$$

Make the similar specifications in this model like above:

$$[\beta_0 L_{A\text{-}i}(t)^{\lambda 1} A_{-i}^{La}(t)^{\eta 1} R_{-i}(t)^{\psi 1}]^{\beta 1} = Q_i(t)^F$$
$$\beta_0^{\beta 2}\gamma = \tilde{\alpha}$$
$$A_i^K(t)^{\beta 3} = \tilde{A}_i^K(t)^A$$
$$K_i(t)^{\beta 4} = \tilde{K}_i(t)^B$$
$$A_i^{La}(t)^{\eta 2\beta 2} A_i^L(t)^{\beta 1} = \tilde{A}_i^L(t)^C$$
$$L_{Ai}(t)^{\lambda 2\beta 2} L_{Wi}(t)^{\beta 2} = \tilde{L}_i(t)^D$$
$$R_i(t)^{\psi\beta} = \tilde{R}_i(t)^E$$

Consequently:

$$dA_i(t) = \tilde{\alpha}\tilde{A}_i^K(t)^A \tilde{K}_i(t)^B \tilde{A}_i^L(t)^C \tilde{L}_i(t)^D \tilde{R}_i(t)^E Q_i(t)^F$$

This model shows that the increase of labor efficiency in an economy in period t is an outcome of a special production process $Y_{Ai} = \tilde{\alpha}\tilde{A}_i^K(t)^A \tilde{K}_i(t)^B \tilde{A}_i^L(t)^C \tilde{L}_i(t)^D \tilde{R}_i(t)^E Q_i(t)^F$ where different production factors have been variously combined with each other to create a special output (invention or innovation).

<u>Aggregate production function of economy i – explicit representation of R&D expenditures</u>:

$$Y_i(t) = F_i[K_i(t), A_i(t), L_i(t), R_i(t)] = G_i[\tilde{A}_i^K(t), \tilde{K}_i(t), \tilde{A}_i^L(t), \tilde{L}_i(t), \tilde{R}_i(t), Q_i(t)^F] = \tilde{\alpha}\tilde{A}_i^K(t)^{G1} \tilde{K}_i(t)^{G2} \tilde{A}_i^L(t)^{G3} \tilde{L}_i(t)^{G4} \tilde{R}_i(t)^{G5} Q_i(t)^{G6}$$

and

$$\tilde{\alpha}\tilde{A}_i^K(t)^{G1} \tilde{K}_i(t)^{G2} \tilde{A}_i^L(t)^{G3} \tilde{L}_i(t)^{G4} \tilde{R}_i(t)^{G5} Q_i^{G6}(t) =$$

$$[\tilde{\alpha}\tilde{A}_i^K(t)^A \tilde{K}_i(t)^B \tilde{A}_i^L(t)^C \tilde{L}_i(t)^D \tilde{R}_i(t)^E Q_i(t)^F]^{w1} [\tilde{\alpha}\tilde{A}_i^K(t)^{H1} \tilde{K}_i(t)^{H2} \tilde{A}_i^L(t)^{H3} \tilde{L}_i(t)^{H4} \tilde{R}_i(t)^{H5} Q_i(t)^{H6}]^{w2} =$$

$$[\tilde{\alpha}\tilde{A}_i^K(t)^A \tilde{K}_i(t)^B \tilde{A}_i^L(t)^C \tilde{L}_i(t)^D \tilde{R}_i(t)^E]^{w1} [\tilde{\alpha}\tilde{A}_i^K(t)^{H1} \tilde{K}_i(t)^{H2} \tilde{A}_i^L(t)^{H3} \tilde{L}_i(t)^{H4} \tilde{R}_i(t)^{H5}]^{w2} Q_i(t)^{F(w1+w2)} =$$

$$[\tilde{\alpha}\tilde{A}_i^K(t)^A \tilde{K}_i(t)^B \tilde{A}_i^L(t)^C \tilde{L}_i(t)^D \tilde{R}_i(t)^E]^{w1} [\tilde{\alpha}\tilde{A}_i^K(t)^{H1} \tilde{K}_i(t)^{H2} \tilde{A}_i^L(t)^{H3} \tilde{L}_i(t)^{H4} \tilde{R}_i(t)^{H5}]^{w2} [\beta_0 L_{A\text{-}i}(t)^{\lambda 1} A_{-i}^{La}(t)^{\eta 1} R_{-i}(t)^{\psi 1}]^{\beta 1(w1+w2)}$$

where $dA_i(t) = \tilde{\alpha}\tilde{A}_i^K(t)^A \tilde{K}_i(t)^B \tilde{A}_i^L(t)^C \tilde{L}_i(t)^D \tilde{R}_i(t)^E Q_i(t)^F$ denotes the „produced“ labor efficiency increase in an economy using (accessible) internal and external sources of technology and $\tilde{\alpha}\tilde{A}_i^K(t)^{H1} \tilde{K}_i(t)^{H2} \tilde{A}_i^L(t)^{H3} \tilde{L}_i(t)^{H4} \tilde{R}_i(t)^{H5} Q_i(t)^{H6}$ contains other products of economic performance that contribute to economic growth, stagnancy or decline. The weighted effects of these processes determine the path of overall economic progress.

Remark: A part of external technological progress is embedded in capital $K_i(t)$ (like through imported production factors)
Corollary: Different convergence level of economies can be explained through an additional factor X(t) in the model. Different economies may posses different values for X(t). For instance, the size of an economy is inversely related to X(t) i.e. higher size of economy slows down the knowledge diffusion and hence dA(t) becomes lower.

1.2.1. Further specifications in the $A^K K A^L L$ model:

General production process:

I call production process the activity, where different combination(s) of production factors has(have) been used directly or indirectly in order to create still existing/earlier existed or new production factors. I call production factors the factors that have an essential role in the production process, therefore they cannot be excluded from this process. Additionally I assume the following classification of production factors: physical capital (it usually has material form), mental capital (it has usually immaterial form) and technology (it lets every production factor be able to participate or participated in a production process).

Notes on Technology in (human) production:

I call technology in (human) production the (human) ability (skill) to exploit or influence some or all of the features, skills that a physical and human capital have or give additional features, skills to these factors by using[11] them with each other under given circumstances and given goals. These goals are (generally) to maximize the effects (outcomes) of the (main) production activity subject to the given goals and circumstances (environment) – i.e. in case of a firm effect means generally the (present value of) profits for this firm/managers, in case of a university effect means generally reaching/achieving good qualification of students by teaching them, on the level of individuals effect means the wealth of individuals etc.; these profits/effects are not always directly quantifiable – e.g. emotions.

Technological progress:

As technological progress I denote in (human) production the improvement of (human) ability to exploit or influence some or all of the features, skills that a physical and human capital have or give additional features, skills to these factors by using them with each other under given circumstances and given goals.

The result of technological progress can be a quantitative or qualitative growth of technology.

I have to distinguish the existence (availability) of production factors (K, L, A^K, A^L) and the use of production factors (A^K x K, A^L x L, A^K x K x A^L x L).

Physical and mental capital denotes the set of physical and mental elements of the world, respectively. Technology is a part of physical and mental capital, products but it (technology)

[11] 'use' refers to e.g. use, apply, combine, distribute, etc.; i.e. to let the production factors be able to participate and participated in the production process)

can be created, used only by creatures and nature – creatures possess both physical and mental capital.

Physical elements (K): everything that has material form or can be derived from properties of physical elements (e.g. gravity, magnetic/electric field, etc.) and cannot acquire skills, abilities by 'themselves' – i.e. machines, computers have abilities to execute some tasks but they get these abilities from humans; metal itself would not be able to execute these tasks unless people would endow it with additional skills, abilities. $A^K K$ denotes the set of physical elements endowed with some technology, quality. Matrix notation:

$$K(t) = \underbrace{\begin{pmatrix} n_1 \\ n_2 \\ \vdots \\ n_j \end{pmatrix}}_{jx1} \bullet \underbrace{\underbrace{\begin{pmatrix} k_1 \\ k_2 \\ \vdots \\ k_j \end{pmatrix}}_{jx1}}_{K(t)} = \begin{pmatrix} n_1 k_1 \\ n_2 k_2 \\ \vdots \\ n_j k_j \end{pmatrix}$$

where n_j denotes the (available) amount of k_j in period t and k_j is the j^{th} physical element in the physical set in period t. If the quantity measure is homogeneous (e.g. kg, volume) for all physical elements, the quantities can be added up. If n means the unit, j refer to the type of physical elements.

$$A^K(t)K(t) = \underbrace{\underbrace{\underbrace{\begin{pmatrix} a_1^{K*} & a_2^{K*} & \dots & a_i^{K*} \end{pmatrix}}_{1xi}}_{A^{K*}(t)} \underbrace{\underbrace{\begin{pmatrix} x_{11} & x_{12} & \dots & x_{1j} \\ x_{21} & x_{22} & \dots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ij} \end{pmatrix}}_{ixj}}_{X^K(t)}}_{A^K(t)} \underbrace{\begin{pmatrix} n_1 k_1 \\ n_2 k_2 \\ \vdots \\ n_j k_j \end{pmatrix}}_{K(t)} = \underbrace{\underbrace{\begin{pmatrix} \sum_i a_{i1}^K & \sum_i a_{i2}^K & \dots & \sum_i a_{ij}^K \end{pmatrix}}_{1xj}}_{A^K(t)} \underbrace{\begin{pmatrix} n_1 k_1 \\ n_2 k_2 \\ \vdots \\ n_j k_j \end{pmatrix}}_{K(t)}$$

where $a_{ij}^K = a_i^{K*} x_{ij}^K$ and a_{ij}^K denotes the available technology (quality) i in physical element j, a_i^{K*} denotes the i^{th} element in the list of physical capital related technologies, x_{ij}^K determines the "amount" of technology i available to physical element j. $A^K(t)$ determines the overall quality of physical capital.

Remark: Technological progress is there if i becomes larger and all a^{K*} are different, aggregate quality can be improved if (i) the value of x increases or (ii) j increases or (iii) both. Horizontal invention or innovation may increase j but relevant for technological progress is the change in i, for increase of labor efficiency is relevant the conditions (i), (ii) and (iii). Higher aggregate quality does not imply automatically higher efficiency, higher efficiency of a physical element can be supposed cet. par. if the average quality of one unit of a physical element j ($[\sum_{ij} x_{ij}]/i$) become higher – based on Lucas's idea (1988). Consequently, higher efficiency does not necessarily imply technological progress and vice versa.

Mental elements (M) (e.g. knowledge, skills, emotions, etc.) are everything except physical capital and have the ability to endow itself and other elements of the nature, world with additional properties, skills, and abilities. So, they can use and 'produce' technology. Consequently, technology 'x' is initially a part of mental capital. A^M denotes the set of mental elements. Matrix notation:

$$(A^M(t))^t = \underbrace{\underbrace{\begin{pmatrix} x_{11} & x_{12} & \dots & x_{1j} \\ x_{21} & x_{22} & \dots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{k1} & x_{k2} & \dots & x_{kj} \end{pmatrix}}_{kxj}}_{X^M(t)} \underbrace{\underbrace{\begin{pmatrix} m_1 \\ m_2 \\ \vdots \\ m_j \end{pmatrix}}_{jx1}}_{A^*(t)}$$

where $(A^M(t))^t$ denotes the transpose of $A^M(t)$ and $X^M(t)$ determines the amount of mental elements (m) available to creature k.

Let $A^L(t)$ denote the matrix that determines the amount of labor related technologies available to labor in period t. Reminder: people (including labor) are special combinations of physical and mental elements. Consequently A^L determines the amount of human related mental and physical technologies, qualities. L determines the size of labor force in quantities (e.g. L=1000 means the labor force consists of 1000 people) and L is a lx1 vector consisting of 1s because there is only 1 "unit" of each people. Labor force can be divided into different subsets consisting of different types of workers. So:

$$L(t) = \begin{pmatrix} l_1 \\ l_2 \\ \vdots \\ l_p \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} = \begin{pmatrix} l_1 \\ l_2 \\ \vdots \\ l_{m-1} \\ l_m \\ \vdots \\ l_p \end{pmatrix} = \begin{pmatrix} L^L(t) \\ L^H(t) \end{pmatrix} = \begin{pmatrix} m \\ p-m \end{pmatrix}$$

where $L^L(t)$ denotes the 'low skilled' workers and $L^H(t)$ denotes the 'high skilled' workers in period t and

$$A^L(t)L(t) = \underbrace{\underbrace{\underbrace{\begin{pmatrix} a_1^{L*} & a_2^{L*} & \dots & a_q^{L*} \end{pmatrix}}_{1xq}}_{A^{L*}(t)} \underbrace{\underbrace{\begin{pmatrix} x_{11} & x_{12} & \dots & x_{1p} \\ x_{21} & x_{22} & \dots & x_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ x_{q1} & x_{q2} & \dots & x_{qp} \end{pmatrix}}_{qxp}}_{X^L(t)}}_{A^L(t)} \underbrace{\begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}}_{L(t)} = \underbrace{\underbrace{\begin{pmatrix} \sum_q a_{q1}^L & \sum_{qi} a_{q2}^L & \dots & \sum_q a_{qp}^L \end{pmatrix}}_{1xq}}_{A^L(t)} \underbrace{\begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}}_{L(t)}$$

and

Remark: Similarly to physical elements, technological progress is there if q becomes larger and all a^{L*} are different, aggregate quality can be improved if (i) the value of x increases or (ii) p increases. Higher aggregate quality does not imply automatically higher efficiency, higher efficiency of a human can be supposed cet. par. if the average quality of this person p ($[\sum_{qp} x_{qp}]/q$) becomes higher – based on Lucas's idea (1988). Consequently, higher labor efficiency does not necessarily imply technological progress and vice versa.
Technology 'x' is embedded in A^L and it is not explicitly represented here.

Remark: one can define, specify different types of production processes by specifying, restricting the characteristics of the production factors (e.g. agricultural production, industrial production, etc.) or specifying the goals or circumstances production process.

This definition of production process presumes the existence of the goal in the production because I assume there is an idea of which and how production factors should be used and this idea embodies the goal. However, the goal can be known or unknown. Furthermore assume that every activity in the world can be seen as a production process where the main goal is the adaption of some elements of the world to the given environment according to some constraints (rules, requirements, etc.). Assume this goal, idea is a product of the use of mental capital, consequently production process presumes the existence and the use of mental capital. Hence, elements of the nature, given environment that solely consists of physical capital cannot adapt to their environment because of the lack of mental capital that would enable this special process (adaption) to the given environment. Consequently, I call creatures every (combination of) elements of the nature, environment that can adapt somehow to its environment. So, a creature is a special combination of physical and mental capital. Hence, humans are also special combinations of these types of production factors.

Remark – Land as basic production factor:

Firstly, I would like to remark that the land as basic production factor does not play here any role because it is assumed fixed. However, land can be assumed as a special combination of physical and creatures' capital.
The growth is getting greater and greater if the production process results in higher and higher value added. However, value added depends on technology and by assumption technology is a manifestation of mental capital. Using the other assumption that only creatures can have mental capital (that does not imply automatically that these creatures have emotions or ideas like human ideas; mental capital means basically that these creatures possess technology using that they can adapt to their environment without loosing their given characteristics) the role of the land as basic production factor can be explained. Assumption is that the bigger the land (surface, volume) is the more it contributes to economic growth. This assumption is based on the following assumption from my point of view: the bigger the land is the more creatures (people, plants, animals, etc.) can be 'placed' on/in it ceteris paribus. More creatures are able to produce more value added according to the assumption relating to technology and creatures, consequently the land as production factor refers to a special combination of physical capital and creatures and that special combination creates a particular environment producing some value added – definition of environment you can find in a later section. This value added is positively related to the quality and quantity of the land – this quality and quantity of the land should refer to the quality and quantity of the physical and creatures capital 'played' on this land. Example: $1000m^2$ land in the Sahara is less useful than $50m^2$ land in Europe.

Human production process:

This is a production process carried out by humans.

Remark: In general, human production is the act of making goods and services/act of manufacturing goods. Normally, people are working in the workplace and they are part of the whole production process, activity – they are usually called as labor[12]. There are leisure activities where people try to relax, i.e. achieve or produce for instance emotions to feel themselves fit in order to be able work more efficient in the workplace. These – working and leisure activities – are special types of production processes.

[12] It is a special part of human society that is employed/participated/involved somehow in the human production process and they possess/represent human capital.

Researchers' production process:

Researchers' production process is a special production process where researchers try to invent, innovate (as a goal) using their knowledge and skills. However, the outcome of such processes may not be clear ex ante and (additionally) ex post observations may not necessarily clarify which production process led to invention/innovation. This problem makes the analyses difficult which analysis is an ex post analysis of data. Ex post analysis faces another problem, namely there is no useful statistics, data on invention and innovation, hence ex post analysis can only indirectly infer from the available data on potential technological progress.

Economic system – complex system of production processes:

This is a complex technological system consisting of any types of production processes (including every possible goal of production processes, every possible types of production factors) that is created, characterized by the type of using the production factors. I assume the type of using production factors is expressed by technology 'x' and so every creature can be separated by the differences between what and how has been produced by creatures. Hence, technology 'x' make every creature separable from each other because the technology that 'creates' the creature itself is belonging to technology 'x'[13]. Example: animals, plants economic system that are basically systems to adapt to their environment as good as possible. It is possible that two or more technological/economic systems have been used, applied in or next to each other (e.g. evolution and human technology; or ants' and human technology etc.)

Human Economy:

It is the economic system of humans.

However, (human) economy, usually defined as a realized social system of production, exchange, distribution, and consumption of goods and services of a country or other area.

I would like to make some notes on human economy: Economy is a special complex system that tries to evaluate, coordinate and influence people's life (i) subject to (their) given environment as optimal as possible and (ii) through giving people jobs, functions, roles. The environment represents needs, ideas and elements of nature etc. and it (environment) is a union of subenvironments of each element of the world, consequently environment is the nature, world. There are many other systems of evaluations of our life - physics, mathematics, literature, history etc. - with their special conversion and evaluation techniques. Economics is one of them. Its main conversion tools are prices and numbers (quantities) by which the variables of economic models (relative) easily can be analyzed - it implies that the tools of mathematics, statistics are often used in economics, economic analysis. However, if economics, economy shall (optimal) evaluate, coordinate, influence people's life through its tools and advices, suggestions, it should use all of the tools that can accurately detail people's life and evaluate the signals, phenomena of their life. Consequently, the tools of any relevant science fields are relevant for economics.
The usual and general measure of economic performance is the GDP that is based on values and thus prices and quantities. So, GDP is an aggregation of subjective evaluations of some elements of our life including wrong, inappropriate evaluations and excluding important

[13] Reminder: technology 'x' is the technology that is responsible for the good/optimal choice of production factors and the good/optimal use of them. The latter refers to a good production technology. A refers to the technology embedded within the production factors.

elements of our life - health, emotions[14]. Hence, wrong evaluations of qualities are the main causes of wrong economic evaluation/coordination. Good evaluations of qualities are optimal subject to any future, current and past periods of time. It means wrong evaluations of qualities are suboptimal and may lead to long run misspecification of the path of the development of our life. The correction of these failures is very costly and may not lead back to the right path of development. Example: historical examples of various types of state formation, privileges formation, etc as elements of a given path of evolution. One can assume there exists the right/optimal evaluation of our life otherwise there would not be any wrong/suboptimal evaluation. Hence, economy tries to react/interact with the signals of our life transmitted and coordinated through prices and quantities.

Remark: optimal means like Pareto optimal – there is no better allocation of any elements of nature that would lead to Pareto superior allocation. Additionally, optimal and optimal way to something has to be separated from each other. Optimal way leads to optimal outcome through optimal and suboptimal elements of this way – example: there are many examples where the contrary of 'something' verifies that this 'something' is optimal; like the evolution of different theories (Greek, Roman, etc.) where some theories turned out to be not optimal, wrong; however, they played important role in development of theories. Consequently we can just assume that we are on an optimal way to optimal outcome; however, it is uncertain that elements of this way or path are optimal – from some aspects these can be seen as optimal but from another they are wrong. In the framework of thesis it is assumed that creatures cannot reach, achieve technological level above nature's technological level. Hence, if creatures reach the technological level of nature, beyond that no more technological progress is possible (by assumption), then creatures may evaluate what is/was the best/optimal allocation of all elements for them and which way would be/have been the optimal way to this outcome – if such optimal outcome exists. However, if they would find such optimal outcome it may be optimal for them but not necessarily for other creatures. In this idea the existence of one (unique) optimal outcome is assumed.
Additionally, more optimal way may exist, however, the most efficient of these ways leads to optimal outcome in shortest period of time.

Notes on Prices, Value:

Value of a product in economics is a function of price and quantity of a product. By assumption the value of a product refers to the quality and quantity of the product, hence price refers to the quality of a product. The market value of a product is the result of complex subjective evaluation processes by at least 2 economic agents (buyer and seller) – assumption of market clearing condition – consequently the market value refers to a common subjective measure of the quality of given amount, quantity of product expressed in nominal units. However, the nominal measures of quality (market price) may not be optimal because subjective valuations of individuals regarding the quality of the product may not be optimal, perfect. Assumption: there exists an objective value of each product determined by nature that is optimal in each period of time and leads to or supports the optimal allocation of any elements of our life, environment and the optimal (most efficient) way of development of environment. In case of

[14] Cinemas, healthcare centres, etc. sell products (films, training courses, etc.) that can create emotions, health in/of people. However, the prices of these products can be maximum the evaluation of emotions and health of those people who attend such programs. So, lot of parts of our life can be/is evaluated indirectly (e.g. by evaluation of complementary products) that shall not be perfect because the evaluated part of our life shall also not be perfect. Economic evaluation means primarily the conversion of elements of our life into their price/value equivalents.

the analysis of aggregate data, especially in case of the analysis of R&D effects on economy the separation of qualitative and quantitative features of aggregate production is important to see whether R&D expenditures have impact on nominal measures of qualitative or quantitative features of the aggregate production.

The role of time: the factor time in the model refers to the changing (economic) circumstances/environment – changing composition/combination/position etc. of physical and mental capital w.r.t. t given by nature and/or creatures, other elements of nature.

Changing environment requires changing composition/combination of physical and mental capital (i.e. different quality and quantity of physical and mental products) consequently there is a necessary need for technological progress that can satisfy these new requirements of the environment. Fixed technological level enables a fixed curve of production possibilities (i.e. fixed possibilities of combination of qualities and quantities) w.r.t. time t. But the fixed composition/combination of capitals is not always optimal/perfect response to changing environment. Variable technological level enables variable production curve(s), and hence changing composition/combination of physical and mental capital that is required by changing environment.

One can see the growth model based on the idea of time as provider of changing environment, as game theoretical model where the time interacts with the nature (nature is represented through their players like physical capital and creatures) and outcomes at each stages of the game (a stage is determined by the time and equals to one period of time) is the result of the interaction of these two main players (time and nature). One can assume that nature sets up the rules of this game (including the time too) and the players are the time and the other players of the nature. In any case the technological progress is the best response to changing environment provided that time requires always (i.e. not in all stage of the game, but in some stages of the game e.g. in every 3rd stages of the game) new compositions of products.

Production factors' quality and quantity: Each production factors may have both qualitative and quantitative growth and both (qualitative and quantitative growth of production factors) may result in more value added cet. par. However, in case of technology as a production factor its quantitative[15] and qualitative[16] growth may increase the marginal productivity of an economy and hence the economic performance cet. par. I call an increase in marginal productivity of an economy w.r.t. t as a possible sign of qualitative improvement of the total economy – however it is not clear that time provides in period t more/less challenging circumstances for the given economy than in other periods[17]. Productivity increase of an economy without increase of marginal productivity is a sign of pure quantitative growth of an economy where technological progress is not necessarily occurred; the growth of an economy is cet. par. a pure result of using more physical capital and employing more people in the production process without increased, improved technological level (and hence efficiency) of these factors over periods. The exact determination of qualitative and quantitative growth of an economy depends on the evaluation of changing circumstances and production factor input. The quantitative growth of physical capital (products) should refer to the growth of the amount of physical capital used in the production process (not meaning the qualitative growth of this physical capital and of the

[15] It means that more technology has been distributed in the economy.

[16] It means that more qualitative technologies would result in higher marginal productivity than less qualitative technologies.

[17] Less challenging circumstances in period t would mean that lower level of technology is enough in period t+1 to satisfy the same value added, marginal productivity in period t+1 like in period t.

production process itself); the qualitative growth of the physical products should refer to the additional technology embodied in the physical products after the production process – through the additional technology of the production input factors. Qualitative growth of human capital means primarily the improved skills and knowledge of humans; the quantitative growth of humans means primarily that more people have been employed in the production process and population growth.

What we call quality is the result of a technology built in the products of production processes and the term qualitative usually refers to products, factors that have advantages over the other products, factors given the type of these products and factors – i.e. given the types of products, their efficiencies in different application ranges are then determined; qualitative (on the level of individuals) refers to products that can satisfy the individual requirements arisen from the side of potential consumer of these products regarding these products as good/efficient/optimal as possible; qualitative (on aggregate level) refers to products that can satisfy the aggregate requirements arisen from the side of potential consumers of these products regarding these products as good/efficient/optimal as possible.

Remark: I use (necessarily) the types of production factors and types of the use of production factors as well, because it would be very complicated to define the technological progress (i.e. qualitative improvement) of products/production factors if I would assume no types of them. I explain it: one can assume that we talk about a new product if this product represents a new combination of production factors; however, according to this definition we cannot measure the qualitative improvement of this product because qualitative improvement would mean a new composition/combination of production factors, hence by assumption it would mean a new product. Consequently, if we want to compare these products, this comparison would necessarily suggest the definition of some ‘rules’ according to that one can make a better/comprehensive comparison of these products and hence better analysis of technological progress. These ‘rules’ should define the types of production factors. Consequently, the existence of types of production factors as well as the types of their use make possible the comparison of elements of given types according to some conversion and evaluation systems.

2. Empirical Part

In the first section of this part I will detail the problems of measuring economic performance, R&D expenditures and the link between these variables. In the last section I will present the estimation results based on the available data on US economy between 1953 and 2006.

2.1. Studies on the link between R&D expenditures and Economic Performance:

First of all, I want to mention here some studies on the link and causality between R&D expenditures and economic performance, growth. In the Background Paper of Congressional Budget Office (USA, 2005) there are represented different models for measuring the effects of R&D on economic growth and some estimation results based on studies of different persons. Table 1, 2 and 3 show some of these results which serve as a good basis for the evaluation of my estimation results.

Before presenting the tables I want to shortly present at this point the model which has been "used" in these analyses and "produced" the estimation results in Table 1, 2 and 3. The model has the following form:

$$\ln Y(t) = \ln A + \lambda t + \alpha \ln K(t-1) + \beta \ln L(t) + \gamma \ln R(t-1) + \varepsilon(t)$$

where Y(t) is the real output, A is the total factor productivity (TFP), K is the stock of capital, L is the labor input, R is the measure of R&D effort and ε is the error term. R&D variable is measured as the investment in R&D in a given year (i.e. R&D expenditures in period t-1 are used as regressor for real output in period t)[18]. TFP is typically estimated as a time trend or a constant in the regression equation. K is usually measured as the productive assets available to firm, an industry or an economy. The preferred measure of L is hours worked or employment – the choice of the variable depends on the availability of these variables. The parameters α, β, and γ are the elasticities of output with respect to K (physical capital), L (labor), and R (R&D), respectively.

This paper of the Congressional Budget Office presents also the main disadvantages of this model. First problem is that parameters might be biased because of omitted variables. For instance firms are more productive than others for reasons unrelated to R&D and those firms spend more money on R&D – in such cases the estimated coefficient on R&D are biased upward. In the empirical part I estimate the elasticity of sectoral value added with respect to the total R&D expenditures and not with respect to the sectoral R&D expenditures – using nominal data and a model similar to this one. Consequently an estimated coefficient on R&D tells us how an additional unit of money spent on R&D would affect the nominal sectoral value added. For instance inflation increases the price level and the nominal value added without increasing the quality and quantity of aggregate production. Hence the estimated R&D elasticity might be biased upward. This problem might "reduce" the plausibility of the estimated coefficients but significant R&D elasticities are though important results. Consequently in the reality value added is expected to be less elastic with respect to R&D effort than the estimation results show.

[18] See Griliches (1979), for details.

However, it is an interesting question whether new designs induce inflation or not. Inflation is an increase of price level without having higher economic performance. Sectoral inflation can be seen as a correction for the application of wrong relative prices. It means that the current economic situation requires an increase in the prices of the products of given sector. Sectoral price increase may however induce a price increase in other sectors that finally results in inflation in the total economy. In this sense "correction for wrong prices" can be seen as a technology that tries to change (maybe optimize) the consumption behaviour in an economy. At this point I do not want to go into details regarding this problem but I want to remark that in the microeconomic theory price system is optimal if it induces "(aggregate) supply equals (aggregate) demand". However, other requirements on the optimal price system can be easily made, for instance an optimal price system may induce "supply equals demand" and influence the consumption behaviour toward an increased consumption of specific products (e.g. domestic products). Other requirement might be that it reflects the quality of products: if we assume that the average quality of products becomes higher and higher as time goes by, price level must increases with respect to time. Because of the fact that different products may "experience" different change of quality, relative prices of these products may vary with respect to time if the price system shall reflect the quality of products. However, analysis of such processes (i.e. link between prices and qualities, new designs and inflation, etc.) requires accurate and complete statistics on these data. Because of the unavailability of such statistics the estimated coefficients in the section 2.4. shall be carefully interpreted.

Furthermore multicollinearity, correlation among independent variables and correlation of the explanatory variables with the error term might be problems in such regressions, especially if they use time-series data.

Further problem with the estimated parameters (coefficients) that they are constant through time. A constant elasticity would imply that an additional unit of money spent on R&D would always induce the same change in output or value added independently of its quality and type. This contradicts to the reality and to the model because R&D expenditures are "only" external effects that may improve the probability of invention or innovation. Furthermore there are new designs that cannot be realized in the economy or there is no demand on such designs. Consequently constant effects in the model can be easily criticized and therefore it requires some assumptions on R&D expenditures: (i) first of all in case of significant R&D elasticity of sectoral value added, the given sector either spends on R&D projects or has connection to other sectors that are elastic to R&D expenditures or both; (ii) secondly an additional unit of money invested in total R&D expenditures may result in an expected increase of sectoral value added (expectation based on the estimated R&D elasticity) if this additional unit is perfectly divisible and this additional unit does not bias the actual ratio of different types of R&D spending. The actual ratio of different types of R&D spending or different R&D projects is given by the ratio of money spent on two different types of R&D spending or two different R&D project. It means if 100% of this additional unit of money has been spent on a given type of R&D activities or a given R&D project, this additional unit would bias the actual ratio of different R&D spending (projects) because the R&D project that has been supported with this additional money, would have a relative larger fraction of the total R&D than before. Consequently such investment of this additional unit would bias the sectoral R&D effects, too. Furthermore (iii) an additional unit of R&D expenditure has rather decreasing effects on sectoral value added – it means an additional unit of R&D expenditure induces lower and lower increase in value added.

Based on Table 1 R&D elasticity (i.e. elasticity of output to R&D expenditures) in my estimations is expected to be about 0.10 on private industry level because my estimations are based also on time-series, including the whole US economic sector. However, this is alone not so meaningful because we do not know here what is the elasticity of output to capital and labor.

Table 1[19]:

Selected Estimates of the Elasticity of Private R&D from Time-Series Studies

Study	R&D Elasticity[a]	Sample
Minasian (1969)	0.08	17 U.S. firms; 1948 to 1957
Griliches (1980b)	0.08	883 U.S. firms; 1957 to 1965
Cuneo and Mairesse (1984)	0.05	182 French manufacturing firms; 1972 to 1977
Subsample 1	0.14	98 firms in scientific sectors
Subsample 2	0.03	84 firms in nonscientific sectors
Griliches and Lichtenberg (1984b)	(0.04)	27 U.S. manufacturing industries; 1959 to 1976
Griliches and Mairesse (1984)	0.09	133 U.S. firms; 1966 to 1977
Griliches (1986)	0.12	652 U.S. firms; 1966 to 1977
Jaffe (1986)	0.10	432 U.S. firms; 1973 and 1979
Bernstein (1988)	0.12	7 Canadian manufacturing industries; 1978 to 1981
Hall and Mairesse (1995)	0 - 0.07	197 French firms; 1980 to 1987
Verspagen (1995)	(0.02) - 0.17	14 industries in 11 OECD countries; 1973 to 1988

Source: Congressional Budget Office based on Mairesse and Sassenou (1991), Mohnen (1992), and Australian Industry Commission (1995).

Note: R&D = research and development; OECD = Organization for Economic Cooperation and Development.

a. Parentheses indicate negative numbers.

Table 2 includes also important observations on R&D effects on output. This table represents cross-sectional studies on R&D effects at different points of time. It shows that the effects of R&D expenditures on economic performance of firms in the sample fluctuates but has a positive trend as time elapses.

[19] Background Paper of Congressional Budget Office (USA, 2005), page 17.

Table 2[20]:

Selected Estimates of the Elasticity of Private R&D from Cross-Sectional Studies

Study	R&D Elasticity[a]	Sample
Minasian (1969)	0.11 - 0.26	17 U.S. firms (chemical industry); 1948 to 1957
Griliches (1980a)	0.03 - 0.07	39 U.S. manufacturing industries; 1959 to 1977
Griliches (1980b)	0.07	883 U.S. firms, 1957 to 1965
Schankerman (1981)	0.10 - 0.16	110 U.S. firms (chemical and oil industries); 1963 cross-section
Sveikauskas and Sveikauskas (1982)	0.22 - 0.25	144 U.S. manufacturing industries; 1959 to 1969
Cuneo and Mairesse (1984)	0.20	182 French manufacturing firms; 1972 to 1977
Subsample 1	0.21	98 firms in scientific sectors
Subsample 2	0.11	84 firms in nonscientific sectors
Griliches and Mairesse (1984)		
Sample 1	0.05	133 U.S. firms; 1966 to 1977
Sample 2	0.19	77 U.S. firms (scientific sectors); 1966 to 1977
Griliches (1986)		491 U.S. firms
Subsample 1	0.11	1972 cross-section
Subsample 2	0.09	1977 cross-section
Jaffe (1986)	0.20	432 U.S. firms; 1973 and 1979
Englander, Evenson, and Hanazaki (1988)	(0.16) - 0.50	16 industries across six countries; 1970 to 1983
Mansfield (1988)	0.42	17 Japanese manufacturing industries
Griliches and Mairesse (1990)		
Sample 1	0.25 - 0.41	525 U.S. manufacturing firms; 1973 to 1980
Sample 2	0.20 - 0.56	406 Japanese manufacturing firms; 1973 to 1980
Hall and Mairesse (1995)	0.05 - 0.25	197 French firms; 1980 to 1987
Wang and Tsai (2003)	0.19	136 Taiwanese manufacturing firms; 1994 to 2000

Source: Congressional Budget Office based on Mairesse and Sassenou (1991), Mohnen (1992), and Australian Industry Commission (1995).

Note: R&D = research and development.

a. Parentheses indicate negative numbers.

The next table shows the estimation results on aggregate level (elasticity of labor productivity, TFP, per capita output to R&D expenditures) and we can conclude that R&D effects vary across countries and time periods. These results approve my expectation on R&D elasticity (0.10) in my sample. Remark – TFP, MFP: The MFP (Multi factor productivity) or TFP (Total

[20] Background Paper of Congressional Budget Office (USA, 2005), page 15.

factor productivity) is defined as the difference between the rate of change of output and the rate of change of total inputs. It is a usual measure for technology, technological change.

$$MFP = \gamma_Y(t) - \gamma_K(t) - \gamma_L(t)$$

where $\gamma_Y(t)$ is the rate of change[21] of output in period t;
$\gamma_K(t)$ is the rate of change of capital in period t;
$\gamma_L(t)$ is the rate of change of labor in period t.

Through this calculation, the input variation effects – i.e. increase the economic growth only by using more inputs – can be neutralized, so the result refers to the value added of the aggregate production process of the economy.
The 'sign' of MFP can be either positive or negative or zero depending of the success of new designs (i.e. adopting new technology) because a wrong combination of production factors may lead to suboptimal solutions and so to 'negative' technological progress reflected by negative MFP.
Remark: This formula excludes the effects of technological progress on capital and labor and hence such calculation of MFP results in negative values for MFPs in most years.

Table 3[22]:

Selected Estimates of the Elasticity of Private R&D from Studies Using Aggregate Data

Study	R&D Elasticity	Sample (Variable Studied)
Nadiri (1980)	0.06 - 0.10	United States (labor productivity); 1949 to 1978
Patel and Soete (1988)	0.61	United States (TFP); 1967 to 1985
Lichtenberg (1992)	0.07	98 countries (per capita output); 1960 to 1985
Coe and Moghadam (1993)	0.17	France (output); 1971 to 1991
Coe and Helpman (1995)	0.23	G7 countries (TFP);[a] 1971 to 1990
Coe and Helpman (1995)	0.08	Non-G7 OECD countries (TFP);[a] 1971 to 1990
Australian Industry Commission (1995)		
Subsample 1	0.02	Australia (TFP); 1975 to 1991
Subsample 2	0.14	Australia (output); 1975 to 1991

Source: Congressional Budget Office based on Mairesse and Sassenou (1991), Mohnen (1992), and Australian Industry Commission (1995).

Note: R&D = research and development; TFP = total factor productivity; OECD = Organization for Economic Cooperation and Development.

a. The G7 countries are Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States.

Jong (2005) studied in a US sample (including pharmaceutical firms) the relationship between capital investments and R&D spending and he used a panel cointegration analysis. He stated that capital investment depends on the success of R&D effort over time. However, there is no

[21] Rate of change is defined as follows: $(X_t - X_{t-1})/X_{t-1}$ where X_t is the corresponding variable in period t.
[22] Background Paper of Congressional Budget Office (USA, 2005), page 22.

short run relationship between these variables but a long run. The following table (Table 4) represents the results. The represented causality relationship insinuates that thriving investment activity in one period may stimulate R&D efforts in the next year, in order to extend the success of the current products. This is an important result because it states that R&D expenditures are not constant over time, on the long run they depend on the state of economic performance. Additionally for the success of R&D activities fluctuating project financing are insufficient, useless – constant, secure long term financing of R&D activities may increase the productivity of firms but short term, unsecure R&D project financing does not necessarily result in expected outcomes.

Table 4[23]: Tests of Long-Run Causality Between Capital Investment-R&D

Firms	Capital Investment → R&D[a]	*p*-value[b]	R&D → Capital Investment[c]	*p*-value[d]
ABAXIS INC	3.62	0.16	27.10	0.00
ALLERGAN INC	29.45	0.00	53.86	0.00
ALKERMES INC	11.59	0.00	17.86	0.00
AMGEN INC	0.80	0.67	14.76	0.00
BIOGEN IDEC INC	5.90	0.05	8.39	0.02
BRISTOL-MYERS SQUIBB CO	12.63	0.00	36.09	0.00
BARR PHARMACEUTICALS INC	3.81	0.15	17.31	0.00
CARRINGTON LABORATORIES INC	9.88	0.01	17.46	0.00
COLUMBIA LABORATORIES INC	0.83	0.66	8.98	0.01
CYPRESS BIOSCIENCE INC	6.20	0.05	8.01	0.02
GENENTECH INC	9.41	0.01	20.47	0.00
EMISPHERE TECHNOLOGIES INC	4.17	0.12	15.74	0.00
ENZON PHARMACEUTICALS INC	7.38	0.02	10.82	0.00
FOREST LABORATORIES	0.36	0.83	22.32	0.00
ICOS CORP	25.29	0.00	28.69	0.00
IDEXX LABS INC	2.31	0.32	9.01	0.01
IMMUNOMEDICS INC	4.10	0.13	17.93	0.00
ISIS PHARMACEUTICALS INC	1.64	0.44	13.95	0.00
JOHNSON & JOHNSON	33.59	0.00	63.88	0.00
LIFECORE BIOMEDICAL INC	1.26	0.53	5.83	0.05
LILLY (ELI) & CO	1.59	0.45	14.64	0.00
MEDIMMUNE INC	3.38	0.18	13.26	0.00
MEDAREX INC	1.91	0.38	7.19	0.03
MGI PHARMA INC	0.60	0.74	8.91	0.01
MYLAN LABORATORIES INC	1.88	0.39	16.48	0.00
MATRITECH INC	2.56	0.28	15.31	0.00
NEUROGEN CORP	5.29	0.07	9.56	0.01
OSI PHARMACEUTICALS INC	9.61	0.01	31.82	0.00
PROTEIN DESIGN LABS INC	11.29	0.00	21.64	0.00
PFIZER INC	23.21	0.00	48.73	0.00
PERRIGO CO	14.44	0.00	17.25	0.00
PAR PHARMACEUTICAL COS INC	1.50	0.47	10.07	0.01
REPLIGEN CORP	0.96	0.62	11.52	0.00
SAVIENT PHARMACEUTICALS INC	16.86	0.00	27.39	0.00
MEDTOX SCIENTIFIC INC	2.08	0.35	11.42	0.00
MERIDIAN BIOSCIENCE INC	1.35	0.51	25.04	0.00

Notes: a – LR test of the joint hypothesis that $\hat{\beta} = 1.0$ and $\hat{\alpha}_Y = 0.0$. b – *p*-value of test in a. c – LR test of the joint hypothesis that $\hat{\beta} = 1.0$ and $\hat{\alpha}_I = 0.0$. d – *p*-value of test in c.

Another important question besides the internal effects of R&D on economic performance is the external effects of R&D. It means how R&D spillovers affect other countries productivity. In the following I present some papers which investigate this question.

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[23] Pieter J. de Jong. The Relationship between Capital Investment and R&D Spending: A Panel Cointegration Analysis, University of Texas at Arlington, USA, 2005, page 20.

Luintel and Khan (2004) have investigated the question whether R&D spillovers are costly for the US. The sample of their study consists of G10 and OECD countries and it states that the dynamics of knowledge diffusion are country-specific and inherently heterogeneous. They stated furthermore that United States (US) is the sole spillover generator for Canada, main spillover generator for Japan, and important "source of knowledge for the UK. This is an important contribution to my work because this study shows that US R&D expenditures improve partly the own economic performance but the economic performance of other countries too. Hence, US R&D activities bring not necessarily big production advantages for US economy over other economies. This has at least one major consequence for the USA: they need to increase secrecy, efficiency of patents regarding the US inventions, innovations if they want to "enjoy" their production advantages over other countries. This result is however not so surprising because the US economy is the largest in the world, hence productivity of USA (including R&D productivity) influences the economic productivity of the world.

Gutierrez & Gutierrez (2002) stated in their study which primarily analyzes the agriculture sector and agricultural R&D that total factor productivity (TFP) of a country is positively and significantly influenced not only by its domestic R&D capital but also by the R&D capital stock of its trade partners. Further result is that in temperate countries like USA benefit more than tropical countries from technological spillovers, hence lower investments in R&D in temperate countries are enough to use the technological knowledge effective and generate sizeable spillover benefits. Additional result is that USA exerts the major impact in transferring agricultural R&D world-wide. So, this study also verifies the study of Luintel and Khan.

Table 5[24]: Elasticity of Total Factor Productivity with respect to R&D capital stock – 1990

	France	Italy	Japan	Netherlands	U.K.	U.S.A.
France	-	0.0372	0.0720	0.0259	0.0627	0.2660
Italy	0.0929	-	0.0370	0.0192	0.0334	0.1835
Japan	0.0025	0.0009	-	0.0004	0.0031	0.2050
Netherlands	0.1389	0.0276	0.1516	-	0.1870	0.7096
U.K.	0.0836	0.0237	0.1580	0.0417	-	0.5182
U.S.A.	0.0045	0.0021	0.0996	0.0010	0.0064	-
India	0.0003	0.0001	0.0030	0.0001	0.0008	0.0035
Pakistan	0.0018	0.0014	0.0485	0.0007	0.0008	0.0360
Philippines	0.0008	0.0002	0.0238	0.0002	0.0099	0.0588
Kenya	0.0040	0.0011	0.0243	0.0010	0.0071	0.0145
Zimbabwe	0.0025	0.0010	0.0089	0.0010	0.0010	0.0313
Avg. Temperated Countries	0.0187	0.0056	0.0624	0.0074	0.0168	0.1227
Avg. Tropical Countries	0.0019	0.0007	0.0130	0.0004	0.0017	0.0255
Avg. 47 Countries	0.0126	0.0038	0.0442	0.0049	0.0113	0.0869

The last study I want to present here is the study of Kao, Chiang, and Chen (1999) on R&D spillovers. They used two different methods in the sample of G7 countries to decide whether foreign R&D capital has impact on TFP. FM (fully modified) OLS estimations support the idea that foreign R&D is related to TFP. However, DOLS (dynamic OLS) method suggests that the impact of foreign R&D on TFP is insignificant. Because of the superiority of DOLS over the FM, this study rejects the Coe and Helpman's hypothesis (i.e. international R&D spillovers are traded related). Table 6 shows some results of this paper. It can be concluded that international R&D spillovers are rather small and insignificant. This result contradicts somehow to the results of the previous study. The previous study used also DOLS but focused primarily on the

[24] Gutierrez, L. and Gutierrez, M. International R&D Spillovers and Productivity Growth in the Agricultural Sector. A Panel Cointegration Approach, Department of Agricultural Economics, University of Sassari, Italy, 2002, page 33.

agricultural sector and stated that in relations based on trades of agricultural products the foreign R&D capital have impact on TFP. However, the last study shows that if there is more complex trading relationship between countries, the foreign R&D capital stock has insignificant effects on TFP. Consequently, I will assume in the following that US TFP is not elastic to foreign R&D stock but to domestic and US R&D activities exert effects on other countries' TFP.

Table 6[25]:
Elasticities of TFP *with Respect to Research and Development Capital Stocks in G7 Countries in 1990 using* DOLS *Estimators: Based on Regression (iii) in Table 5*

	US	*Japan*	*Germany*	*France*	*Italy*	*UK*	*Canada*
United States	...	0.0108	0.0019	0.0007	0.0003	0.0012	0.0012
Japan	0.0126	...	0.0004	0.0002	0.0001	0.0002	0.0001
West Germany	0.0230	0.0048	...	0.0040	0.0012	0.0030	0.0001
France	0.0182	0.0024	0.0077	...	0.0012	0.0024	0.0001
Italy	0.0126	0.0013	0.0082	0.0038	...	0.0016	0.0001
United Kingdom	0.0262	0.0034	0.0065	0.0023	0.0006	...	0.0001
Canada	0.0354	0.0010	0.0003	0.0001	0.0001	0.0003	...
Australia	0.0202	0.0045	0.0010	0.0002	0.0001	0.0009	0.0001
Austria	0.0149	0.0051	0.0302	0.0020	0.0016	0.0015	0.0001
Belgium	0.0459	0.0057	0.0401	0.0168	0.0019	0.0114	0.0002
Denmark	0.0222	0.0031	0.0124	0.0018	0.0006	0.0033	0.0001
Finland	0.0176	0.0051	0.0081	0.0013	0.0006	0.0026	0.0001
Greece	0.0143	0.0068	0.0142	0.0032	0.0028	0.0035	0.0001
Ireland	0.0510	0.0046	0.0047	0.0014	0.0004	0.0187	0.0001
Israel	0.0587	0.0022	0.0060	0.0015	0.0009	0.0041	0.0001
Netherlands	0.0411	0.0037	0.0212	0.0041	0.0008	0.0056	0.0001
New Zealand	0.0228	0.0064	0.0010	0.0002	0.0001	0.0018	0.0001
Norway	0.0318	0.0041	0.0091	0.0016	0.0006	0.0047	0.0003
Portugal	0.0268	0.0046	0.0145	0.0077	0.0024	0.0063	0.0002
Spain	0.0177	0.0023	0.0049	0.0030	0.0009	0.0018	0.0001
Sweden	0.0245	0.0045	0.0101	0.0018	0.0005	0.0034	0.0001
Switzerland	0.0224	0.0040	0.0198	0.0042	0.0016	0.0028	0.0001
Average elasticity of foreign *TFP*	0.0209	0.0068	0.0045	0.0016	0.0005	0.0016	0.0006

2.2. Economic growth and problems of measuring it:

Economic growth can be the result of simple input variation in the economy or a result of the productivity growth of the economy or both – productivity growth may imply quantitative and qualitative growth. Quantitative means primarily the productivity growth of the economy where more products have been produced in the given period of time but it does not mean automatically the growth of their quality. Qualitative growth is the result of the technological progress and increase of labor efficiency – i.e. products can be used more efficient, have wider application range or better social policy -, but it does not primarily indicate the growth of production and sales. Thus, in both cases we have a productivity growth because in the given

[25] Kao, C., Chiang, M-H., and Chen, B. International R&D spillovers: An application of estimation and interference in panel cointegration, Oxford Bulletin of Economics and Statistics, 61, 4, 1999, page 709.

period of time more goods and/or ‘better’ goods has been produced than in the earlier periods – ‘better’ refers to higher technological level. In case of simple input variation fixed technological level is assumed and the growth of economic performance is just a result of using more/less inputs. However, it is hard to identify the limits of effects of given technologies on economic performance and hence the identification of whether input variation or productivity growth led to economic growth is very complicated.

2.2.1. Estimated models:

The aggregate production function is the same to the aggregate function model with (only) own technological progress (see the theoretical part) because USA as largest economy in the world supports other countries’ development through direct and indirect channels (like US R&D spillover) and not contrary.

$$Y(t) = F[K(t), A(t), L(t), R(t)] = G[\tilde{A}^K(t), \tilde{K}(t), \tilde{A}^L(t), \tilde{L}(t), \tilde{R}(t)] = \tilde{\alpha}\tilde{A}^K(t)^{G1}\tilde{K}(t)^{G2}\tilde{A}^L(t)^{G3}\tilde{L}(t)^{G4}\tilde{R}(t)^{G5}$$

where $A(t) = A^*(t)X(t)$ and

$$\tilde{\alpha}\tilde{A}^K(t)^{G1}\tilde{K}(t)^{G2}\tilde{A}^L(t)^{G3}\tilde{L}(t)^{G4}\tilde{R}(t)^{G5} = [\tilde{\alpha}\tilde{A}^K(t)^{A}\tilde{K}(t)^{B}\tilde{A}^L(t)^{C}\tilde{L}(t)^{D}\tilde{R}(t)^{E}]^{w1}[\tilde{\alpha}\tilde{A}^K(t)^{H1}\tilde{K}(t)^{H2}\tilde{A}^L(t)^{H3}\tilde{L}(t)^{H4}\tilde{R}(t)^{H5}]^{w2}$$

where $dA(t) = \tilde{\alpha}\tilde{A}^K(t)^{A}\tilde{K}(t)^{B}\tilde{A}^L(t)^{C}\tilde{L}(t)^{D}\tilde{R}(t)^{E}$ denotes the „produced“ labor efficiency increase in an economy and $\tilde{\alpha}\tilde{A}^K(t)^{H1}\tilde{K}(t)^{H2}\tilde{A}^L(t)^{H3}\tilde{L}(t)^{H4}\tilde{R}(t)^{H5}$ contains other products of economic performance that contribute to economic growth, stagnancy or decline. The weighted effects of these processes determine the path of overall economic progress.

The endogenous model framework is theoretically important for the inclusion of R&D expenditures in the model. If technological progress is exogenous in the model, financing R&D projects (with R&D expenditures) is not justified. In endogenous model framework the reason of R&D expenditures is justified because it may support the technological progress and hence the productivity growth of an economy. However, R&D expenditures are not sufficient conditions for the success of R&D activities, projects, because people can invent, innovate without R&D expenditures, capital stock. Furthermore, if the level of R&D stocks, expenditures reaches a (critical) level beyond the marginal effect of an additional R&D stock on the success of R&D activities is zero, higher R&D stock cannot influence the success of R&D activities. Based on the previously presented empirical studies on R&D the amount of R&D stocks, expenditures have not reached this critical level.

Further specifications in the model (variables without tilde ($\tilde{}$) have the same interpretation like variable with tilde):

Instead of R(t) in the model, I will use R(t-1) because I assume there is lag (ca. 1 year) between the payment of R&D expenditures and realization of R&D products in the production processes, economy. Within this period R&D staffs (researchers) invents or innovates and distribute their products among given sectors, firms, divisions, etc. The realized R&D products are able to increase the productivity of an economy, labor efficiency in an economy. R&D expenditures have not only effect on the economy if financed R&D activities were successful; they are usually spent on new equipments, factors that are likely to support, improve the probability of R&D success and this increases the sales of firms which producing such equipments, factors. Furthermore, there are new designs which have been realized in the economy in the same period as the payment of respective R&D expenditures. Consequently, R(t) can also have an effect on Y(t), but these are mainly "sales" effects not "productivity" effects.

$A^K(t)K(t)$ at the beginning of period t is the same as $A^K(t-1)K(t-1)$ at the end of period t-1. Additionally, it is likely that R(t-1) influences $A^K(t)K(t)$ through new investment techniques, new designs that are likely to improve the amount and quality of $A^K(t)K(t)$ and hence $A^K(t)K(t)$ would include some effects of R&D expenditures and then R(t-1) would become insignificant. Consequently, I will use $A^K(t-1)K(t-1)$. Additionally, technology distribution possibilities during period t depend partly on physical capital input at the beginning of period t.

$A^L(t)L(t)$ does not change in the model. Its coefficient is likely to include some effects of R&D expenditures, hence R(t-1) may become as a redundant variable in the regressions.

$Y(t) = F[K(t-1), A(t), L(t), R(t-1)] = G[\tilde{A}^K(t-1), \tilde{K}(t-1), \tilde{A}^L(t), \tilde{L}(t), \tilde{R}(t-1)] = \tilde{\alpha}\tilde{A}^K(t-1)^{G1}\tilde{K}(t-1)^{G2}\tilde{A}^L(t)^{G3}\tilde{L}(t)^{G4}\tilde{R}(t-1)^{G5}$

where $A(t) = A^*(t)X(t)$ and

$\tilde{\alpha}\tilde{A}^K(t-1)^{G1}\tilde{K}(t-1)^{G2}\tilde{A}^L(t)^{G3}\tilde{L}(t)^{G4}\tilde{R}(t-1)^{G5} =$
$[\tilde{\alpha}\tilde{A}^K(t-1)^A\tilde{K}(t-1)^B\tilde{A}^L(t)^C\tilde{L}(t)^D\tilde{R}(t-1)^E]^{w1}[\tilde{\alpha}\tilde{A}^K(t-1)^{H1}\tilde{K}(t-1)^{H2}\tilde{A}^L(t)^{H3}\tilde{L}(t)^{H4}\tilde{R}(t-1)^{H5}]^{w2}$

<u>Remark on TFP (MFP)</u>: it is a resulting synergy effect of production factors, hence it just partly depends on the state of technology. TFP cannot be seen as a measure of technology because it depends not only on technology. Consider the following representation of the model:

G_1 depends on $A^K(t-1)$ and on the correlation between $A^K(t-1)$ and other production factors in period t. If there is a positive correlation between the variables, positive external effects on aggregate production are there – e.g. simple input variation may result in higher TFP. So:

$G_1 = g(A^K(t-1), Corr(A^K(t-1), [\tilde{K}(t-1), \tilde{A}^L(t), \tilde{L}(t), \tilde{R}(t-1)])) = g_1(K(t-1)) + Corr_1$. Analogously to other coefficients:

$G_2 = g(K(t-1), Corr(K(t-1), [\tilde{A}^K(t-1), \tilde{A}^L(t), \tilde{L}(t), \tilde{R}(t-1)])) = g_2(K(t-1)) + Corr_2$
$G_3 = g(A^L(t), Corr(A^L(t), [\tilde{A}^K(t-1), \tilde{K}(t-1), \tilde{L}(t), \tilde{R}(t-1)])) = g_3(A^L(t)) + Corr_3$
$G_4 = g(L(t), Corr(L(t), [\tilde{A}^K(t-1), \tilde{K}(t-1), \tilde{A}^L(t), \tilde{R}(t-1)])) = g_4(L(t)) + Corr_4$
$G_5 = g(R(t-1), Corr(R(t-1), [\tilde{A}^K(t-1), \tilde{K}(t-1) \tilde{A}^L(t), \tilde{L}(t)])) = g_5(R(t-1)) + Corr_5$

where $TFP^{\alpha(TFP)} = T^{Corr1+ Corr2+Corr3+Corr4+Corr5}$ and

$Y(t) = \tilde{\alpha}\tilde{A}^K(t-1)^{g1}\tilde{K}(t-1)^{g2}\tilde{A}^L(t)^{g3}\tilde{L}(t)^{g4}\tilde{R}(t-1)^{g5}T^{\alpha(TFP)}$. By taking logarithms of this equation g1, g2, g3, g4, g5 and α(TFP) are elasticities of Y(t) with respect to the regressors.

<u>The „endogenous“ growth path of an economy</u>:

In the reality we can observe A^KK and A^LL and after such observations we can identify A^K, K, A^L and L as mentioned earlier. The initial level of production factors (denoted by 0 in the subscript) is determined by nature. Consequently, the growth path is determined by (for any positive integer t):

$(A^K K)_t = (A^K K)_{t-1} e^{dAk(t)+dK(t)} = A^K_{t-1} e^{dAk(t)} K_{t-1} e^{dK(t)} = A^K_t K_t$
$(A^L L)_t = (A^L L)_{t-1} e^{dAl(t)+dL(t)} = A^L_{t-1} e^{dAl(t)} L_{t-1} e^{dL(t)} = A^L_t L_t$

$Y_t = (A^K K)_t^{\alpha} (A^L L)_t^{\beta} = (A^K_t)^{\alpha 1} (K_t)^{\alpha 2} (A^L_t)^{\beta 3} (L_t)^{\beta 4} = \tilde{\alpha} \tilde{A}^K(t-1)^{G1} \tilde{K}(t-1)^{G2} \tilde{A}^L(t)^{G3} \tilde{L}(t)^{G4} \tilde{R}(t-1)^{G5}$

where

$dA^K(t) = \tilde{\alpha}_K \tilde{A}^K(t-1)^A \tilde{K}(t-1)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t-1)^E$ denotes the quality growth of physical capital in period t;
$dK(t) = K(t) – K(t-1)$ growth rate of the quantity of physical capital in period t – it is primarily endogenously determined through saving and investments and depreciation;
$dA^L(t) = \tilde{\alpha}_L \tilde{A}^K(t-1)^A \tilde{K}(t-1)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t-1)^E$ denotes the quality growth of labor force in period t that is endogenously determined.
$dL(t) = L(t) – L(t-1)$ growth rate of the size of labor force in period t that is exogenously determined but the unemployment rate is endogenously determined by "sacrifice ratio".

Nature's role is to determine A^K_0, K_0, A^L_0, L_0 and dL(t) as well as the environment (of "human world") in each period of time.

(Coefficients with same notation have different meanings in different equations.)

Taking natural logarithm of this equation and adding an error term ε(t) we get the model that serves as basic model in the estimations in the last section of this thesis:

$\ln Y(t) = \ln\tilde{\alpha} + G_1 \ln\tilde{A}^K(t-1) + G_2 \ln\tilde{K}(t-1) + G_3 \ln\tilde{A}^L(t) + G_4 \ln\tilde{L}(t) + G_5 \ln\tilde{R}(t-1) + \varepsilon(t)$ where

$G_1 = \partial\ln Y(t)/\partial\ln A^K(t-1)$
$G_2 = \partial\ln Y(t)/\partial\ln K(t-1)$
$G_3 = \partial\ln Y(t)/\partial\ln A^L(t)$
$G_4 = \partial\ln Y(t)/\partial\ln L(t)$
$G_5 = \partial\ln Y(t)/\partial\ln R(t-1)$

and additionally in model $Y(t) = [\tilde{\alpha} \tilde{A}^K(t-1)^A \tilde{K}(t-1)^B \tilde{A}^L(t)^C \tilde{L}(t)^D \tilde{R}(t-1)^E]^{w1} [\tilde{\alpha} \tilde{A}^K(t-1)^{H1} \tilde{K}(t-1)^{H2} \tilde{A}^L(t)^{H3} \tilde{L}(t)^{H4} \tilde{R}(t-1)^{H5}]^{w2}$ after taking logarithm:

$w_2 H_1 + w_1 A = \partial\ln Y(t)/\partial\ln A^K(t-1)$
$w_2 H_2 + w_1 B = \partial\ln Y(t)/\partial\ln K(t-1)$
$w_2 H_3 + w_1 C = \partial\ln Y(t)/\partial\ln A^L(t)$
$w_2 H_4 + w_1 D = \partial\ln Y(t)/\partial\ln L(t)$
$w_2 H_5 + w_1 E = \partial\ln Y(t)/\partial\ln R(t-1)$

ε(t) denotes the observable errors (residuals) in the given regression.

<u>The regressors and explained variables used in the estimations</u>:

Unlike to most of the empirical analyses concerning the link between R&D expenditures and economic performance I will use nominal data instead of real data. The intuition behind that is to see what the observable outcomes of R&D expenditures are on economic performance. The real GDP measures the quantitative growth of an economy by excluding the changing price and valuation mechanisms whereas nominal GDP measures, describes the economic performance with actual prices and values during a given period of time. The problem of real GDP is that it uses, applies the same valuation of products and production factors in each period of time and quantity is the only factor that can change the overall value of the economy. Nominal prices and values may reflect the change in valuations of products and production factors over periods and hence it may better reflect the change in qualitative and quantitative characteristics of the products. Nominal prices and values are results of complex valuation processes of some economic agents[26] regarding the qualities and quantities of elements of the world at a given point of time.

The problem of fixed prices – reference prices - is that they represent the valuation of goods/services at a given point of time or in a given period of time and this valuation can be wrong for other points/periods of time – changing environment can require new valuations of products, hence fixed valuation may lead to problems. Other problem is that not all goods/services exist in the reference period that also makes the story more complicated. Therefore the estimation results using real data reflect primarily how the quantitative growth of the economy can be increased – qualitative results cannot be derived, just assumed that qualitative growth exists as a result of technological progress as we assumed in growth models.

It is important to mention here that quantitative and qualitative growth involve each other to a certain extent, if we assume that more qualitative products are able to increase sales. However, lower quality products with lower prices can also increase sales. This is a problem of competitiveness, type of goods (normal or inferior), rational expectations/valuations etc. in the economy that results in appropriate price movements where price is a result of complex valuation process of goods/services by economic agents (e.g. producer, customer) – shortly: types of production factors, processes, evaluation systems etc. determines the economic performance and its evaluation. Thus, price movements do not reflect automatically and correctly the quality change of the product but the technological progress/decline in the (whole) production process - effects like sales system[27] (market structure, tradition, marketing, (infrastructure), logistics etc.), cost structure (i.e. firm structure/constitution) also affects the price of the product. Ceteris paribus analysis of price movements subject to factors that can influence the prices is not so complicate but letting 'work' all of these factors in the analysis can make the story very complicated.

The problem of observation of economic relevant data is related to this section. So I begin with brief explanation of such problems.

<u>2.2.2. The problem of observation of factor characteristics</u>:

Factor characteristics mean the quality and quantity of a given factor. Not all of the characteristics can be observed by people's sense organs therefore there is a need for additional techniques to convert the characteristics into observable characteristics by sense organs. Consequently, such conversion techniques can be seen as special production processes where

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[26] I use the concept of agent-based computational economics because I think the most important thing in the definition of economic agent is the term interacting – economic agent is assumed a human person because e.g animals, plants can also interact with human economy, production. The way how they interact in the economy can additionally define their roles like buyers-sellers, principals-agents. What is important, they should interact.

[27] Defect of the sales system can also contribute to the fall in prices and value added. Improvements of sales system are also counting as technological progress and contribute to higher value added. It is a moral problem if sales system and/or firm structure/constitution contribute more to the price of good than the product itself.

the main goal is the 'conversion into observable characteristics'. Through such special use of given factors the observable characteristics can be converted into given measures of observed characteristics (e.g. price as measure of observed qualities, efficiency of labor in a given production process). Based on these measures, people may learn to use the production factors more efficient. However, the conversion techniques of people need not to be perfect or optimal that would lead to suboptimal consequences. In the following I will present a brief overview of an initial problem, namely how the factor characteristics can be observed and evaluated.

As mentioned earlier in this thesis technology 'x' is responsible for the use, combination of production factors. Different use, combination of factors makes different characteristics of the given factors observable. Let D(i) denote the conversion and evaluation system of individual i and furthermore let $D(i) = D(A_i^L)$ a function of i's mental capital. Consequently, individual i uses $'x'_i = 'x'(A_i^L)$ in a given production process $(A^K K)\ x_i\ (A^L L)$ and he/she observes given qualities, characteristics (behavior) of production factors. After observation of these qualities he/she (may) convert and evaluate these qualities as follows:

$(A^K K)\ x_i\ (A^L L) = Y_i$ denotes a particular production process of i and
$(A^K K)_{D(i)}\ (x_i)_{D(i)}\ (A^L L)_{D(i)} = (Y_i)_{D(i)}$ denotes the conversion and evaluation of production factors, production process.

The observed qualities and quantities depend on the quality of D(i) including sense organs. Consequently, individual i may split the whole production process into its production factors: $(A^K)_{D(i)}$, $(K)_{D(i)}$, $(A^L)_{D(i)}$, $(L)_{D(i)}$ and $('x_i')_{D(i)}$. Through this mechanism people are able to study, learn the world, its elements, and mechanisms.

In economics, especially on aggregate level, the main "sense organs" are values, prices and quantities. Value (V) is a function of price (P) and quantity (Q) as follows: V = P*Q. Based on the consideration that each factor has quality and quantity, price is a nominal measure of factors quality. Based on the above explained mechanism prices can be represented as a function of a subjectivity factor (χ) that convert and evaluate of observed physical qualities into prices based on own mental capital: $P = P(\chi(A^K, A^L))$. If Price building mechanism is defined as $\chi(A^L)$ and price building mechanism concerning the qualities of physical element k is defined as $\chi(A_k^K, A^L)$ and P is positively related to $\chi(.)$. Consequently, price of factor i from individual j's point of view: $P_{ij} = P(\chi_j(A_i^K, A_j^L))$. There is a possibility that individual j's price building mechanism $\chi_j(A_j^L)$ can be influenced by other individual(s)' price building mechanisms like $P_{ijn} = P(\chi_j(A_i^K, A_j^L, \chi_{k1}(A_{k1}^L), \chi_{k2}(A_{k2}^L), \ldots, \chi_{kn}(A_{kn}^L))$ where $1 \leq n \leq p-1$ and population consists of p individuals. <u>Remark</u>: in this model the prices of other elements take indirect effect on price building mechanism. Firstly, they (prices) influence the A^L and A^L influences P through the mechanism χ.

Value is then given by $V = P_{ijn}Q = P(\chi_j(A_i^K, A_j^L, \chi_{k1}(A_{k1}^L), \chi_{k2}(A_{k2}^L), \ldots, \chi_{kn}(A_{kn}^L))Q$. Market value is in equilibrium if $V_1 = V_2$ and $P_{iB} = P_{iS}$ where $V_1 = P_{iB}Q_i^B = P(\chi_B(A_i^K, A_B^L))Q_i^B$ denotes the value of physical element i given by buyers and $V_2 = P_{iS}Qi^S = P(\chi_S(A_i^K, A_S^L))Q_i^S$ denotes the value of element i given by sellers. <u>Remark</u>: $\chi_{Bi} = \chi_B(A_i^K, A_B^L)$ denotes the aggregate price building mechanism of buyers; $\chi_{Si} = \chi_S(A_i^K, A_S^L)$ denotes the aggregate price building mechanism of sellers. Consequently, equilibrium price for element i (P_i*) depends on two different price building mechanisms: $P_i^* = P_i^*(\chi_{Bi}^*, \chi_{Si}^*)$ if $P(\chi_{Bi}^*) = P(\chi_{Si}^*)$ and $Q_i^B = Q_i^S$, consequently the mechanisms χ_{Bi}*and χ_{Si}* are equilibrium constituting mechanisms.

<u>Price and Quantity Indices</u>:

Fisher Price Index:

$$P_F = \frac{P_{c,t_n}}{P_{c,t_0}} = \sqrt{P_P * P_L} = \sqrt{\frac{\sum_c (P_{c,t_n} * Q_{c,t_n})}{\sum_c (P_{c,t_0} * Q_{c,t_n})}} * \sqrt{\frac{\sum_c (P_{c,t_n} * Q_{c,t_0})}{\sum_c (P_{c,t_0} * Q_{c,t_0})}}$$

P_F represents the geometrical mean of Paasche Price Index (P_P) and Laspeyres Price Index (P_L).

Fisher Ideal Quantity Index:

$$Q_F = \frac{Q_{c,t_n}}{Q_{c,t_0}} = \sqrt{Q_L * Q_P} = \sqrt{\frac{\sum_c (P_{c,t_0} * Q_{c,t_n})}{\sum_c (P_{c,t_0} * Q_{c,t_0})}} * \sqrt{\frac{\sum_c (P_{c,t_n} * Q_{c,t_n})}{\sum_c (P_{c,t_n} * Q_{c,t_0})}}$$

Q_F represents the geometrical mean of Paasche Quantity Index (Q_P) and to Laspeyres Quantity Index (Q_L).

Additionally,

$$P_F * Q_F = \frac{\sum (P_{c,t_n} * Q_{c,t_n})}{\sum (P_{c,t_0} * Q_{c,t_0})}$$ = Yearend change of output value between the two periods of time.

Fisher Price and Fisher Ideal Quantity Indices have been used as proxies for aggregate prices and quantity of the given (aggregate) production factors. Prices are the economic measures of factor qualities, by assumption. However, because of the subjective feature of prices they may reflect other effects than quality change of given production factors: for instance there is a (physical) good with a given quality and given prices; after a better, more successful marketing techniques a seller may sell this product (same quality) at higher prices and make more profit. In this case an increase in prices is not a result of (physical) factor quality increase but better marketing techniques (idea of production process, marketing as mental factor). Furthermore it is also possible that without any quality change in the total production process, prices can be increased or decreased: for instance speculative processes can generate such price fluctuations. If one assumes that the effects of speculative processes – quality neutral, simply price changing processes - cannot influence the non-speculative (real) production processes than the overall price level may reflect the overall quality change in the economy. If this assumption is false – for instance the world financial crisis nowadays or earlier in the 20th century – the aggregate price level cannot be seen as an economic measure of overall quality without further assumptions. However, prices remain basic tools for coordination of the economy and hence prices, price levels remain important for the analysis.

R&D expenditures may influence prices and this effect is observable if prices reflect overall quality change to some extent and R&D effects are large enough to become observable in overall price changes. Quality is obviously dependent on R&D expenditures because R&D activities generally result in quality improvement. Furthermore I presume that R(t-1) have no or very small effects on A^K(t-1) but R(t-1) may influence the price level of some physical element through the market demand that R(t-1) can generate. The problem is that direct, accurate data

on quality change in an economy does not exist. However, a gradual increase in labor efficiency is not a crucial assumption in my opinion.
As mentioned above in case of speculative processes further assumptions on price indices are required to use them as proxies for aggregate qualities. I presume that prices (of a given good) resulting from speculative processes fluctuate around the price(s) (of the same good) resulting from non-speculative processes. (Remark: Non-speculative prices reflect the quality of production factors, processes, by assumption.) Otherwise speculative processes and prices become not credible; speculative processes cannot then influence the prices anymore because nobody would believe in such processes and prices and nobody would apply these speculative prices. Consequently if somebody wants to "use" speculative processes longer than one or two periods then he or she needs to make credible these processes. It implies that speculative prices may not fluctuate with too large amplitude around non-speculative prices and may not fluctuate independently of factor quality. Additionally I presume that the overall price level contains (the effects of) speculative and non-speculative processes and hence the trend of overall price level may reflect the aggregate quality change in the economy. Hence, the cycle term would refer to the effects of speculative processes and trend term would give the non-speculative price effects. Consequently I analyze another two cases in order to see whether R&D expenditures have effect on aggregate price level and on the aggregate price level trend.

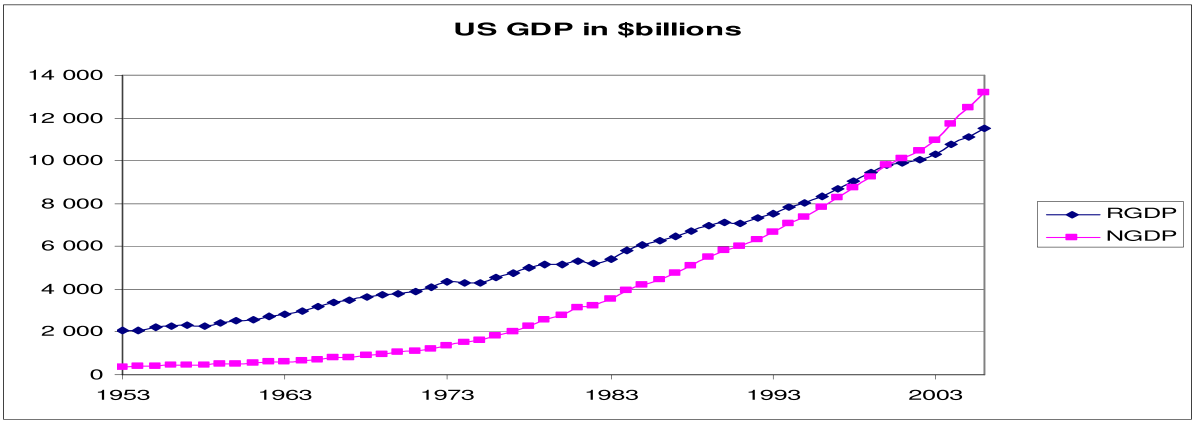
In the following I briefly present the (explained and explanatory) variables (yearly data) used in the estimations. Primarily the trends and relative weights of the variables to the total are interesting to see which variable can be a plausible regressor for the different regressands.

2.3. Trends in the US Economy and US R&D expenditures:

The main sources of data on US economy are the economic databases of Organisation for Economic Co-operation and Development (OECD), Bureau of Economic Analysis (US Department of Commerce), Federal Reserve Bank of St. Louis and National Science Foundation (USA).

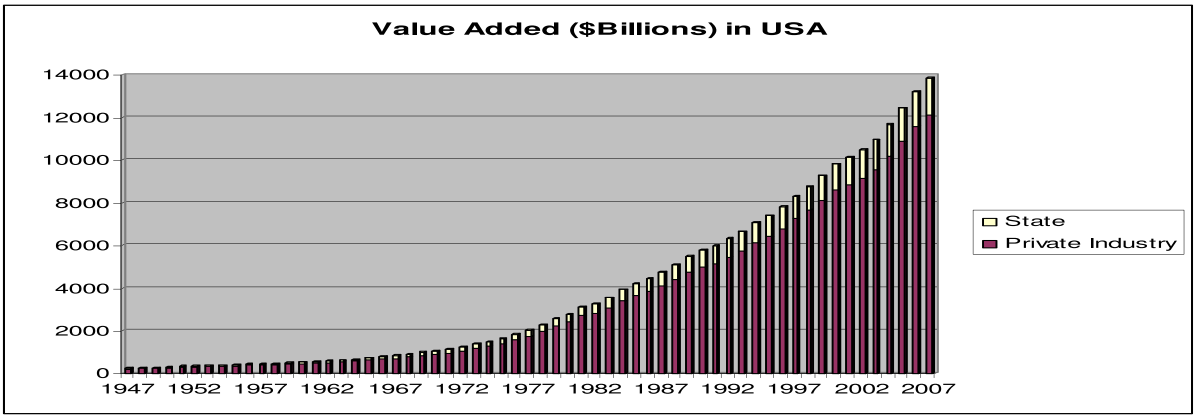
2.3.1. Value Added:

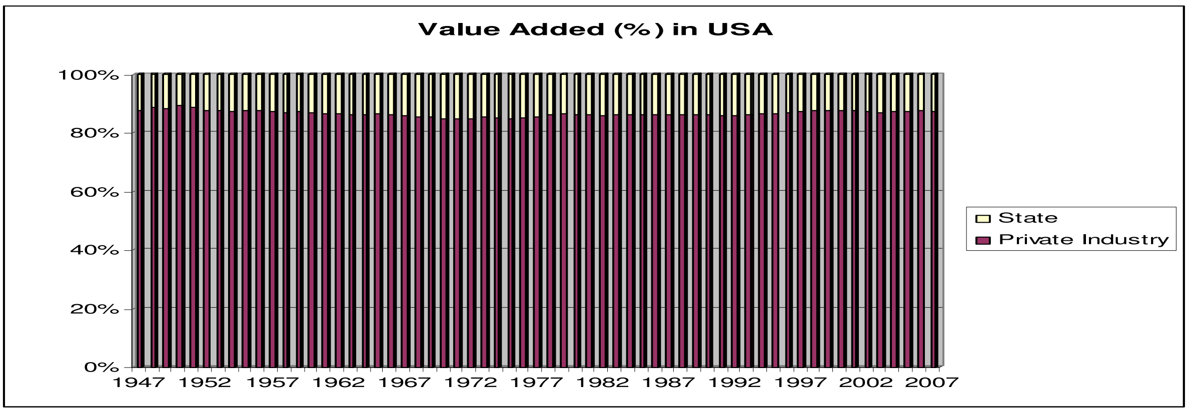
The sources of data on US value added on sectoral and national level are the homepage of the OECD (www.oecd.org) and of the Bureau of Economic Analysis (www.bea.gov).
The first figure shows the evolution of nominal and real GDP over time. Real GDP is calculated on the basis of 2000's price system. Both variables have increasing and fluctuating trend over time. These two curves show how the valuation of products has changed over time: before 2000, the application of price system of 2000 would lead to higher nominal values than the original price system in the given years; after 2000, the application of price system of 2000 would result in lower economic performance from monetary point of view. Furthermore real data has an advantage that it reflects better the fluctuation of sales volume: for instance in the period of oil price shocks the economic production volume (i.e. quantity) has stagnated or decreased for some periods of time. In case of nominal data there is a need for additional data transformation in order to separate the quantitative and price (subjective qualitative) movements from each other – using Fisher Price and Ideal Quantity Indices. I favor this latter method because I want to analyze how the aggregate production volume and price level affected by R&D expenditures and Fisher indices may reflect better, more accurate the evolution of aggregate production volume and price level than real data. Furthermore I use nominal data because I presume that nominal data reflects better the change in observable characteristics (quality, efficiency, quantity) of production factors than real data.



Instead of GDP I will use value added as explained variable for different economic sectors in the estimation models, however on aggregate (national) level GDP and total value added are the same. Value added is one type of measure of economic performance where the efficiency of each sector, firm plays more role than in case of other measures – value of input plays here secondary role. The next three figures show the value added of the US State and Private Industry in absolute and relative values, observed from a monetary point of view. Value added is a function of quantity and quality (efficiency) of production factors, hence higher value added can be also achieved only by higher input without technological progress.

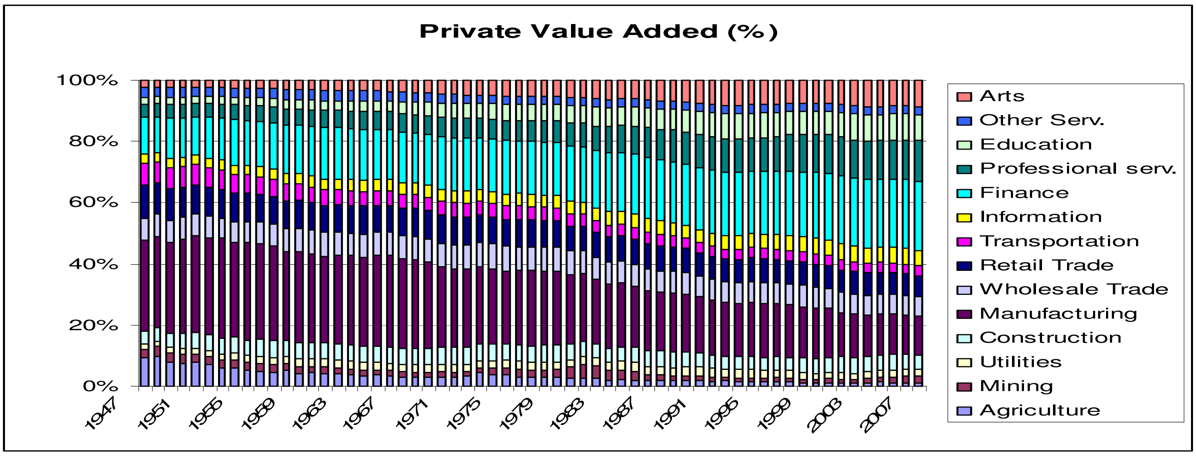
Value added is increasing with respect to time and the relative role of state in the value added is constant over time – ca. 10-15%. Hence Private Industry plays the main role in economic growth.

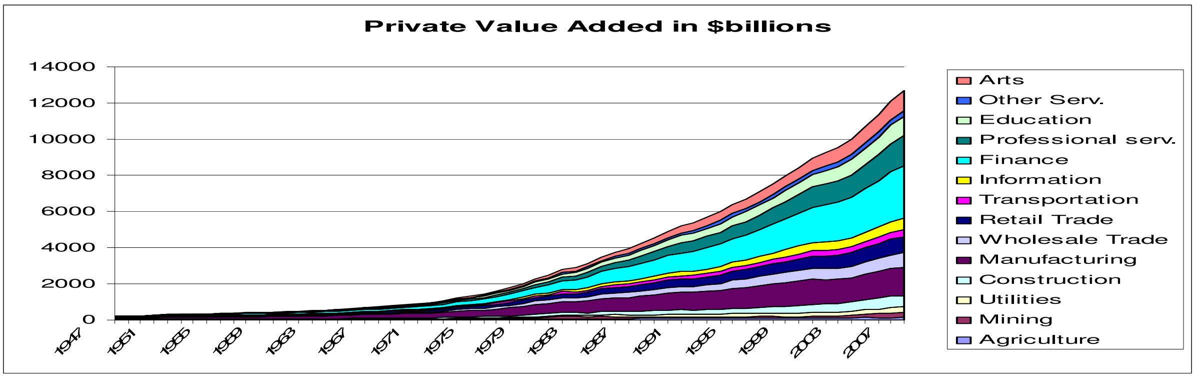




The following figures show the value added by sectors Services' value added in the US economy has an increasing tendency over time. The main fields of services are Finance (including insurance, real estate, rental, and leasing), Professional and Educational services,

Trade. The value added of Finance and Professional Services take the largest parts in Services' value added. One possible cause for it can be the financial speculation in the US economy. The negative effects of these speculations we experience nowadays. Other cause can be the increasing demand on (financial) insurance as a result of risk management. However, these fields of the economy are very sensible for any type of dangers, risks that may not necessarily be real dangers or risks – artificial dangers and risks may have large impacts on these economic sectors. However, Finance is a very technology-intensive sector of the economic that can give large impulses, incentives to technological progress – stock exchanges, brokers are 'working' with high-tech computers, mobiles, etc. Hence, Professional Services are somehow related to the performance of Finance, as figures show. Other sectors experience a constant growth of their value added because they cannot make so big profits by simple speculation like Finance.
Manufacturing has the largest value added among goods producing private sectors. This sector contributes in the last 15 years with almost the same value added (in absolute terms) to the total value added. Other good producing industries have much lower contributions to the total value added.
Value added of US economic sectors are highly positively correlated with each other. It means that these sectors support each others' productivity.





Coding of variables:

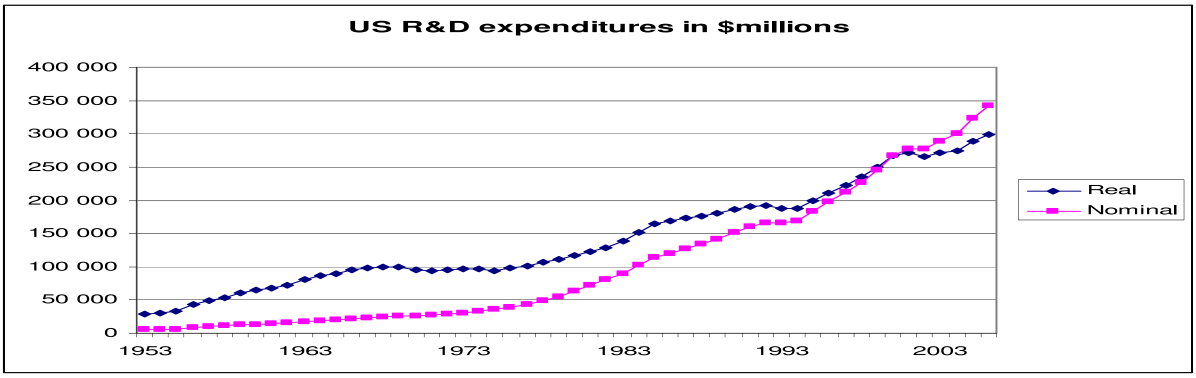
Private: Private industries
Agric(ulture): Farms, Forestry, fishing, and related activities (hunting)
Mining: Oil and gas extraction Mining; except oil and gas; Support activities for mining
Utilities Utilities
Construction: Construction
Manuf(acturing): **Durable goods** (Wood products, Nonmetallic mineral products, Primary metals, Fabricated metal products, Machinery Computer and electronic products, Electrical equipment,

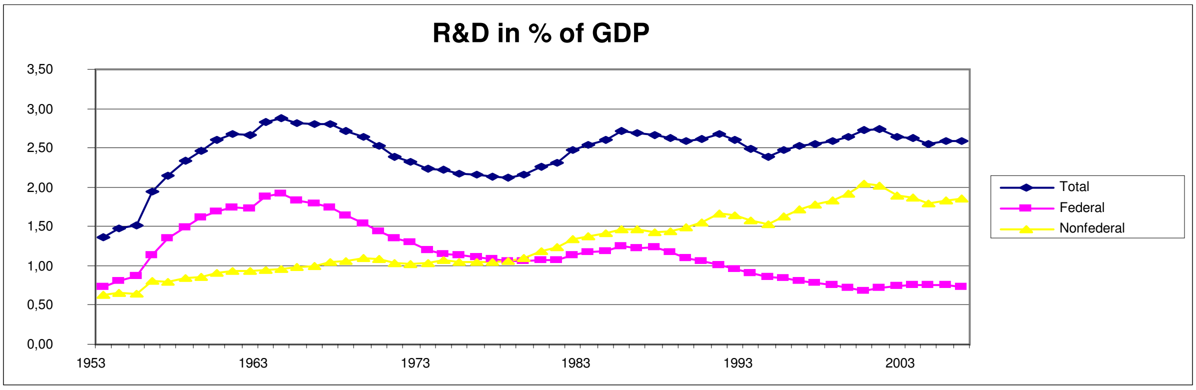
appliances, and components, Motor vehicles, bodies and trailers, and parts, Other transportation equipment, Furniture and related products, Miscellaneous manufacturing)**; Nondurable goods** (Food and beverage and tobacco products, Textile mills and textile product mills, Apparel and leather and allied products, Paper products, Printing and related support activities, Petroleum and coal products, Chemical products, Plastics and rubber products)
Wholesale: Wholesale trade
Retail: Retail trade
Transp(ortation): Air transportation, Rail transportation, Water transportation, Truck transportation, Transit and ground passenger transportation, Pipeline transportation, Other transportation and support activities, Warehousing and storage
Info: Publishing industries (includes software), Motion picture and sound recording industries, Broadcasting and telecommunications, Information and data processing services
Finance: Federal Reserve banks, credit intermediation, and related activities, Securities, commodity contracts, and investments, Insurance carriers and related activities, Funds, trusts, and other financial vehicles
Realest: Real estate, Rental and leasing services and lessors of intangible assets
Professional: Legal services, Computer systems design and related services, Miscellaneous professional, scientific, and technical services
Management: Management of companies and enterprises
Admin: Administrative and support services, Waste management and remediation services
Eduserv: Educational services
Healthcare: Ambulatory health care services, Hospitals and nursing and residential care facilities, Social assistance
Arts: Performing arts, spectator sports, museums, and related activities, Amusements, gambling, and recreation industries
Accomm: Accommodation, Food services and drinking places
Otherserv: Other services; except government

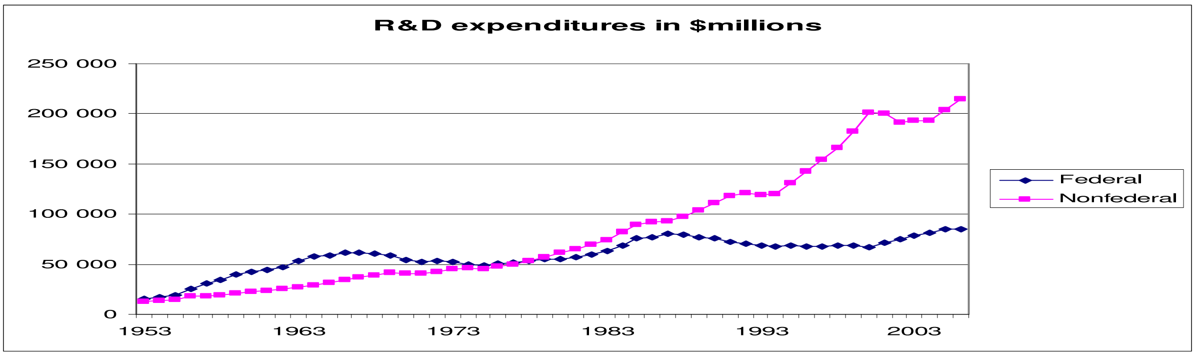
2.3.2. R&D expenditures:

The sources of data on US R&D expenditures are the homepage of the OECD and of the National Science Foundation (www.nsf.gov).

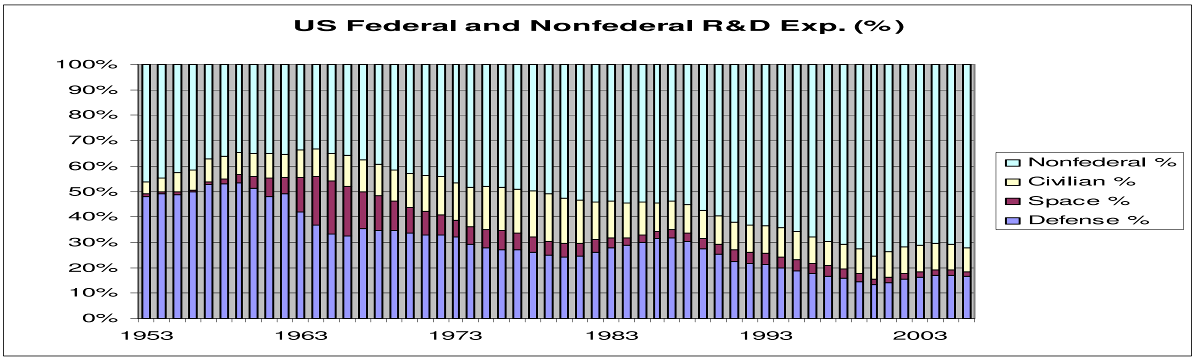
The following figures represent R&D expenditures in absolute and relative values. Federal and Nonfederal R&D expenditures are the two main sources of R&D expenditures in the US economy. The overall R&D expenditures of the US economy tend to be stabilized about 2.5% of the overall economic performance but its structure is not constant over time; after the oil shocks Non-federal R&D expenditures become relatively higher than Federal R&D expenditures. Remark: in Austria the R&D expenditures relative to GDP have an upward trend and they reached the 2.5-2.6% level to GDP. So, Austria spends relatively as much money on R&D activities as the USA.





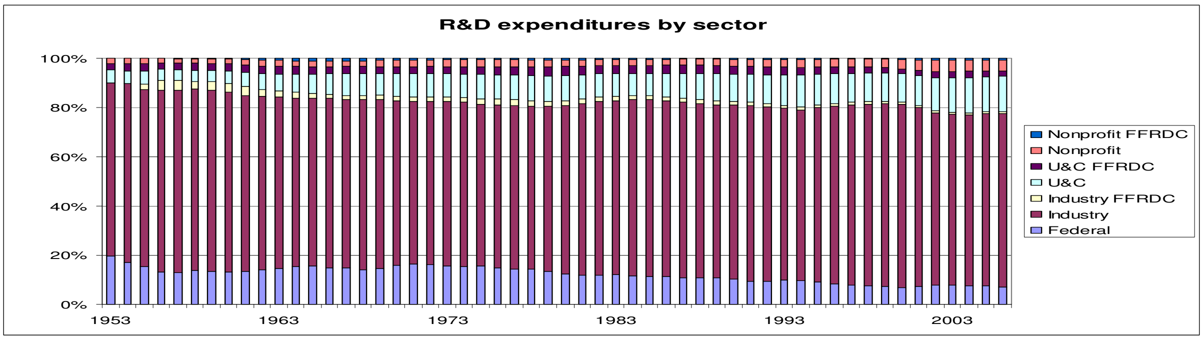


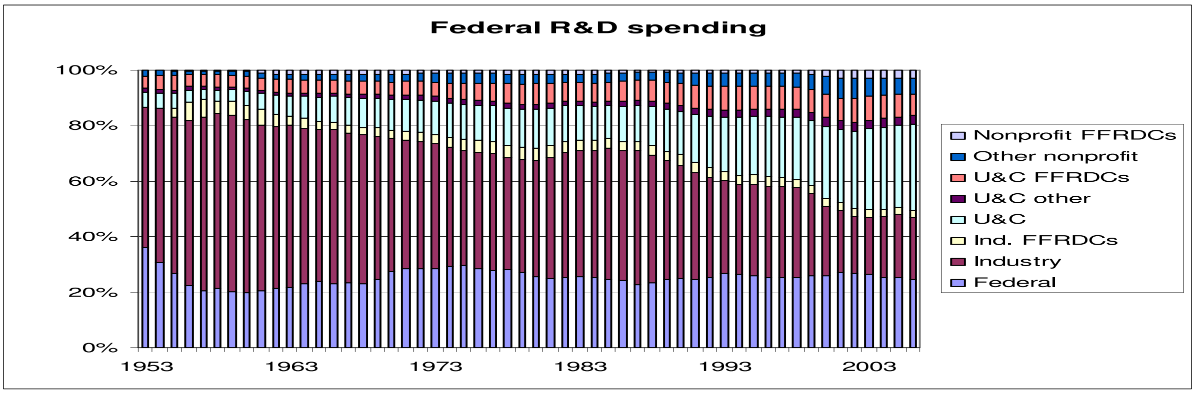
The next figure represents the ratios of Federal and Nonfederal R&D expenditures:



A relative large fraction of Federal R&D expenditures are Defense related R&D expenditures and Civilian related Federal R&D expenditures accounts for very small fraction of the total (federal) R&D expenditures. It means Federal Civilian related R&D expenditures should have relative small impact on Nonfederal production and additionally government finances such (secret) projects that usually do not influence economic performance but military and other projects.

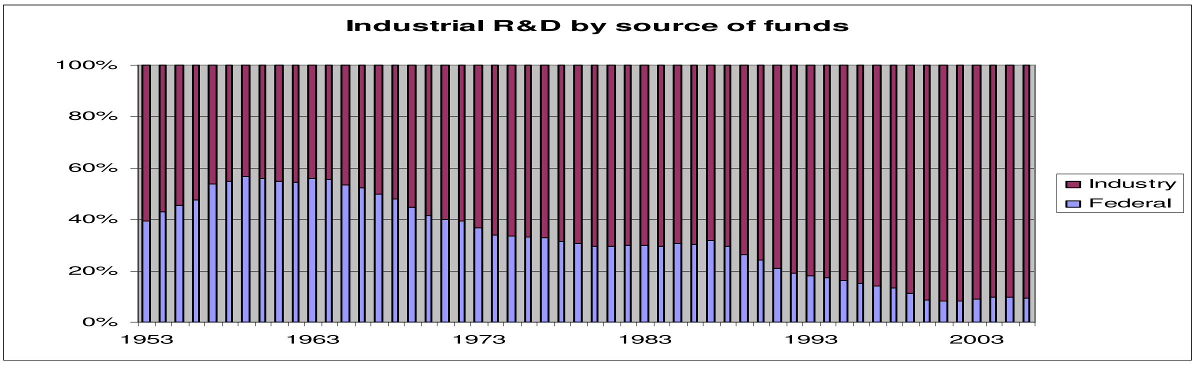
The following figure represents how in the different fields of the economy R&D activities have been financed. Industrial R&D activities have been financed at most that is not surprising because it takes the largest share of production in the economy. Universities and Colleges (U&C) and Federal R&D activities are the most financed fields after Industry, however, federal R&D spending became smaller and smaller relative to the total R&D spending. Federally founded R&D Centers (FFRDC) account for very small fraction of the total R&D spending hence they have minimal effects on the economic performance.

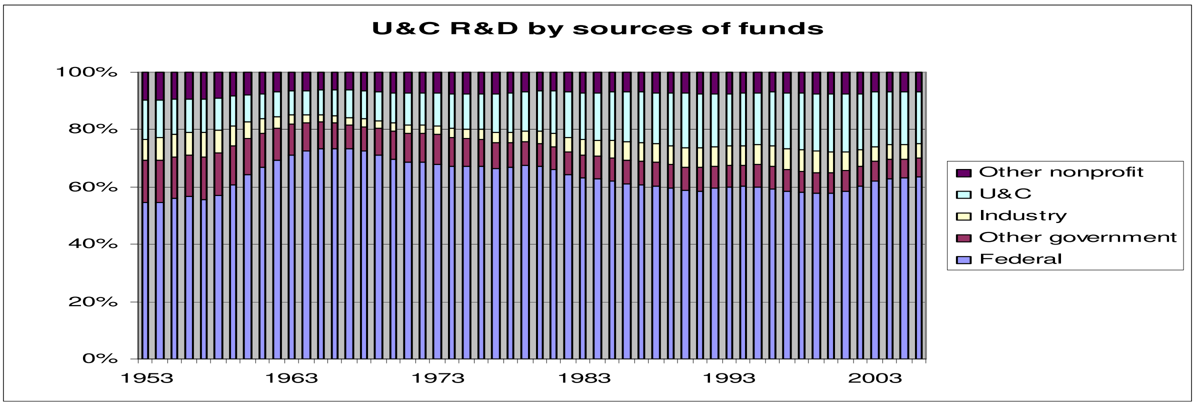




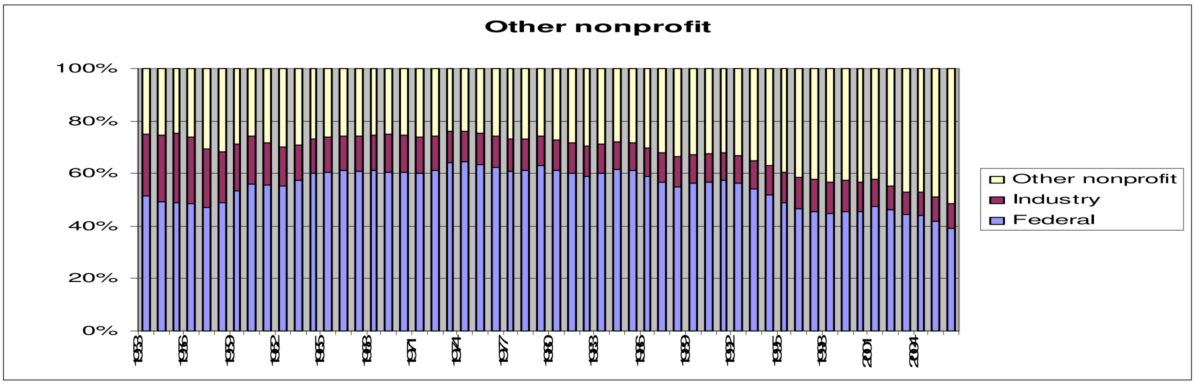
This figure shows how the federal R&D expenditures have been allocated to different economic sectors. Federal R&D activities are financed at a constant rate (ca. 25%) relative to total; Financing of U&C R&D activities became larger and larger over time and take ca. 30-35% of the total; Financing of industrial R&D activities became smaller and smaller over time because Industry became sufficient large to finance its own R&D activities. However, this fraction takes ca. 20% of the total spending. One possible cause for this fall in R&D spending by government can be that 'federal' money is not be spent so efficient on R&D activities in Industry like the money of 'industry' – different incentives.

The next figure shows that ca. 90% of industrial R&D investments are financed by Industry itself.

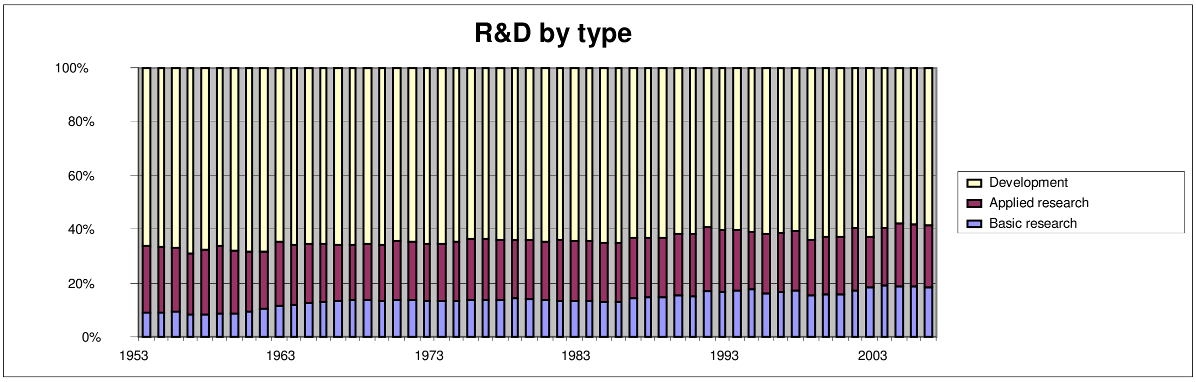




The two main financers of U&C R&D activities are government and U&C. Other sources of R&D capital play small role.



Other nonprofit organizations' R&D activities are financed mainly by themselves and the government.



This figure represents the R&D investments by type of R&D activities. One can see that the role of Basic research R&D investments became larger and larger over time and development lost a bit of its importance. However, the latter gets ca. 60% of the total R&D spending. Applied research is financed at a constant level relative to the total over time.

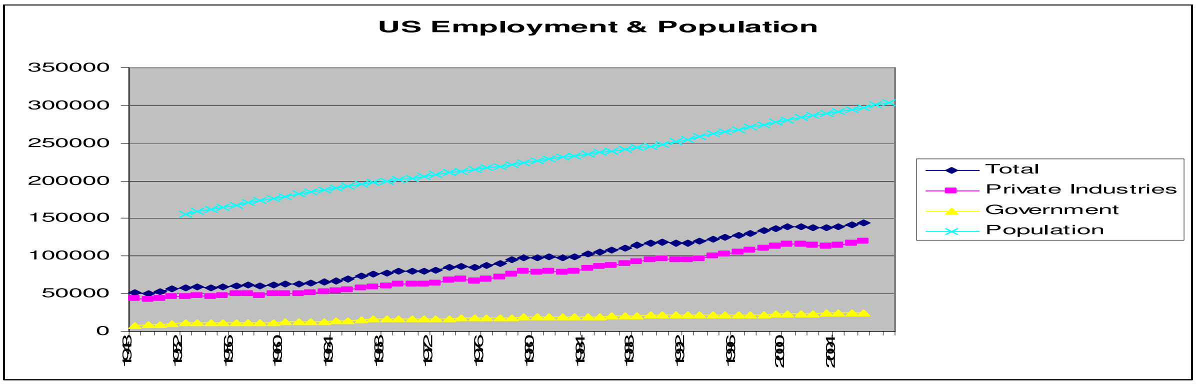
Basic research (BR) covers investigations and analyses focused on a better or fuller understanding of a subject, phenomenon, or a basic law of nature — instead of on a specific practical application of the results. It is in the Industries, Manufacturing, & Technology subject. In Industries, however, basic research is the main source of new techniques, inventions and innovations. So, significant effects of basic research on economic performance are expected.

Applied research (AR) covers investigations of the findings of 'pure' or basic research, to determine if they could be used to develop new products or technologies. Also, the research conducted to solve specific problems or to answer specific questions. AR are there in the Industries, Manufacturing.

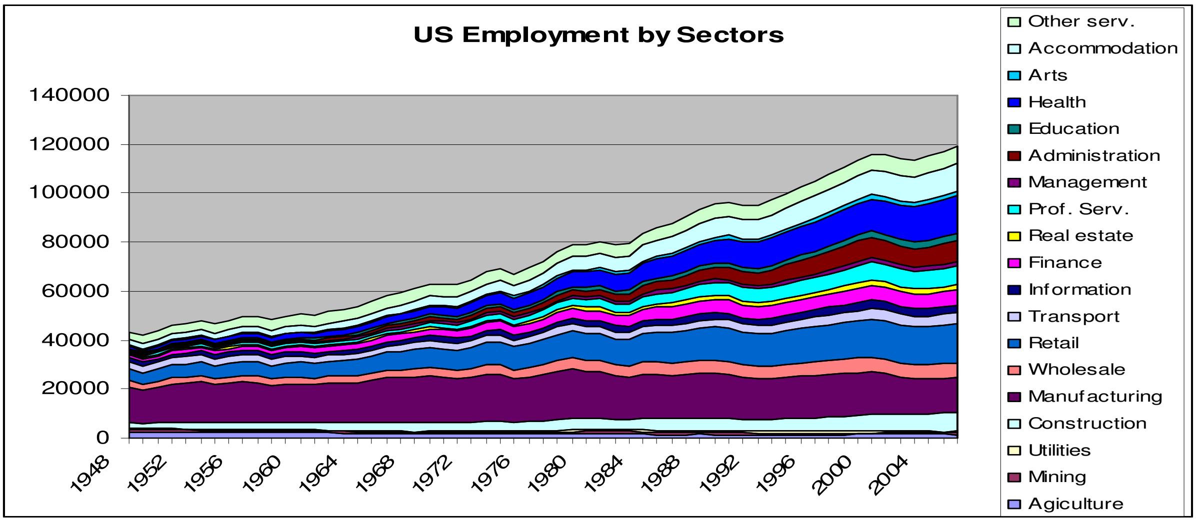
Experimental) Development (DE) is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.
Using this classification of types of R&D activities one can see why each of these types plays important role in technological progress and why development is the most financed part of R&D activities. Development is responsible for the improvement of qualities of physical and mental products that may improve the industrial production (qualitative and quantitative); therefore the products of this field contribute at most to economic value added and hence this is the most financed type of R&D activities. The products of Basic and Applied research may improve the quality (efficiency) and quantity of research fields and tools, hence they build important background for development. Development activities can be seen as application of research tools to industrial production.

<u>2.3.3. Labor (Human capital) input</u>:

The sources of data on US employment, labor compensation and average weekly working hours are the homepage of the Federal Reserve Bank of St. Louis (http://research.stlouisfed.org/fred2/) and of the Bureau of Economic Analysis.

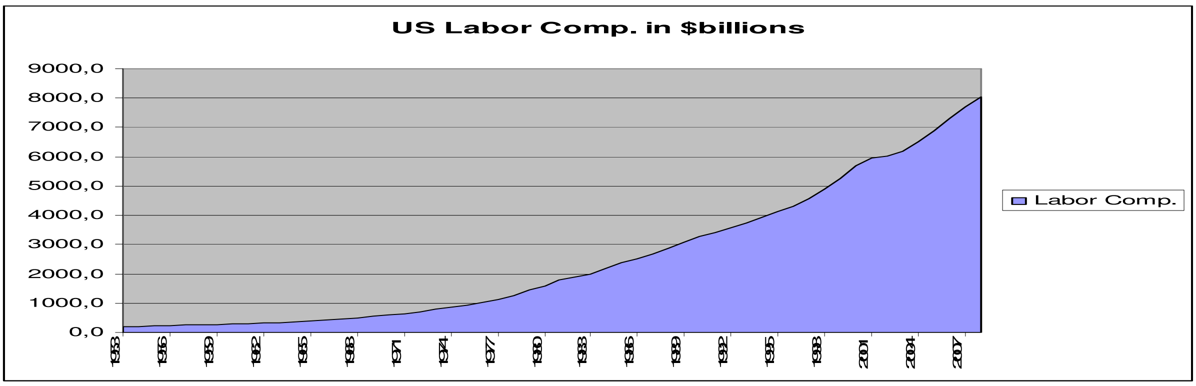


Population can be seen as a quantitative proxy for total human capital input because it is assumed that population without employment has effect on employment and economic performance – contribution of unregistered workers to economic performance, value added.
This figure represents also the employment in Private Industries and Government. One can see that the total employment takes ca. 33% of the population in 1960's and takes ca. 50% after 1990's. Consequently, the increase of (registered) labor (employees) plays an important role in the growth of economic performance. However, the number of employees is not a sufficient proxy for labor input because the amount of working hours influences also the economic performance. A possible proxy for labor input can be a new variable generated by the number of employees multiplied by average weekly working hours in the given sector. However, statistics on average weekly working hours are not available for each sector of the economy. I will analyze which of these two variables have (more) significant effects on economic performance.
Average education or experience level of employment or population would serve as a proxy for qualitative features of human capital input. Unfortunately such experience index is not available to me. Furthermore such index is not necessarily a good, accurate proxy for average quality of labor – hidden abilities, knowledge or not perfect examination system of education institutions, etc.
Most of the people are employed in Mining, Retail and Health. Surprisingly, in Real estate and Finance very few people are employed, however, these sectors contribute at most to the total value added of the US economy.



Another possible proxy for labor input can be the labor compensation. It is an economic measure of labor (human capital) input in a given period of time. This has an advantage that it lacks the disadvantages of employment and working hours. However, labor compensation depends on past and future performance of the given employee, worker, so this variable may react with a given lag to the change of employee's quality. Rigid wages also contribute to data problems.

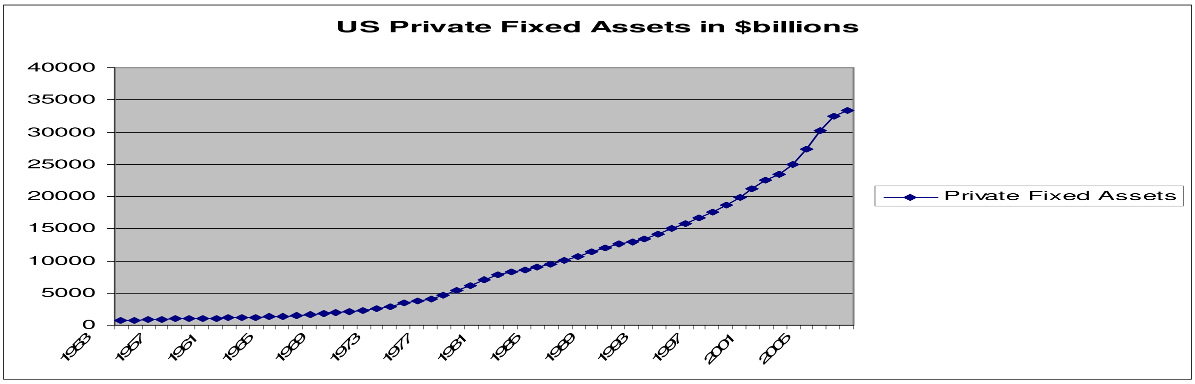
All of these measures may not be exact measures of labor input because data problem is an issue in case of these variables. Problems: there are many not-registered employees in the economy. Working hours may not reflect exactly the duration/period of time in that people deal with their jobs – e.g. people go home and continue there their jobs in order to be able to finish it. Labor compensation – includes every benefits, wages paid to employees – may be incorrect because many people get minimum wages (if it is possible/mandatory) in order to pay less taxes to tax authorities and collect illegal earnings. Additionally, unregistered employees get also money that is not declared to tax authorities. And one can continue this. Hence, this analysis can deal with 'booked' economy, so a specific part of the economy can be analyzed for which data is available. However, it is assumed that the available data does not deviate significantly from the real data; hence these data problems have very small/insignificant effects on the quality of the analysis.

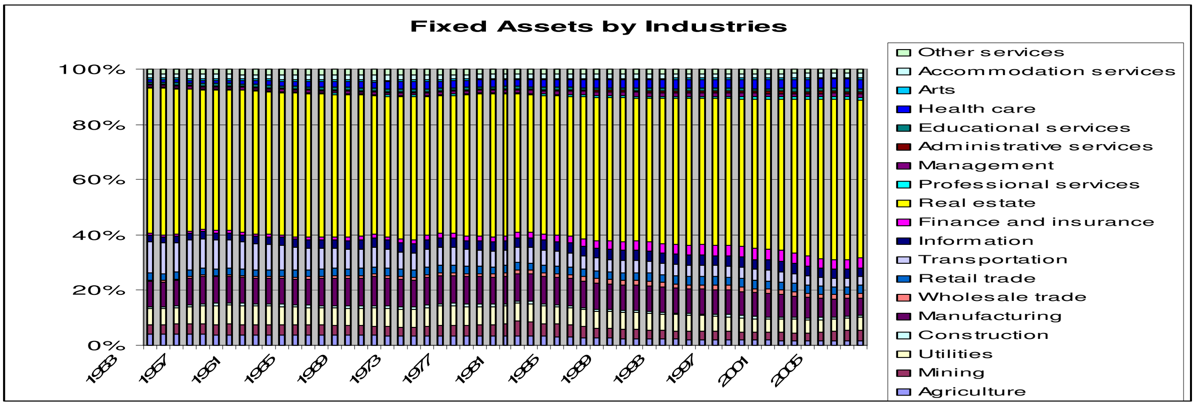


2.3.4. Capital Input:

The source of data on US fixed assets is the homepage of the Bureau of Economic Analysis.

Total fixed assets will be used as proxy for capital input because they represent such elements of the production that are determined to support the production in one or more periods of time. For instance cars, buildings and other physical elements captured by US accounting system are "contained" by fixed assets. Unfortunately data on intermediate inputs is constrained and the available data shows that in each sector of the economy the same quantity of intermediate inputs have been used.





Upward convex trend of private fixed assets after 1990 and until 2005/2006– fixed assets can be used as proxy for capital. This graph represents the monetary overvaluation of real estates after 1990 and the increasing fraction of finance and insurance fixed assets as a follow up of overestimating of real estates. Real estate, lending and leasing takes a very large fraction of total fixed assets therefore the appropriate valuation of these elements of the economy is essential. Low fraction of services' fixed assets refers to one special feature of services.

2.4. Estimated models and estimation results:

The basic models are (same as in the previous section):

$$\ln Y(t) = \ln\tilde{\alpha} + G_1\ln[\tilde{A}^K(t-1)\tilde{K}(t-1)] + G_2\ln[\tilde{A}^L(t)\tilde{L}(t)] + G_3\ln\tilde{R}(t-1) + \varepsilon(t)$$

without price and quantity indices;

$$\ln Y(t) = \ln\tilde{\alpha} + G_1\ln\tilde{A}^K(t-1) + G_2\ln\tilde{K}(t-1) + G_3\ln\tilde{A}^L(t) + G_4\ln\tilde{L}(t) + G_5\ln\tilde{R}(t-1) + \varepsilon(t)$$

with price (P^K, P^L) and quantity (Q^K, Q^L) indices where $P^K(t-1)$ is a proxy for $\tilde{A}^K(t-1)$ and $P^L(t)$ is a proxy for $\tilde{A}^L(t)$.

Let TFP be contained in error terms in each case.

The available (nominal) data enables the following proxies for the variables:

As mentioned in the previous section, (lagged) fixed assets (denoted by FA or FXAS) by industries have been used as proxies for physical capital input by industry - $\tilde{A}^K(t-1)\tilde{K}(t-1)$. However, this variable is not a proxy for the entire physical capital input because it lacks the intermediate inputs (denoted by INTM). Unfortunately there is very few data available on intermediate inputs therefore this variable and its effects will be not estimated directly. The effects of intermediate inputs will be collected in the error term. The coefficient on price index of fixed assets (P^K) may explain the effects of fixed assets' quality (efficiency) on the economic performance if the required assumptions are fulfilled.

R&D expenditures (denoted by RD) will be used as proxy for R&D-activities-related technological progress. It will enter as a lagged variable into the regression. The hidden effects of R&D activities are collected in the error term or expressed by the coefficients of other variables (like price indices).

The error term additionally includes any other effects that have impact on economic performance – like the effects of past inventions and innovations in the current period.

In the framework of the A^KKA^LL model A^LL in period t denotes the effective labor, hence the coefficient on this variable includes the observable effects of human capital on economic performance (e.g. learning-by-doing effects). The available data enables different proxies on A^LL. Employment (EMPL), employment with average weekly working hours (LAB), and labor compensation (LABCOMP) has been used as proxies for labor or human capital input, 'used' in a given production process. None of these are exact measures of real human capital input because employment and employment with average working hours are primarily quantitative measures of human capital input. Labor compensation can be seen as an economic measure of quantitative and qualitative characteristics of labor input because wages and other benefits to labor depends on both how much people are employed and which qualities of these employees have, how efficient they are. Unfortunately, data on labor compensation by industry sectors is not available therefore the error term includes the deviations of effects of labor compensation by industry from total. Total labor compensation will be used as proxy for each sector of industry.

Additional problem with labor compensation and fixed assets is that R&D fixed assets and staff compensation may be included by these variables and hence R&D expenditures as variable may turn out to be redundant in the regression.

Hence the error term expresses different information depending on the 'used' regressors - the coefficients represent the elasticities of Y with respect to each production factor:

(i) $\ln Y_t = B\ln(R_{t-1}) + C\ln(A^K_{t-1}K_{t-1}) + D\ln(A^L_t L_t) + a^1_t$ where $a^1_t = F\ln(INTM_{t-1}) + \varepsilon^1_t$ that is:

$\ln Y_t = B\ln(R_{t-1}) + C\ln(A^K_{t-1}K_{t-1}) + D\ln(A^L_tL_t) + F\ln(A^K_{t-1}) + \varepsilon_t = B\ln(R_{t-1}) + C\ln(FXAS_{t-1}) + D\ln(LABCOMP_t) + F\ln(INTM_{t-1}) + \varepsilon_t$

(Observed) Error term expresses the effects of intermediate inputs and other effects that cannot be explained by regressors 'fixed assets', 'labor compensation' and R&D expenditures.

(ii) $\ln Y_t = G_5 \ln(R_{t-1}) + G_1 \ln(A_{t-1}^K) + G_2 \ln(K_{t-1}) + G_3 \ln(A_l^L) + G_4 \ln(L_t) + a_t^2$ where $a_t^2 = F\ln(INTM_{t-1}) + \varepsilon_t^2$ that is:

$\ln Y_t = G_5\ln(R_{t-1}) + G_1\ln(A^K_{t-1}) + G_2\ln(K_{t-1}) + G_3\ln(A^L_t) + G_4\ln(L_t) + \varepsilon_t = G_5\ln(R_{t-1}) + G_1\ln(PRC\_FXAS_{t-1}) + G_2\ln(QNTY\_FXAS_{t-1}) + G_3\ln(PRC\_EMPL_t) + G_4\ln(EMPL_t) + F\ln(INTM_{t-1}) + \varepsilon_t$

(Observed) Error term expresses the effects of intermediate inputs, and other effects that cannot be explained by regressors 'physical capital quality' (expressed by price index for fixed assets), quantity of 'fixed assets', 'labor quality' (expressed by aggregate wage index), 'employment' and R&D expenditures.

iii) $\ln Y_t = B\ln(R_{t-1}) + C\ln(A_{t-1}^K K_{t-1}) + E\ln(L_t) + a_t^3$ where $a_t^3 = F\ln(INTM_{t-1}) + H\ln(A_t^L) + \varepsilon_t^3$ that is:

$\ln Y_t = B\ln(R_{t-1}) + C\ln(A^K_{t-1}K_{t-1}) + D\ln(L_t) + F\ln(INTM_{t-1}) + H\ln(A^L_t) + \varepsilon_t = B\ln(R_{t-1}) + C\ln(FXAS_{t-1}) + D\ln(LAB_t) + F\ln(INTM_{t-1}) + H\ln(PRC\_EMPL_t) + \varepsilon_t$

(Observed) Error term expresses the effects of intermediate inputs, labor quality (expressed by aggregate wage index) and other effects that cannot be explained by regressors 'fixed assets', 'average weekly labor input' and R&D expenditures. The coefficients are different than in ii) because of different regressors.

Remark: These models have been estimated on aggregate national and sectoral level and hence the above represented regressors refer rather to the type of regressors and not to concrete regressors.

The regression results (OLS estimates) of the estimated models on aggregate national and sectoral level show that employment is the best proxy for labor input. The cause can be that other proxies for labor input cannot precisely reflect the changes of additional labor input characteristics that these proxies additionally embody. However, all of these regressions have an R-squared and Adjusted R-squared over 0.99 but low Durbin-Watson statistic and low Serial Correlation LM Tests (Breusch-Godfrey LM Test) values indicate serial correlation in the error terms – unbiased OLS coefficient estimates but standard errors tend to be underestimated. White Heteroskedasticity Tests also reject the null hypothesis of Homoskedasticity against the alternative hypothesis of Heteroskedasticity in these cases. Based on these two criterions, the OLS estimates of these regressions are BLUE (best linear unbiased estimator) but the variance of the coefficients tends to be underestimated and possibly making insignificant variables appear to be statistically significant.

In order to remove the serial correlation and heteroskedasticity in the model I insert AR(1) or MA(1) or both terms into the basic regressions. With this correction insignificant variables remain insignificant. AR and MA terms turned out to be significant in the regressions but regressions with MA terms seem to be more plausible than regressions with AR terms. In case of MA terms industrial R&D expenditures are significant whilst AR terms result in significant U&C R&D terms. Because of the small size of U&D R&D expenditures to the total R&D spending relatively large and significant effects of U&C is implausible.

Remarks on AR and MA terms in the regression:

There are two different residuals associated with an AR model. The first are the estimated unconditional residuals u(t) and the second set of residuals are the estimated one-period ahead forecasts errors e(t). In case of AR terms the estimated unconditional residuals have been used for correction of estimations. In case of MA terms the estimated one-period ahead forecasts errors have been used as regressors.

$u(t) = y(t) – x(t)'b$

$u(t) = \rho u(t-1) + e(t)$ and insert this into the previous model we get an AR(1) model:

$y(t) = \rho y(t-1) + (x(t) – \rho x(t-1))'b + e(t)$.

In case of MA(1) model:

$u(t) = e(t) + \theta e(t-1)$ and the program backcasts MA terms.

So, the estimated models have these types of form:

$\ln Y(t) = \ln\tilde{\alpha} + G_1\ln[\tilde{A}^K(t-1)\tilde{K}(t-1)] + G_2\ln[\tilde{A}^L(t)\tilde{L}(t)] + G_3\ln\tilde{R}(t-1) + AR(1) + \varepsilon(t)$ or
$\ln Y(t) = \ln\tilde{\alpha} + G_1\ln[\tilde{A}^K(t-1)\tilde{K}(t-1)] + G_2\ln[\tilde{A}^L(t)\tilde{L}(t)] + G_3\ln\tilde{R}(t-1) + MA(1) + \varepsilon(t)$ or

$\ln Y(t) = \ln\tilde{\alpha} + G_1\ln\tilde{A}^K(t-1) + G_2\ln\tilde{K}(t-1) + G_3\ln\tilde{A}^L(t) + G_4\ln\tilde{L}(t) + G_5\ln\tilde{R}(t-1) + AR(1) + \varepsilon(t)$ or
$\ln Y(t) = \ln\tilde{\alpha} + G_1\ln\tilde{A}^K(t-1) + G_2\ln\tilde{K}(t-1) + G_3\ln\tilde{A}^L(t) + G_4\ln\tilde{L}(t) + G_5\ln\tilde{R}(t-1) + MA(1) + \varepsilon(t)$
or the equations include both terms (AR(1) and MA(1))

In the following I present the estimation results that have the following structure: in the first step I analyze the R&D effects on national level with different regressor in order to see which of the presented regressors seem to be the most significant. After having the most significant regressors I analyze the effects of different types of R&D expenditures on sectoral (total) value added. In the last step I present the estimation results concerning the link between price and quantity indices and R&D expenditures. As an additional step the estimated effects of value added on R&D expenditures will be listed.

2.4.1. Estimation results – Table 1:

The first table of estimation results shows a comparison of different regressors (with different lags) and their effects on aggregate value added.

- EMPL_TOT denotes the total employment in the US economy;
- LAB_PRIVATE denotes the total employment multiplied with average weekly working hours; LABCOMP denotes the labor compensation;
- VA_GDP denotes the total value added in the economy;
- RD denotes the R&D expenditures;
- FXASTOT denotes the total value/amount of fixed assets in the economy;
- POP denotes the population;
- C denotes the intercept.

In these regressions I corrected with MA(1) and AR(1) terms for serial correlation and heteroskedasticity. Consequently the estimated coefficients are BLUE. All regressions have a very high R-squared (>0.99) and adjusted R-squared values (>0.99) and lower AIC (Akaike

Information Criteria) and SC (Schwarz Criterion) values (<-4.0) compared to other type of regressions[28]. Furthermore I want to remark here the US economy is divided into two main sectors: the first includes the Federal activities and the second includes the Private activities including Private Industry and U&C (Universities and Colleges). R&D expenditures can be also divided into these three types. The estimation show that lagged proxies on labor input turned out to be insignificant in most cases and theoretically these lagged variables cannot be seen as plausible regressors – past labor performance influence current labor performance for sure but current economic performance depend primarily on current labor performance and current environment; current environment may include factors that cannot be derived from past performance, behavior of variables like past labor performance. Thus I concentrate on non-lagged variables concerning the labor input. In these cases R&D expenditures turned out to be significant in the regression with LAB_PRIVATE. In other cases it remained insignificant. Population tends to be a significant regressor but it "makes" R&D expenditures insignificant. Based on these results it would be hard to say anything on the types of significant regressors.
Hence in the following step I examined how the regressors "behave" with 'types of R&D expenditures' in the regressions. Remark: RD_IND2 refers to industrial R&D expenditures (projects) financed from industrial sources. RD_IND refers to industrial R&D expenditures (projects) financed from all possible sources. RD_FED refers to federal R&D expenditures into federal R&D projects. RD_UC refers to U&C R&D projects financed by all possible sources. These regression results show that only EMPL_TOT seem to be a significant and plausible regressor if I want to analyze the effects of different types of R&D expenditures on value added. In case of LAB_PRIVATE it is hard to accept that industrial R&D expenditures have no impact on economic performance; Federal and U&C R&D expenditures may not have so much impact on yearly value added because of their relative unimportance (based on spent $ values) and different goals – it is therefore an implausible result. Furthermore RD_IND2 tend to be a more significant variable than RD_IND. This result suggests me that sources of R&D expenditures other than Private Industry may not be used so efficient in industrial R&D departments than industrial R&D sources and hence it results in lower effects on aggregate value added.

Based on the significant and plausible estimates the expected effects of labor input on economic performance are about 1.0, that of the fixed assets are about 0.5-0.7 and that of the R&D expenditures are about 0.13-0.15. Remark: an effect (elasticity) of 0.5 of fixed assets means that a 1% change in the amount of fixed assets would result in 0.5% change in value added (positive or negative). However, these coefficients, estimated effects are average effects in the given sample and if we assume decreasing returns to scale: a +1% change of fixed assets may result in less than +0.5% change of value added and a -1% change of fixed assets may result in more than |-0.5%| change of value added – analogously to the other variables. If we compare these results (R&D effects) with other empirical studies on R&D effects (elasticities) they seem to be plausible indeed.

I estimated models with interaction terms in order to see whether federal R&D expenditures support economic performance but these terms turned out to be insignificant. Consequently there are no observable effects of additional federal R&D support in Private Sector on economic performance.

Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
Variable	Coefficient	Std. Error	Prob.	Variable	Coefficient	Std. Error	Prob.

[28] 'Other type' means they include more or less types of variables than the presented regression models.

LN_EMPL_TOT(-1)	0.387530	0.227064	0.0943	LN_EMPL_TOT	1.168457	0.119073	0.0000
LN_FXASTOT(-1)	0.825031	0.049696	0.0000	LN_FXASTOT(-1)	0.678383	0.025883	0.0000
LN_RD(-1)	**0.137656**	**0.042416**	**0.0021**	**LN_RD(-1)**	**0.039145**	**0.030304**	**0.2026**
C	-5.576363	1.947113	0.0062	C	-12.07462	1.008333	0.0000
MA(1)	0.785161	0.087014	0.0000	MA(1)	0.978593	0.023009	0.0000
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_LAB_PRIVATE(-1)	0.068737	0.215178	0.7512	LN_LAB_PRIVATE	0.647327	0.166592	0.0004
LN_FXASTOT(-1)	0.839264	0.036098	0.0000	LN_FXASTOT(-1)	0.772624	0.028331	0.0000
LN_RD(-1)	**0.281636**	**0.078256**	**0.0009**	**LN_RD(-1)**	**0.126811**	**0.058784**	**0.0374**
C	-3.967476	2.323674	0.0961	C	-10.09488	1.823539	0.0000
MA(1)	0.887561	0.070196	0.0000	MA(1)	0.720777	0.112429	0.0000
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_LABCOMP(-1)	0.570021	0.125231	0.0000	LN_LABCOMP	0.865858	0.082643	0.0000
LN_FXASTOT(-1)	0.382682	0.115647	0.0018	LN_FXASTOT(-1)	0.122167	0.075502	0.1122
LN_RD(-1)	**0.073185**	**0.037029**	**0.0539**	**LN_RD(-1)**	**0.005435**	**0.023951**	**0.8215**
C	-0.533507	0.443213	0.2346	C	0.400486	0.285983	0.1678
MA(1)	0.678369	0.097274	0.0000	MA(1)	0.554559	0.119112	0.0000
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_POP(-1)	0.964625	0.424004	0.0274	LN_POP	0.992051	0.419495	0.0221
LN_FXASTOT(-1)	0.819574	0.041042	0.0000	LN_FXASTOT(-1)	0.816921	0.040783	0.0000
LN_RD(-1)	**0.051871**	**0.066449**	**0.4389**	**LN_RD(-1)**	**0.052108**	**0.064283**	**0.4216**
C	-11.96899	4.257529	0.0071	C	-12.29763	4.235991	0.0056
MA(1)	0.845987	0.077765	0.0000	MA(1)	0.835823	0.079401	0.0000
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_EMPL_TOT	1.190105	0.153860	0.0000	LN_EMPL_TOT	1.088189	0.122668	0.0000
LN_FXASTOT(-1)	0.620920	0.031484	0.0000	LN_FXASTOT(-1)	0.550011	0.037734	0.0000
LN_RD_FED(-1)	**0.027207**	**0.043079**	**0.5308**	**LN_RD_FED(-1)**	**0.061022**	**0.037443**	**0.1100**
LN_RD_IND(-1)	**0.082324**	**0.030253**	**0.0092**	**LN_RD_IND2(-1)**	**0.146037**	**0.036629**	**0.0002**
LN_RD_UC(-1)	**-0.028208**	**0.044051**	**0.5251**	**LN_RD_UC(-1)**	**-0.050415**	**0.037781**	**0.1886**
C	-12.22368	1.531601	0.0000	C	-11.14751	1.192357	0.0000
MA(1)	0.858157	0.075366	0.0000	MA(1)	0.979954	0.027091	0.0000
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_LAB_PRIVATE	0.661919	0.173635	0.0005	LN_LAB_PRIVATE	0.575290	0.150656	0.0005
LN_FXASTOT(-1)	0.572487	0.045888	0.0000	LN_FXASTOT(-1)	0.563972	0.043561	0.0000
LN_RD_FED(-1)	**0.187802**	**0.068361**	**0.0094**	**LN_RD_FED(-1)**	**0.140242**	**0.058514**	**0.0219**
LN_RD_IND(-1)	**-0.009950**	**0.054185**	**0.8554**	**LN_RD_IND2(-1)**	**0.072784**	**0.055822**	**0.2006**
LN_RD_UC(-1)	**0.109090**	**0.061620**	**0.0854**	**LN_RD_UC(-1)**	**0.075274**	**0.056446**	**0.1907**
C	-9.548911	2.325671	0.0002	C	-8.323700	2.033918	0.0002
AR(1)	0.475062	0.197470	0.0216	MA(1)	0.585048	0.140104	0.0002
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_LABCOMP	0.801858	0.098205	0.0000	LN_LABCOMP	0.756428	0.111155	0.0000
LN_FXASTOT(-1)	0.157258	0.078343	0.0506	LN_FXASTOT(-1)	0.165139	0.078816	0.0417
LN_RD_FED(-1)	**-0.038812**	**0.036429**	**0.2923**	**LN_RD_FED(-1)**	**-0.029089**	**0.038080**	**0.4488**
LN_RD_IND(-1)	**0.016292**	**0.024579**	**0.5107**	**LN_RD_IND2(-1)**	**0.042993**	**0.040490**	**0.2939**
LN_RD_UC(-1)	**0.036323**	**0.035952**	**0.3176**	**LN_RD_UC(-1)**	**0.030762**	**0.036330**	**0.4015**
C	0.473415	0.176347	0.0101	C	0.428576	0.186076	0.0258
MA(1)	0.550156	0.124344	0.0001	MA(1)	0.580607	0.127513	0.0000
Dependent Variable: LN_VA_GDP_2				**Dependent Variable: LN_VA_GDP_2**			
LN_POP	-0.060188	0.525157	0.9093	LN_POP	-0.221190	0.478628	0.6462
LN_FXASTOT(-1)	0.764813	0.038087	0.0000	LN_FXASTOT(-1)	0.649250	0.052137	0.0000
LN_RD_FED(-1)	**-0.091618**	**0.083983**	**0.2810**	**LN_RD_FED(-1)**	**-0.058724**	**0.076778**	**0.4483**

LN_RD_IND(-1)	**0.045546**	**0.043810**	**0.3040**	**LN_RD_IND2(-1)**	**0.174877**	**0.054223**	**0.0023**
LN_RD_UC(-1)	**0.203168**	**0.097704**	**0.0432**	**LN_RD_UC(-1)**	**0.158093**	**0.090814**	**0.0884**
C	0.335728	6.098562	0.9563	C	2.146663	5.569378	0.7017
MA(1)	0.762668	0.096763	0.0000	MA(1)	0.776197	0.096932	0.0000

2.4.2. Estimation results – Table 2:

The next table shows the effects of industrial and U&C R&D expenditures on value added by industry sectors. I have decided for these two types of R&D because based on the big difference between the relative value added of Federal and Non-federal (Private) sectors to the aggregate value added, the performance of Private sector seems the most relevant for the aggregate economic performance. Consequently, I analyze here how these two main sources of "private" R&D influence the economic performance.

Theoretical intuition behind the relevance of U&C R&D expenditures: U&C R&D may have impact on value added because of its distributive feature and not its direct effect on value added. It means that U&C are not involved directly in production process like managers or workers but they play a significant role as basic distributor of knowledge and new technologies. Professors and other U&C (R&D) staff may possess up-to-date knowledge, skills of respective sectors of economy and they may distribute, improve these knowledge among them (researchers) and their students. Consequently, they have 'double' importance in overall economic performance: they are assumed to invent, innovate higher than average people and they should distribute knowledge, skills more efficient as usual. However, their indirect roles in the economy may reduce their overall effects. U&C (R&D) and other educational services can be seen as main distributor of basic know-how, expertise. This intuition is plausible in a sense that academic research institutions (i.e. U&C R&D departments) see generally themselves as entities in the economy that try to provide support and strategic planning to promote faculty, research and creative activities.

I want remark here that these are aggregate R&D spending (no sectoral spending) and hence I presume that every sector of the economy is elastic to or related with R&D expenditures. It means every sector of the economy spends on R&D activities or a given sector has connection to one or more sectors of the economy that spend on R&D projects. Consequently, the estimated effects of R&D expenditures on sectoral value added show how the aggregate R&D stock affect the value added of a given sector. It means the estimated coefficients, effects reflect the common effects of more things: (i) if the given sector makes R&D investments, these effects are embedded in the coefficient; (ii) additionally the coefficient embeds the effect of another sector(s) that are connected to the given sector and spends on R&D activities. Hence, for instance the value added of a given sector can be improved without own R&D spending if it is connected to R&D-products-intensive sector(s).

These results show that if the estimated coefficients on labor input and fixed assets are "far away" from the estimated coefficients in the significant and plausible regressions in the previous table, these variables become insignificant (and implausible). For instance in case of Arts fixed assets' effect (-0.026298) are far below 0.5 or in case of educational services (EDUSERV) employment's effect are also far below 1.0.

Dependent Variable: LN_VA_ACCOMM				**Dependent Variable: LN_VA_ADMIN**			
Variable	Coefficient	Std. Error	Prob.	Variable	Coefficient	Std. Error	Prob.
C	-8.198615	0.941937	0.0000	C	-4.558968	0.471181	0.0000
LN_EMPL_ACCOMM	1.091463	0.157097	0.0000	LN_EMPL_ADMIN	0.561347	0.078604	0.0000
LN_FA_ACCOMM(-1)	0.504406	0.059191	0.0000	LN_FA_ADMIN(-1)	0.546901	0.049842	0.0000

LN_RD_IND2(-1)	**0.140581**	**0.051102**	**0.0084**	**LN_RD_IND2(-1)**	**0.118976**	**0.079327**	**0.1403**
LN_RD_UC(-1)	**-0.086330**	**0.026723**	**0.0023**	**LN_RD_UC(-1)**	**0.099709**	**0.042618**	**0.0236**
MA(1)	0.790721	0.092641	0.0000	MA(1)	0.753785	0.097927	0.0000
Dependent Variable: LN_VA_AGRIC				**Dependent Variable: LN_VA_ARTS**			
C	1.576467	2.515736	0.5339	C	-10.41339	1.283782	0.0000
LN_EMPL_AGRIC	-0.162675	0.335129	0.6296	LN_EMPL_ARTS	1.241116	0.292579	0.0001
LN_FA_AGRIC(-1)	0.703596	0.126186	0.0000	LN_FA_ARTS(-1)	-0.026298	0.114486	0.8193
LN_RD_IND2(-1)	**0.009788**	**0.176864**	**0.9561**	**LN_RD_IND2(-1)**	**0.632565**	**0.090140**	**0.0000**
LN_RD_UC(-1)	**-0.004678**	**0.174755**	**0.9788**	**LN_RD_UC(-1)**	**-0.175990**	**0.061611**	**0.0064**
MA(1)	0.506423	0.126928	0.0002	MA(1)	0.640431	0.111115	0.0000
Dependent Variable: LN_VA_CONSTRUCTION				**Dependent Variable: LN_VA_EDUSERV**			
C	-6.526318	0.710636	0.0000	C	-5.062863	1.137213	0.0001
LN_EMPL_CONSTRUCTION	0.807194	0.099885	0.0000	LN_EMPL_EDUSERV	0.278259	0.220264	0.2127
LN_FA_CONSTRUCTION(-1)	0.362869	0.048789	0.0000	LN_FA_EDUSERV(-1)	0.437551	0.083744	0.0000
LN_RD_IND2(-1)	**0.234155**	**0.054645**	**0.0001**	**LN_RD_IND2(-1)**	**0.109539**	**0.068682**	**0.1174**
LN_RD_UC(-1)	**0.086435**	**0.044214**	**0.0566**	**LN_RD_UC(-1)**	**0.355606**	**0.082936**	**0.0001**
MA(1)	0.754441	0.096517	0.0000	MA(1)	0.971069	0.013246	0.0000
Dependent Variable: LN_VA_FINANCE				**Dependent Variable: LN_VA_HEALTHCARE**			
C	-6.257757	2.208325	0.0068	C	-9.314667	1.557656	0.0000
LN_EMPL_FINANCE	0.656474	0.294879	0.0309	LN_EMPL_HEALTHCARE	1.142354	0.248259	0.0000
LN_FA_FINANCE(-1)	0.363265	0.108479	0.0016	LN_FA_HEALTHCARE(-1)	0.195813	0.124620	0.1228
LN_RD_IND2(-1)	**0.171125**	**0.099779**	**0.0931**	**LN_RD_IND2(-1)**	**0.415677**	**0.051309**	**0.0000**
LN_RD_UC(-1)	**0.260034**	**0.097158**	**0.0103**	**LN_RD_UC(-1)**	**-0.126585**	**0.051394**	**0.0175**
AR(1)	0.914497	0.050337	0.0000	MA(1)	0.997318	0.033615	0.0000
Dependent Variable: LN_VA_INFO				**Dependent Variable: LN_VA_MANAGEMENT**			
C	-3.304032	1.065145	0.0032	C	-6.784577	1.018798	0.0000
LN_EMPL_INFO	0.084803	0.165335	0.6104	LN_EMPL_MANAGEMENT	1.051385	0.177614	0.0000
LN_FA_INFO(-1)	0.448377	0.071983	0.0000	LN_FA_MANAGEMENT(-1)	0.421218	0.095683	0.0001
LN_RD_IND2(-1)	**0.484101**	**0.066351**	**0.0000**	**LN_RD_IND2(-1)**	**-0.003363**	**0.088021**	**0.9697**
LN_RD_UC(-1)	**-0.007384**	**0.048546**	**0.8798**	**LN_RD_UC(-1)**	**0.176913**	**0.085852**	**0.0450**
MA(1)	0.979122	0.022667	0.0000	AR(1)	0.873375	0.071918	0.0000
Dependent Variable: LN_VA_MANUFACTURING				**Dependent Variable: LN_VA_MINING**			
C	-5.416502	1.331082	0.0002	C	-13.08177	2.802170	0.0000
LN_EMPL_MANUFACTURING	0.600375	0.123732	0.0000	LN_EMPL_MINING	1.526816	0.316435	0.0000
LN_FA_MANUFACTURING(-1)	0.335877	0.067123	0.0000	LN_FA_MINING(-1)	0.219740	0.253512	0.3905
LN_RD_IND2(-1)	**0.350925**	**0.083188**	**0.0001**	**LN_RD_IND2(-1)**	**0.493223**	**0.249475**	**0.0539**
LN_RD_UC(-1)	**0.011042**	**0.052573**	**0.8345**	**LN_RD_UC(-1)**	**0.083865**	**0.147892**	**0.5734**
MA(1)	0.770506	0.100427	0.0000	MA(1)	0.724230	0.103433	0.0000
Dependent Variable: LN_VA_OTHERSERV				**Dependent Variable: LN_VA_PRIVATE**			
C	-5.280820	1.599313	0.0018	C	-9.682417	1.106368	0.0000
LN_EMPL_OTHERSERV	0.318829	0.232730	0.1772	LN_EMPL_PRIVATE	1.014106	0.120199	0.0000
LN_FA_OTHERSERV(-1)	0.259236	0.119122	0.0346	LN_FA_PRIVATE(-1)	0.518135	0.032398	0.0000
LN_RD_IND2(-1)	**0.618196**	**0.073295**	**0.0000**	**LN_RD_IND2(-1)**	**0.119471**	**0.037301**	**0.0024**
LN_RD_UC(-1)	**-0.092977**	**0.073187**	**0.2102**	**LN_RD_UC(-1)**	**0.036364**	**0.020416**	**0.0814**
MA(1)	0.689975	0.097474	0.0000	MA(1)	0.653564	0.112238	0.0000
Dependent Variable: LN_VA_PROFESSIONAL				**Dependent Variable: LN_VA_REALEST**			
C	-6.843046	0.535340	0.0000	C	-3.985281	0.330619	0.0000
LN_EMPL_PROFESSIONAL	0.958953	0.092283	0.0000	LN_EMPL_REALEST	0.379229	0.079516	0.0000
LN_FA_PROFESSIONAL(-1)	0.323395	0.046543	0.0000	LN_FA_REALEST(-1)	0.385683	0.043800	0.0000
LN_RD_IND2(-1)	**0.279335**	**0.070098**	**0.0002**	**LN_RD_IND2(-1)**	**0.301978**	**0.038722**	**0.0000**
LN_RD_UC(-1)	**-0.018533**	**0.030583**	**0.5474**	**LN_RD_UC(-1)**	**0.095708**	**0.021686**	**0.0001**
MA(1)	0.640450	0.112539	0.0000	MA(1)	0.622166	0.116646	0.0000

Dependent Variable: LN_VA_RETAIL				Dependent Variable: LN_VA_TRANSP			
C	-6.165682	1.075492	0.0000	C	-6.720702	0.681968	0.0000
LN_EMPL_RETAIL	0.811647	0.131495	0.0000	LN_EMPL_TRANSP	0.728034	0.105943	0.0000
LN_FA_RETAIL(-1)	0.442473	0.054135	0.0000	LN_FA_TRANSP(-1)	0.748639	0.074382	0.0000
LN_RD_IND2(-1)	**0.168494**	**0.054671**	**0.0034**	**LN_RD_IND2(-1)**	**-0.166216**	**0.096978**	**0.0931**
LN_RD_UC(-1)	**4.07E-05**	**0.036458**	**0.9991**	**LN_RD_UC(-1)**	**0.324629**	**0.056365**	**0.0000**
MA(1)	0.683626	0.106335	0.0000	MA(1)	0.553949	0.122285	0.0000
Dependent Variable: LN_VA_UTILITIES				**Dependent Variable: LN_VA_WHOLESALE**			
C	-4.963809	0.816867	0.0000	C	-6.287965	2.735394	0.0260
LN_EMPL_UTILITIES	0.323198	0.119381	0.0094	LN_EMPL_WHOLESALE	0.763742	0.329291	0.0248
LN_FA_UTILITIES(-1)	0.552567	0.079110	0.0000	LN_FA_WHOLESALE(-1)	0.192212	0.096839	0.0530
LN_RD_IND2(-1)	**0.340328**	**0.075192**	**0.0000**	**LN_RD_IND2(-1)**	**0.374028**	**0.083229**	**0.0000**
LN_RD_UC(-1)	**0.030759**	**0.048478**	**0.5288**	**LN_RD_UC(-1)**	**0.043667**	**0.056560**	**0.4439**
MA(1)	0.666279	0.110468	0.0000	MA(1)	0.859289	0.078758	0.0000

In most of the sectors industrial R&D turned out to be significant and some of the case U&C R&D also significant – but not necessarily plausible. In sectors, like Management Services, Educational Services, Administrational Services where the estimated coefficients on R&D are insignificant but U&C R&D significant the following two intuitions I have: (i) there is indeed no significant effect of the industrial R&D expenditures but U&C R&D affect their economic performance (except AGRIC) or (ii) the coefficients of U&C R&D "include" the effects of industrial R&D – bad regressions. In case of (i) U&C R&D may have large impact on economic performance because U&C (researcher) staff have large influence on these sectors. In case of Education Services it seems to be plausible but in other sectors the intuition (ii) seems to be plausible.
In cases where both types of R&D are significant the "allocation" of R&D effects to different sources is guessed. In cases where one of these two variables is negative the negative term is considered as a "correction" for estimated high positive R&D effects in the given sector (e.g. ACCOMM, ARTS, HEATHCARE or TRANSPORTATION (ca. 16%)).
In other cases where capital input or labor input turned out to be insignificant other variables like R&D expenditures may (implicitly) explain the effects of insignificant variables and so they become implausibly high. Such sectors are Wholesale (0.374), Other Services (0.618), Mining (0.49), Information (0.48), Healthcare (0.415) and Arts (0.63).
On aggregate Private level (PRIVATE) the estimated total R&D effect is about 15.6 % (12% by Industry, 3.6% by U&C) that is a bit above w.r.t. 14.6% estimated in the first table. If we take strictly the 0.05 significance level the coefficient on U&C R&D becomes insignificant and the total R&D effect on Private level falls to 12%. This value is 2.6% below w.r.t. 14.6%. These results confirm each other because PRIVATE includes the total non-federal sector in the US economy (ca. 85-90% of the total economy based on GDP) and hence the expected (industrial) R&D expenditures may be close to each other on national and Private level. Consequently, they tend to be plausible estimates. In the following I briefly discuss the sectoral estimates in the US economy.

ACCOMM includes accommodation and food services that is positively related to total industrial R&D spending and negatively to U&C R&D. The total R&D effect on the sectoral value added lies about 5-6% (14% by Industry R&D, -8.6% by U&C R&D). Negative effects of R&D investments are implausible but here it should refer to such circumstance that additional U&C R&D spending instead of e.g. additional spending on accommodation and food services would negatively affect the value added of ACCOMM. It may have an interpretation that relevant private sectors should spend more money on ACCOMM or industrial R&D activities if they want to increase the value added of ACCOMM. The coefficients of employment (1.09) and fixed assets (0.5) seem to be plausible because in services the human capital is assumed more important than fixed assets. However, accommodation and food service require buildings, real estates and many other physical capital and products that support the satisfaction of customer needs.

ADMIN includes administrative and waste management services and it is positively related to U&C R&D. However, industrial R&D seems to be insignificant which is implausible because industrial R&D spending may increase the turnover and hence the size of the company. Higher size of the economy and volume of sales is assumed positively related with the increase of administrative activities and waste. Employment and fixed assets in this sector have almost the same effects on value added (0.56 by Employment and 0.546 by Fixed Assets) that is not surprising because administrative activities require papers, computers, printers, etc. and waste management requires appropriate vehicles and places where waste can be stored or recycled. Assumption is that a given employee of this sector work with more types of physical production factors and these physical factors determine the overall productivity of the given worker – an additional worker in this sector must be endowed with these physical factors in order to do his/her job; these physical factors have high value in general. Hence fixed assets have almost the same role in this sector than workers. In case of ACCOMM an additional worker may not be endowed with such high-value physical factors like workers of sector ADMIN therefore fixed assets have relative lower effects on value added.

AGRIC includes agriculture and farms. The estimation results show that only the fixed assets (0.70) and MA term have significant effects on the sectoral value added. This interesting result can be interpreted as follows if it is considered as plausible: an additional machine like tractor generate more marginal product, revenue than an additional worker. Nowadays efficient, competitive agricultural sector cannot exist without machines that make easier and faster the cultivation. If somebody wants to replace machines with people, he/she needs to hire a large size of labor force in order to be able to produce the amount of products with machines. Furthermore the machines enable people to concentrate on very simple tasks during the production process. Consequently the role (quality) of employees is not (so) relevant in this sector. However, this interpretation can be easily criticized by arguing that people's skills, expertise have relevant (irreplaceable) role in each field. (Quality and quantity of) Land as regressor may play important, significant role for sectoral value added. Insignificant R&D may imply that employees do not need high education to accomplish their jobs and this sector is not able to regularly change its physical equipment that reduces the effects of 'new' products on the value added. This is the only US economic sector where no significant R&D effect has been found.

ARTS includes leisure activities, performing arts where human skills have primary role in the production process (1.24). 'Arts' is not a physical capital intensive sector of the economy because physical capital have very small effect on talent as a basic and most important production factor in Arts. So in this sector relatively more weight is attached to human capital input. For instance the quality of actors and actresses is more important than the quality of the strip. The total estimated R&D effect is ca. 45% (63% by Industrial R&D and ca. -18% by U&C R&D) that is very large compared to other sectors. Probably total R&D effect may include effects of fixed assets that cannot be measured with the given regressor. U&C R&D effects can be seen as correction for large industrial R&D effects.

The estimated values in sector CONSTRUCTION seem to be plausible and significant. This sector consists of building and assembling of infrastructure. Employment has about twice as large effect on value added than fixed assets. This is usual based on significant and plausible estimates in this table. Industrial and U&C R&D play important role in this sector based on the estimated effect 34% - 23.4% by Industry R&D and 8.6% by U&C R&D.

EDUSERV includes educational services that play important role for the total economic performance. The significance and plausibility of this estimation result is questionable because employment has no significant effect on value added. This result is however is implausible because the quality of education, teaching mainly determined by the quality of the staff (employment). U&C R&D play important role here as expected and industrial R&D is insignificant because educational services should influence industrial R&D and not conversely.
FINANCE is a good example of technology intensive sectors – high R&D effects (26%) refer to the fact that FINANCE is a big customer of 'new' products. Computers, high-tech mobile services, cars are "attributes" of this sector. However, large U&C R&D effects and almost insignificant coefficient on industrial R&D is not automatically plausible. Probably the coefficient of U&C R&D includes some effects of industrial R&D. Based on relative value added of this sector (including real estate sector) this is the most important sector for the USA (ca. 20% of the total).
The sector 'Manufacturing' is also highly elastic to industrial R&D (0.35) that is higher than the elasticity to fixed assets (0.335). Probably the intermediate input is a better regressor in for the sectoral value added because fixed assets refer rather to the capacity (change) of this sector. This sector is one of the most important sectors in the USA based on relative value added to the total. Recently the relative importance of this sector's value added has fallen from 30% to 15% in the sample but it still remains one of the largest sectors in the US economy. This is a sector producing primarily physical product and the competitiveness of firms depends greatly on the success of R&D departments. Hence R&D activities (cost intensive experiments with physical products) have very important role in producing better, more efficient or new products. Consequently an appropriate support of money is necessary for future profits, development of this sector.
The estimation results concerning MANAGEMENT seem to be plausible – 1.05 by Employment, 0.42 by Fixed assets. This is a sector belonging to Services where generally labor has more weight in production processes. This sector contains activities relating to organizational issues in firms. So, the behavior, quality of 'managers' play relevant and essential role here and fixed assets like computers, mobile phones, cars, etc. generally support the more efficient, faster and easier execution of managerial activities but they cannot replace 'managers'. U&C R&D seems to plausible (17.7%) because of academic research activities that promote the quality of managers.
Professional Services (ca. 28% effect by industrial R&D) include legal services, computer systems design and related services and miscellaneous scientific and technical services. Based on relative value added of this sector to the total this is the 2nd or 3rd most important sector of the USA (ca. 15%). Probably this sector is intensively connected to other sectors of the economy because of the fields of activities. Computer systems design, scientific and technical services require relevant and successful R&D activities (vertical and horizontal invention and innovation) in order to be and to remain competitive on national and international level in the future. If this sector looses its national competitiveness other sectors may annex such services because of higher efficiency instead of outsourcing these activities. On international level the lack of competitiveness of this sector would lead to takeover of these services by foreign firms. Hence the appropriate support of R&D expenditures is necessary for this sector, too.
In case of Real estates, the labor, capital and R&D input have almost the same weight in sectoral value added (ca. 37-39%). This result shows the relative importance of fixed assets (quality and quantity) in this sector. The effect of R&D on sectoral value added is not necessarily so high because the traditional research activities may have large impact on this sector. The following argumentation seems to be plausible: part of the R&D expenditures may be spent on new building, rents or other expenses representing income for Real Estate sector.

Obviously new techniques in house building may also contribute to higher value added of this sector.
The Retail sector buys products in large quantities from manufacturers or importers, either directly or through sector WHOLESALE and sells smaller quantities to end-user. In this sector the estimated coefficient seem to be plausible – effects of labor (0.81) and capital (0.44) input lie a bit under the average of Private sector. Industrial R&D (16.8%) affect the sectoral value added because industrial R&D activities (through vertical and horizontal innovations) may improve the prices of such products that this sector (later) retail. However these effects are expected to be lower than in the Wholesale sector because Retail sector may buy new products indirectly – Wholesale sector buys directly these new products, therefore I expect higher R&D effects.
Sector Utilities shows an interesting result. Employment (0.32) has lower effect on sectoral value added than Fixed assets (0.55). This is however not surprising because this sector contains firms that provide gas, electricity and water to other firms. Consequently these activities require big plants, machines and some staff to control the activities. Industrial R&D expenditures can have two main effects on this sector's value added like in case of Real estates. On the one hand R&D activities (e.g. experimental research activities) may require gas, electricity and water to be able to conduct experiments. On the other hand innovations may increase the efficiency of this sector.
Sector Wholesale sells products to retailers or itself or other sectors. The estimated coefficients on employment (0.767) and fixed assets (0.192) seem to be significant and plausible because this sector's profit depends primarily on intermediate inputs (products they sell to other sectors, buyers) and hence there is a need only for storages where these inputs can be stored. Intuition behind the high R&D effect (0.374): R&D expenditures may have an indirect effect on the sectoral profit because the producers of these intermediate inputs spend probably on R&D projects that may improve the quality of these products. Higher quality induces the increase of the price level. If this sector uses fixed mark-up (e.g. 10%), a higher value of an intermediate input increases the value added of WHOLESALE without changing the mark-up. RETAIL "works" in a same way but with lower mark-ups in order to avoid possible losses because of low demand (induced by high prices) and high storage costs. Consequently the R&D effects may become lower. Obviously these R&D effects depend also on market structure.

As a conclusion I can say that in significant and plausible cases of estimations the effects of labor are about 1.0, the capital about 0.5, the R&D varies across different sectors. In less elastic sectors with respect to R&D like ACCOMM, ADMIN, MANAGEMENT, RETAIL and TRANSPORTATION the R&D effects are less than 17%. These sectors are close to the average in Private sector (12-15%). In more elastic sectors like CONSTRUCTION, MANUFACTURING, PROFESSIONAL, REALEST and UTILITIES the R&D effects are more than ca. 30% - almost double than in less elastic sectors. These two groups of sectors imply that R&D expenditures have generally lower expected effects on value added in sectors providing Services and have higher expected effects in sectors producing (providing) physical products (Goods).

<u>2.4.3. Estimation results – Table 3:</u>

In the next step I analyze the effects of industrial R&D expenditures by type on the sectoral value added – BR refers to basic research, AR to applied research, DE to development. (INDIND means that industrial R&D are financed only from industrial sources) Primarily I analyze the results in the two given groups of sectors (high and low elastic sector w.r.t. R&D) and compare them with the previously estimated values.

Dependent Variable: LN_VA_ACCOMM				Dependent Variable: LN_VA_ADMIN			
Variable	Coefficient	Std. Error	Prob.	Variable	Coefficient	Std. Error	Prob.
LN_EMPL_ACCOMM	1.140285	0.157381	0.0000	LN_EMPL_ADMIN	0.669510	0.075047	0.0000
LN_FA_ACCOMM(-1)	0.474730	0.088530	0.0000	LN_FA_ADMIN(-1)	0.506041	0.043661	0.0000
LN_BR_INDIND(-1)	**0.002191**	**0.021781**	**0.9203**	**LN_BR_INDIND(-1)**	**-0.032021**	**0.028729**	**0.2708**
LN_AR_INDIND(-1)	**0.025300**	**0.032976**	**0.4470**	**LN_AR_INDIND(-1)**	**0.052695**	**0.038040**	**0.1727**
LN_DE_INDIND(-1)	**0.034956**	**0.053754**	**0.5188**	**LN_DE_INDIND(-1)**	**0.174065**	**0.059521**	**0.0053**
C	-8.377534	1.032768	0.0000	C	-5.158129	0.309365	0.0000
AR(1)	0.764641	0.098933	0.0000	MA(1)	0.727815	0.104471	0.0000
Dependent Variable: LN_VA_AGRIC				**Dependent Variable: LN_VA_ARTS**			
LN_EMPL_AGRIC	-0.164928	0.224346	0.4660	LN_EMPL_ARTS	1.355683	0.255592	0.0000
LN_FA_AGRIC(-1)	0.749674	0.137897	0.0000	LN_FA_ARTS(-1)	0.038718	0.134764	0.7752
LN_BR_INDIND(-1)	**0.095496**	**0.103507**	**0.3610**	**LN_BR_INDIND(-1)**	**0.063044**	**0.042009**	**0.1404**
LN_AR_INDIND(-1)	**-0.208536**	**0.167903**	**0.2205**	**LN_AR_INDIND(-1)**	**0.073881**	**0.059360**	**0.2197**
LN_DE_INDIND(-1)	**0.085160**	**0.144191**	**0.5577**	**LN_DE_INDIND(-1)**	**0.234003**	**0.088188**	**0.0110**
C	1.715470	1.848910	0.3583	C	-9.872052	1.235738	0.0000
MA(1)	0.449066	0.133704	0.0016	AR(1)	0.836508	0.084779	0.0000
Dependent Variable: LN_VA_CONSTRUCTION				**Dependent Variable: LN_VA_EDUSERV**			
LN_EMPL_CONSTRUCTION	0.827634	0.102875	0.0000	LN_EMPL_EDUSERV	1.082578	0.151744	0.0000
LN_FA_CONSTRUCTION(-1)	0.424577	0.064119	0.0000	LN_FA_EDUSERV(-1)	0.278501	0.106630	0.0121
LN_BR_INDIND(-1)	**0.072212**	**0.041493**	**0.0885**	**LN_BR_INDIND(-1)**	**-0.048971**	**0.040225**	**0.2297**
LN_AR_INDIND(-1)	**-0.000380**	**0.055269**	**0.9945**	**LN_AR_INDIND(-1)**	**0.090382**	**0.056503**	**0.1165**
LN_DE_INDIND(-1)	**0.201659**	**0.060875**	**0.0018**	**LN_DE_INDIND(-1)**	**0.281453**	**0.066162**	**0.0001**
C	-6.296426	0.739705	0.0000	C	-9.295417	0.909905	0.0000
MA(1)	0.765289	0.102302	0.0000	MA(1)	0.967228	0.015898	0.0000
Dependent Variable: LN_VA_FINANCE				**Dependent Variable: LN_VA_HEALTHCARE**			
LN_EMPL_FINANCE	0.524158	0.237534	0.0325	LN_EMPL_HEALTHCARE	0.182921	0.258670	0.4830
LN_FA_FINANCE(-1)	0.264818	0.081910	0.0023	LN_FA_HEALTHCARE(-1)	0.656595	0.141585	0.0000
LN_BR_INDIND(-1)	**0.014214**	**0.025865**	**0.5853**	**LN_BR_INDIND(-1)**	**0.152564**	**0.030121**	**0.0000**
LN_AR_INDIND(-1)	**-0.000425**	**0.035928**	**0.9906**	**LN_AR_INDIND(-1)**	**-0.115703**	**0.040625**	**0.0066**
LN_DE_INDIND(-1)	**0.075057**	**0.066177**	**0.2627**	**LN_DE_INDIND(-1)**	**0.263157**	**0.040630**	**0.0000**
C	-7.006461	5.543085	0.2127	C	-2.763369	1.675800	0.1060
AR(1)	1.007105	0.007499	0.0000	MA(1)	0.997450	0.050665	0.0000
Dependent Variable: LN_VA_INFO				**Dependent Variable: LN_VA_MANAGEMENT**			
LN_EMPL_INFO	0.049441	0.167411	0.7691	LN_EMPL_MANAGEMENT	1.246953	0.164554	0.0000
LN_FA_INFO(-1)	0.403688	0.074612	0.0000	LN_FA_MANAGEMENT(-1)	0.380709	0.054462	0.0000
LN_BR_INDIND(-1)	**0.022455**	**0.033945**	**0.5116**	**LN_BR_INDIND(-1)**	**0.014795**	**0.030846**	**0.6337**
LN_AR_INDIND(-1)	**0.072061**	**0.047901**	**0.1393**	**LN_AR_INDIND(-1)**	**0.020151**	**0.040239**	**0.6189**
LN_DE_INDIND(-1)	**0.424595**	**0.059936**	**0.0000**	**LN_DE_INDIND(-1)**	**0.114987**	**0.056121**	**0.0462**
C	-2.898049	1.065861	0.0092	C	-7.909202	0.807795	0.0000
MA(1)	0.972391	0.022697	0.0000	MA(1)	0.962619	0.036062	0.0000
Dependent Variable: LN_VA_MANUFACTURING				**Dependent Variable: LN_VA_MINING**			
LN_EMPL_MANUFACTURING	0.612685	0.103762	0.0000	LN_EMPL_MINING	1.330832	0.295072	0.0000
LN_FA_MANUFACTURING(-1)	0.374688	0.066144	0.0000	LN_FA_MINING(-1)	0.319087	0.243561	0.1967
LN_BR_INDIND(-1)	**0.096781**	**0.034922**	**0.0080**	**LN_BR_INDIND(-1)**	**-0.092619**	**0.115596**	**0.4271**
LN_AR_INDIND(-1)	**-0.004920**	**0.051602**	**0.9245**	**LN_AR_INDIND(-1)**	**-0.072686**	**0.183325**	**0.6936**
LN_DE_INDIND(-1)	**0.243242**	**0.051715**	**0.0000**	**LN_DE_INDIND(-1)**	**0.635399**	**0.168271**	**0.0005**
C	-5.146785	1.050858	0.0000	C	-11.53719	2.496161	0.0000
MA(1)	0.786285	0.095999	0.0000	MA(1)	0.758578	0.099432	0.0000
Dependent Variable: LN_VA_OTHERSERV				**Dependent Variable: LN_VA_PRIVATE**			
LN_EMPL_OTHERSERV	0.986132	0.208761	0.0000	LN_EMPL_PRIVATE	1.048548	0.123016	0.0000

LN_FA_OTHERSERV(-1)	0.613954	0.099784	0.0000	LN_FA_PRIVATE(-1)	0.526704	0.033131	0.0000
LN_BR_INDIND(-1)	**0.056061**	**0.030117**	**0.0692**	**LN_BR_INDIND(-1)**	**0.044374**	**0.015203**	**0.0054**
LN_AR_INDIND(-1)	**-0.034033**	**0.043539**	**0.4385**	**LN_AR_INDIND(-1)**	**-0.011981**	**0.023875**	**0.6182**
LN_DE_INDIND(-1)	**0.186271**	**0.064749**	**0.0061**	**LN_DE_INDIND(-1)**	**0.111581**	**0.034556**	**0.0023**
C	-9.066164	1.633280	0.0000	C	-9.925492	1.134803	0.0000
AR(1)	0.816013	0.057667	0.0000	MA(1)	0.689388	0.104635	0.0000
Dependent Variable: LN_VA_PROFFESIONAL				**Dependent Variable: LN_VA_REALEST**			
LN_EMPL_PROFESSIONAL	0.996683	0.071172	0.0000	LN_EMPL_REALEST	0.414851	0.095679	0.0001
LN_FA_PROFESSIONAL(-1)	0.370162	0.033996	0.0000	LN_FA_REALEST(-1)	0.358604	0.052269	0.0000
LN_BR_INDIND(-1)	**0.094492**	**0.016992**	**0.0000**	**LN_BR_INDIND(-1)**	**0.033693**	**0.020049**	**0.0996**
LN_AR_INDIND(-1)	**-0.003928**	**0.029675**	**0.8953**	**LN_AR_INDIND(-1)**	**0.086037**	**0.033254**	**0.0129**
LN_DE_INDIND(-1)	**0.104600**	**0.047608**	**0.0331**	**LN_DE_INDIND(-1)**	**0.293489**	**0.039868**	**0.0000**
C	-6.277458	0.346983	0.0000	C	-4.006180	0.387668	0.0000
MA(1)	0.479144	0.134366	0.0009	MA(1)	0.612049	0.124749	0.0000
Dependent Variable: LN_VA_RETAIL				**Dependent Variable: LN_VA_TRANSP**			
LN_EMPL_RETAIL	0.833194	0.100528	0.0000	LN_EMPL_TRANSP	0.979804	0.172397	0.0000
LN_FA_RETAIL(-1)	0.438902	0.046390	0.0000	LN_FA_TRANSP(-1)	0.339682	0.125922	0.0098
LN_BR_INDIND(-1)	**0.042961**	**0.020433**	**0.0410**	**LN_BR_INDIND(-1)**	**0.021386**	**0.032370**	**0.5122**
LN_AR_INDIND(-1)	**-0.029901**	**0.030669**	**0.3347**	**LN_AR_INDIND(-1)**	**-0.062307**	**0.044910**	**0.1722**
LN_DE_INDIND(-1)	**0.152255**	**0.041721**	**0.0007**	**LN_DE_INDIND(-1)**	**-0.021343**	**0.077986**	**0.7856**
C	-6.174654	0.742422	0.0000	C	-2.042462	3.436115	0.5552
MA(1)	0.703186	0.101899	0.0000	AR(1)	0.985823	0.008170	0.0000
Dependent Variable: LN_VA_UTILITIES				**Dependent Variable: LN_VA_WHOLESALE**			
LN_EMPL_UTILITIES	0.116713	0.168436	0.4919	LN_EMPL_WHOLESALE	0.773638	0.301107	0.0135
LN_FA_UTILITIES(-1)	0.738138	0.107833	0.0000	LN_FA_WHOLESALE(-1)	0.184760	0.093631	0.0545
LN_BR_INDIND(-1)	**0.066217**	**0.041637**	**0.1188**	**LN_BR_INDIND(-1)**	**0.012838**	**0.038678**	**0.7415**
LN_AR_INDIND(-1)	**-0.004463**	**0.059846**	**0.9409**	**LN_AR_INDIND(-1)**	**0.052641**	**0.055832**	**0.3507**
LN_DE_INDIND(-1)	**0.186300**	**0.072780**	**0.0139**	**LN_DE_INDIND(-1)**	**0.355761**	**0.060347**	**0.0000**
C	-3.246413	1.074551	0.0041	C	-6.206343	2.445877	0.0146
AR(1)	0.713619	0.123259	0.0000	MA(1)	0.813704	0.106319	0.0000

The first remark is that employment elasticity and capital elasticity are about 1.0 and 0.5 in most of the sectors, respectively. In sectors where the respective elasticities are "far away" from these estimated values, the respective variables tend to be insignificant.
In the "low" sector (containing ACCOMM, ADMIN, MANAGEMENT, RETAIL and TRANSP) the R&D elasticity varies between 11% and 19%. However, in sectors ACCOMM and TRANSP industrial R&D expenditures turned out to be insignificant. Compared to the previous table of regression result, in case of TRANSP the industrial R&D was significant at 5% level and ACCOMM showed a very low elasticity to R&D expenditures (5-6%). Additionally the here estimated coefficients in ADMIN, MANAGEMENT and REATAIL are close to the previously estimated effects. Thus this result does not speak against the previous estimated effects and they tend to plausible.
In the "high" sector (containing CONSTRUCTION, MANUFACTURING, PROFESSIONAL, REALEST, UTILITIES and WHOLESALE) the R&D elasticity varies between 19% and 38%. In sector UTILITIES the estimated coefficients do not justify the previously estimated coefficients but in other sectors the estimated coefficients are close to the previous ones (except PROFESSIONAL). In case of PROFESSIONAL the here estimated R&D effect is ca. 10% lower than in the previous estimation.
In the remaining sectors (containing AGRIC, ARTS, EDUSERV, FINANCE, HEALTHCARE, INFO, MINING and OTHERSERV) the estimated coefficients on employment or fixed assets are insignificant (except EDUSERV, FINANCE and OTHERSERV) and therefore I do not interpret those results. In the remaining plausible cases FINANCE turned out to be inelastic to

R&D expenditures but EDUSERV (28% R&D effect) and OTHERSERV (18-24% R&D effect) seem to be highly elastic to R&D. These two sectors enrich the group of highly elastic sectors with respect to R&D. These results show that the main goods and service producing sectors are rather highly elastic to R&D expenditures.
On the aggregate Private level the estimated total effect of industrial R&D is about 15%. This is close to the previous one (ca. 12%) and the coefficients on employment and fixed assets. Hence these estimates seem to be plausible.
Other remark is that applied research is significant only in sector REALEST. In other cases BR and DE R&D expenditures exert the largest and most significant effects on sectoral value added. This result may have the following interpretation: aggregate AR expenditures have a constant relative weight w.r.t the total R&D expenditures and a slightly increasing trend in absolute values. However, total R&D expenditures fluctuate about 2.5% of the GDP. It means AR gives relatively almost constant impulses concerning the value added over the years. The trend of sectoral and total value added is however positive and exponential that suggest me to consider other sources R&D expenditures that have an absolute positive trend and a positive relative trend w.r.t. the total R&D. Such sources may give (absolutely and relatively) increasing impulses concerning the value added over the years. BR satisfies this criterion. DE has however negative but fluctuating relative trend but it takes about 60% of the total R&D expenditures. Consequently its effect on the value added is more than expected and plausible. Furthermore based on the definition of DE (systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes) this field of R&D activities is expected to be the most responsible and significant producer of new useful designs. BR is significant and plausible source of new designs (invention, innovation) by definition but these designs need not to be successful (useful). So this field of R&D expenditures is also for important for the growth of the economy (economic value added). AR can be seen as a juncture or filter between BR and DE that has to choose the expected successful (useful) designs and "transfer" them to DE. Thus it is also important area of R&D activities but not as important as BR and DE.

2.4.4. Estimation results – Table 4:

In the following I split the sectoral value added into price and quantity indices in order to see how these effects are "allocated" between these variables. It means I regress two types of regressions in each sector with same regressors but with different regressands. Consequently I analyze which variable have more or less effect on sectoral aggregate prices and quantities. Value added is a product of price and quantity indices therefore I place the regression results w.r.t price and quantity indices in a sector side by side. The expectation is that the aggregate effects of each variable (i.e. the sum of the estimated coefficients of a given regressor in the two types of regressions in a given sector) are about the previously estimated effects.

Example for aggregate effect of a regressor:

Dependent Variable: LN_VA_PRC_ADMIN				**Dependent Variable: LN_VA_QNTY_ADMIN**			
LN_AR_INDIND(-1)	**0.099579**	**0.034669**	**0.0061**	**LN_AR_INDIND(-1)**	**-0.069550**	**0.027240**	**0.0141**

The aggregate effect of AR on ADMIN value added is ca. 3% (at 5% significance level).

Remark: Instead of analyzing the following regressions (see at the beginning of this section):

$\ln Y(t) = \ln\tilde{\alpha}_1 + G_1\ln\tilde{A}^K(t\text{-}1) + G_2\ln\tilde{K}(t\text{-}1) + G_3\ln\tilde{A}^L(t) + G_4\ln\tilde{L}(t) + G_5\ln\tilde{R}(t\text{-}1) + AR(1) + \varepsilon_1(t)$
or
$\ln Y(t) = \ln\tilde{\alpha}_2 + G_1\ln\tilde{A}^K(t\text{-}1) + G_2\ln\tilde{K}(t\text{-}1) + G_3\ln\tilde{A}^L(t) + G_4\ln\tilde{L}(t) + G_5\ln\tilde{R}(t\text{-}1) + MA(1) + \varepsilon_2(t)$
or the equation includes both terms (AR(1) and MA(1))

I estimated the following ones:

$\ln P^Y(t) = \ln\tilde{\alpha}_1 + G_1\ln[\tilde{A}^K(t\text{-}1)\tilde{K}(t\text{-}1)] + G_2\ln[\tilde{L}(t)] + G_3\ln\tilde{R}(t\text{-}1) + AR(1) + \varepsilon_1(t)$ or
$\ln Q^Y(t) = \ln\tilde{\alpha}_2 + G_1\ln[\tilde{A}^K(t\text{-}1)\tilde{K}(t\text{-}1)] + G_2\ln[\tilde{L}(t)] + G_3\ln\tilde{R}(t\text{-}1) + AR(1) + \varepsilon_2(t)$ or
$\ln P^Y(t) = \ln\tilde{\alpha}_3 + G_1\ln[\tilde{A}^K(t\text{-}1)\tilde{K}(t\text{-}1)] + G_2\ln[\tilde{L}(t)] + G_3\ln\tilde{R}(t\text{-}1) + MA(1) + \varepsilon_3(t)$ or
$\ln Q^Y(t) = \ln\tilde{\alpha}_4 + G_1\ln[\tilde{A}^K(t\text{-}1)\tilde{K}(t\text{-}1)] + G_2\ln[\tilde{L}(t)] + G_3\ln\tilde{R}(t\text{-}1) + MA(1) + \varepsilon_4(t)$ or
the equations include both terms (AR(1) and MA(1)) and where P^Y denotes the Fisher price index for GDP and Q^Y denotes the Fisher ideal quantity index for GDP.

I have decided to present these estimation results because the previous ones show in few cases the significance of R&D expenditures. Furthermore if Y(t) has been substituted with $P^Y(t)$ and $Q^Y(t)$ then the R&D expenditures become in fewer cases significant. The reason for that might be that price indices of regressors explain their qualities, the change in their qualities initiated by R&D activities (expenditures) and hence R&D expenditures become insignificant. Generally the tendency is in each sector that aggregate price index is influenced primarily by price indices of regressors and aggregate quantity index primarily by quantity indices of regressors.

The estimated values are more interesting and presented below (sector TRANSP is excluded from the analysis because of insufficient data):

Dependent Variable: LN_VA_PRC_ACCOMM				**Dependent Variable: LN_VA_QNTY_ACCOMM**			
Variable	Coefficient	Std. Error	Prob.	Variable	Coefficient	Std. Error	Prob.
LN_EMPL_ACCOMM	0.023201	0.134846	0.8642	LN_EMPL_ACCOMM	1.138697	0.170335	0.0000
LN_FA_ACCOMM(-1)	0.593387	0.089620	0.0000	LN_FA_ACCOMM(-1)	-0.095153	0.095761	0.3257
LN_BR_INDIND(-1)	**0.022936**	**0.019800**	**0.2528**	**LN_BR_INDIND(-1)**	**-0.031096**	**0.024984**	**0.2197**
LN_AR_INDIND(-1)	**0.015008**	**0.028298**	**0.5985**	**LN_AR_INDIND(-1)**	**0.002121**	**0.035556**	**0.9527**
LN_DE_INDIND(-1)	**0.024791**	**0.049593**	**0.6196**	**LN_DE_INDIND(-1)**	**0.015193**	**0.060542**	**0.8030**
C	0.331586	0.914352	0.7186	C	-5.285763	1.109191	0.0000
AR(1)	0.882979	0.050233	0.0000	AR(1)	0.780354	0.084532	0.0000
Dependent Variable: LN_VA_PRC_ADMIN				**Dependent Variable: LN_VA_QNTY_ADMIN**			
LN_EMPL_ADMIN	-0.149440	0.073065	0.0466	LN_EMPL_ADMIN	0.796957	0.056692	0.0000
LN_FA_ADMIN(-1)	0.417779	0.043477	0.0000	LN_FA_ADMIN(-1)	0.073824	0.037596	0.0556
LN_BR_INDIND(-1)	**-0.046378**	**0.027896**	**0.1032**	**LN_BR_INDIND(-1)**	**0.035540**	**0.022652**	**0.1235**
LN_AR_INDIND(-1)	**0.099579**	**0.034669**	**0.0061**	**LN_AR_INDIND(-1)**	**-0.069550**	**0.027240**	**0.0141**
LN_DE_INDIND(-1)	**0.153578**	**0.056587**	**0.0093**	**LN_DE_INDIND(-1)**	**0.050256**	**0.043168**	**0.2503**
C	1.469440	0.312605	0.0000	C	-3.088694	0.272760	0.0000
MA(1)	0.828041	0.088103	0.0000	MA(1)	0.970923	0.046571	0.0000
Dependent Variable: LN_VA_PRC_AGRIC				**Dependent Variable: LN_VA_QNTY_AGRIC**			
LN_EMPL_AGRIC	0.847157	0.407240	0.0432	LN_EMPL_AGRIC	0.332166	0.145568	0.0272
LN_FA_AGRIC(-1)	-0.048906	0.379483	0.8980	LN_FA_AGRIC(-1)	-0.127214	0.090606	0.1670
LN_BR_INDIND(-1)	**0.007673**	**0.110104**	**0.9447**	**LN_BR_INDIND(-1)**	**0.080499**	**0.072332**	**0.2715**
LN_AR_INDIND(-1)	**-0.142753**	**0.150046**	**0.3465**	**LN_AR_INDIND(-1)**	**-0.046623**	**0.120600**	**0.7008**
LN_DE_INDIND(-1)	**-0.112046**	**0.265982**	**0.6756**	**LN_DE_INDIND(-1)**	**0.362416**	**0.102137**	**0.0009**

C	2.169182	6.010295	0.7199	C	-1.549589	1.204352	0.2047
AR(1)	0.968721	0.025795	0.0000	MA(1)	0.174583	0.150009	0.2505
Dependent Variable: LN_VA_PRC_ARTS				**Dependent Variable: LN_VA_QNTY_ARTS**			
LN_EMPL_ARTS	0.413217	0.099435	0.0001	LN_EMPL_ARTS	0.759856	0.192141	0.0003
LN_FA_ARTS(-1)	0.179144	0.055413	0.0023	LN_FA_ARTS(-1)	0.072003	0.074358	0.3379
LN_BR_INDIND(-1)	**0.001517**	**0.015211**	**0.9210**	**LN_BR_INDIND(-1)**	**0.212539**	**0.032332**	**0.0000**
LN_AR_INDIND(-1)	**0.036762**	**0.021341**	**0.0918**	**LN_AR_INDIND(-1)**	**-0.051183**	**0.052033**	**0.3304**
LN_DE_INDIND(-1)	**0.137604**	**0.032050**	**0.0001**	**LN_DE_INDIND(-1)**	**-0.055228**	**0.078343**	**0.4844**
C	-1.324116	0.515008	0.0135	C	-2.115544	0.797819	0.0110
AR(1)	0.853000	0.094143	0.0000	MA(1)	0.397774	0.142820	0.0077
Dependent Variable: LN_VA_PRC_CONSTRUCTION				**Dependent Variable: LN_VA_QNTY_CONSTRUCTION**			
LN_EMPL_CONSTRUCTION	0.211810	0.104135	0.0479	LN_EMPL_CONSTRUCTION	0.857881	0.095417	0.0000
LN_FA_CONSTRUCTION(-1)	0.575757	0.089599	0.0000	LN_FA_CONSTRUCTION(-1)	-0.211875	0.080390	0.0115
LN_BR_INDIND(-1)	**0.028559**	**0.037238**	**0.4471**	**LN_BR_INDIND(-1)**	**0.035165**	**0.033987**	**0.3064**
LN_AR_INDIND(-1)	**0.018609**	**0.053139**	**0.7278**	**LN_AR_INDIND(-1)**	**0.001282**	**0.049083**	**0.9793**
LN_DE_INDIND(-1)	**0.204067**	**0.075201**	**0.0094**	**LN_DE_INDIND(-1)**	**-0.021992**	**0.068606**	**0.7500**
C	-2.863399	0.892057	0.0025	C	-2.052100	0.820737	0.0161
AR(1)	0.894171	0.048888	0.0000	AR(1)	0.865856	0.064848	0.0000
Dependent Variable: LN_VA_PRC_EDUSERV				**Dependent Variable: LN_VA_QNTY_EDUSERV**			
LN_EMPL_EDUSERV	0.267030	0.088318	0.0041	LN_EMPL_EDUSERV	0.928318	0.106628	0.0000
LN_FA_EDUSERV(-1)	0.467274	0.058890	0.0000	LN_FA_EDUSERV(-1)	-0.107497	0.072924	0.1473
LN_BR_INDIND(-1)	**0.042372**	**0.023505**	**0.0780**	**LN_BR_INDIND(-1)**	**-0.066428**	**0.029690**	**0.0301**
LN_AR_INDIND(-1)	**-0.006410**	**0.033484**	**0.8490**	**LN_AR_INDIND(-1)**	**0.051355**	**0.042546**	**0.2336**
LN_DE_INDIND(-1)	**0.118418**	**0.041171**	**0.0061**	**LN_DE_INDIND(-1)**	**0.078982**	**0.053293**	**0.1452**
C	-1.598515	0.508646	0.0029	C	-2.939164	0.615679	0.0000
MA(1)	0.844549	0.064783	0.0000	MA(1)	0.807335	0.087540	0.0000
Dependent Variable: LN_VA_PRC_FINANCE				**Dependent Variable: LN_VA_QNTY_FINANCE**			
LN_EMPL_FINANCE	-0.202165	0.133474	0.1367	LN_EMPL_FINANCE	0.800925	0.197017	0.0002
LN_FA_FINANCE(-1)	0.429297	0.051780	0.0000	LN_FA_FINANCE(-1)	0.036297	0.076220	0.6362
LN_BR_INDIND(-1)	**0.089768**	**0.031491**	**0.0065**	**LN_BR_INDIND(-1)**	**-0.011443**	**0.025911**	**0.6609**
LN_AR_INDIND(-1)	**-0.039783**	**0.047498**	**0.4066**	**LN_AR_INDIND(-1)**	**-0.012817**	**0.035723**	**0.7214**
LN_DE_INDIND(-1)	**0.064802**	**0.056057**	**0.2537**	**LN_DE_INDIND(-1)**	**0.051508**	**0.065876**	**0.4384**
C	2.395795	0.935212	0.0138	C	-3.508641	1.337945	0.0119
MA(1)	0.778043	0.091198	0.0000	AR(1)	1.052796	0.041200	0.0000
Dependent Variable: LN_VA_PRC_HEALTHCARE				**Dependent Variable: LN_VA_QNTY_HEALTHCARE**			
LN_EMPL_HEALTHCARE	1.217910	0.328969	0.0006	LN_EMPL_HEALTHCARE	0.262061	0.259847	0.3186
LN_FA_HEALTHCARE(-1)	-0.079455	0.176870	0.6554	LN_FA_HEALTHCARE(-1)	0.231589	0.130903	0.0836
LN_BR_INDIND(-1)	**0.032055**	**0.028064**	**0.2594**	**LN_BR_INDIND(-1)**	**0.010967**	**0.020573**	**0.5966**
LN_AR_INDIND(-1)	**0.050040**	**0.040795**	**0.2263**	**LN_AR_INDIND(-1)**	**-0.031410**	**0.028332**	**0.2735**
LN_DE_INDIND(-1)	**0.148274**	**0.063182**	**0.0234**	**LN_DE_INDIND(-1)**	**-0.050845**	**0.047255**	**0.2877**
C	-9.040849	2.691614	0.0016	C	1.604941	2.702991	0.5556
AR(1)	0.941546	0.044774	0.0000	AR(1)	0.955295	0.042705	0.0000
Dependent Variable: LN_VA_PRC_INFO				**Dependent Variable: LN_VA_QNTY_INFO**			
LN_EMPL_INFO	-0.120364	0.129225	0.3566	LN_EMPL_INFO	0.353196	0.141451	0.0163
LN_FA_INFO(-1)	0.243787	0.080793	0.0042	LN_FA_INFO(-1)	-0.083008	0.121910	0.4994
LN_BR_INDIND(-1)	**0.025403**	**0.024362**	**0.3027**	**LN_BR_INDIND(-1)**	**-0.087017**	**0.026661**	**0.0021**
LN_AR_INDIND(-1)	**0.005178**	**0.033253**	**0.8770**	**LN_AR_INDIND(-1)**	**0.068284**	**0.037046**	**0.0719**
LN_DE_INDIND(-1)	**0.136931**	**0.066079**	**0.0440**	**LN_DE_INDIND(-1)**	**-0.092034**	**0.072724**	**0.2122**
C	2.446630	0.838554	0.0055	C	-30.80008	65.34285	0.6397
AR(1)	1.045443	0.038378	0.0000	AR(1)	1.002024	0.003923	0.0000
Dependent Variable: LN_VA_PRC_MANAGEMENT				**Dependent Variable: LN_VA_QNTY_MANAGEMENT**			
LN_EMPL_MANAGEMENT	0.402757	0.213759	0.0660	LN_EMPL_MANAGEMENT	0.677160	0.229518	0.0050

LN_FA_MANAGEMENT(-1)	0.495841	0.131276	0.0005	LN_FA_MANAGEMENT(-1)	-0.065972	0.137110	0.6327
LN_BR_INDIND(-1)	**-0.039082**	**0.035293**	**0.2740**	**LN_BR_INDIND(-1)**	**0.007724**	**0.036919**	**0.8352**
LN_AR_INDIND(-1)	**0.085014**	**0.048936**	**0.0892**	**LN_AR_INDIND(-1)**	**-0.076398**	**0.050824**	**0.1398**
LN_DE_INDIND(-1)	**0.022409**	**0.087416**	**0.7988**	**LN_DE_INDIND(-1)**	**-0.018843**	**0.093410**	**0.8410**
C	-2.022254	1.869953	0.2853	C	1.232252	2.432422	0.6149
AR(1)	0.946233	0.038205	0.0000	AR(1)	0.968613	0.015892	0.0000
Dependent Variable: LN_VA_PRC_MANUFACTURING				**Dependent Variable: LN_VA_QNTY_MANUFACTURING**			
LN_EMPL_MANUFACTURING	-0.062442	0.087308	0.4783	LN_EMPL_MANUFACTURING	1.019873	0.122612	0.0000
LN_FA_MANUFACTURING(-1)	0.546017	0.095306	0.0000	LN_FA_MANUFACTURING(-1)	-0.212583	0.098284	0.0360
LN_BR_INDIND(-1)	**0.003264**	**0.020164**	**0.8721**	**LN_BR_INDIND(-1)**	**0.017004**	**0.030794**	**0.5836**
LN_AR_INDIND(-1)	**-0.019891**	**0.028646**	**0.4911**	**LN_AR_INDIND(-1)**	**-0.044764**	**0.042335**	**0.2961**
LN_DE_INDIND(-1)	**0.004499**	**0.052836**	**0.9325**	**LN_DE_INDIND(-1)**	**-0.122565**	**0.074882**	**0.1088**
C	-714.0484	715080.5	0.9992	C	1473.282	145097.4	0.9919
AR(1)	0.999981	0.018908	0.0000	AR(1)	0.999959	0.004047	0.0000
MA(1)	0.243199	0.158119	0.1312	MA(1)	-0.246726	0.165469	0.1431
Dependent Variable: LN_VA_PRC_MINING				**Dependent Variable: LN_VA_QNTY_MINING**			
LN_EMPL_MINING	0.997411	0.317663	0.0030	LN_EMPL_MINING	0.301730	0.121279	0.0166
LN_FA_MINING(-1)	0.549382	0.280856	0.0565	LN_FA_MINING(-1)	-0.175801	0.098529	0.0811
LN_BR_INDIND(-1)	**-0.049372**	**0.148350**	**0.7408**	**LN_BR_INDIND(-1)**	**0.030718**	**0.050064**	**0.5426**
LN_AR_INDIND(-1)	**-0.159576**	**0.210546**	**0.4524**	**LN_AR_INDIND(-1)**	**-0.046739**	**0.076310**	**0.5433**
LN_DE_INDIND(-1)	**0.382186**	**0.193023**	**0.0537**	**LN_DE_INDIND(-1)**	**0.233671**	**0.086492**	**0.0097**
C	-7.619150	2.753141	0.0081	C	1.270619	1.053672	0.2342
MA(1)	0.968519	0.021770	0.0000	AR(1)	0.809007	0.087087	0.0000
Dependent Variable: LN_VA_PRC_OTHERSERV				**Dependent Variable: LN_VA_QNTY_OTHERSERV**			
LN_EMPL_OTHERSERV	-0.199823	0.146503	0.1795	LN_EMPL_OTHERSERV	0.541247	0.135900	0.0002
LN_FA_OTHERSERV(-1)	0.179051	0.106086	0.0985	LN_FA_OTHERSERV(-1)	0.248044	0.071782	0.0012
LN_BR_INDIND(-1)	**0.002902**	**0.015387**	**0.8513**	**LN_BR_INDIND(-1)**	**0.093788**	**0.032411**	**0.0058**
LN_AR_INDIND(-1)	**-0.011256**	**0.021555**	**0.6041**	**LN_AR_INDIND(-1)**	**-0.089644**	**0.046893**	**0.0622**
LN_DE_INDIND(-1)	**0.079991**	**0.039335**	**0.0481**	**LN_DE_INDIND(-1)**	**-0.077131**	**0.052824**	**0.1510**
C	-1.272904	6.124256	0.8363	C	-0.567549	0.996716	0.5718
AR(1)	1.006605	0.007672	0.0000	MA(1)	0.840545	0.090636	0.0000
MA(1)	0.517931	0.143261	0.0008				
Dependent Variable: LN_VA_PRC_PRIVATE				**Dependent Variable: LN_VA_QNTY_PRIVATE**			
LN_EMPL_PRIVATE	-0.001904	0.083039	0.9818	LN_EMPL_PRIVATE	0.955453	0.092040	0.0000
LN_FA_PRIVATE(-1)	0.532467	0.065257	0.0000	LN_FA_PRIVATE(-1)	-0.187937	0.047719	0.0003
LN_BR_INDIND(-1)	**0.007772**	**0.010101**	**0.4457**	**LN_BR_INDIND(-1)**	**-0.008769**	**0.013672**	**0.5246**
LN_AR_INDIND(-1)	**-0.012588**	**0.014235**	**0.3814**	**LN_AR_INDIND(-1)**	**-0.004161**	**0.018682**	**0.8248**
LN_DE_INDIND(-1)	**0.044979**	**0.025316**	**0.0825**	**LN_DE_INDIND(-1)**	**-0.046935**	**0.031436**	**0.1426**
C	-329.4250	424148.7	0.9994	C	6.415562	9.508939	0.5034
AR(1)	0.999978	0.028363	0.0000	AR(1)	0.996814	0.002666	0.0000
MA(1)	0.413387	0.150568	0.0087	MA(1)	-0.236768	0.160060	0.1462
Dependent Variable: LN_VA_PRC_PROFESSIONAL				**Dependent Variable: LN_VA_QNTY_PROFESSIONAL**			
LN_EMPL_PROFESSIONAL	0.035245	0.120307	0.7709	LN_EMPL_PROFESSIONAL	0.740341	0.122508	0.0000
LN_FA_PROFESSIONAL(-1)	0.248729	0.079413	0.0031	LN_FA_PROFESSIONAL(-1)	-0.096622	0.089575	0.2866
LN_BR_INDIND(-1)	**0.003264**	**0.017015**	**0.8488**	**LN_BR_INDIND(-1)**	**0.015236**	**0.023412**	**0.5186**
LN_AR_INDIND(-1)	**-0.012130**	**0.022801**	**0.5974**	**LN_AR_INDIND(-1)**	**0.022652**	**0.031998**	**0.4827**
LN_DE_INDIND(-1)	**0.030042**	**0.041823**	**0.4764**	**LN_DE_INDIND(-1)**	**0.027597**	**0.060568**	**0.6509**
C	3.413166	1.835651	0.0697	C	1756.099	2237383.	0.9994
AR(1)	0.982362	0.012006	0.0000	AR(1)	0.999989	0.014223	0.0000
MA(1)	0.583680	0.134642	0.0001	MA(1)	0.142644	0.171372	0.4097
Dependent Variable: LN_VA_PRC_REALEST				**Dependent Variable: LN_VA_QNTY_REALEST**			
LN_EMPL_REALEST	0.160868	0.082878	0.0587	LN_EMPL_REALEST	0.175072	0.067555	0.0128
LN_FA_REALEST(-1)	0.362108	0.059925	0.0000	LN_FA_REALEST(-1)	0.008100	0.061132	0.8952

LN_BR_INDIND(-1)	**0.012021**	**0.014387**	**0.4079**	**LN_BR_INDIND(-1)**	**-0.019512**	**0.013543**	**0.1566**
LN_AR_INDIND(-1)	**0.013480**	**0.020185**	**0.5077**	**LN_AR_INDIND(-1)**	**0.008199**	**0.018700**	**0.6631**
LN_DE_INDIND(-1)	**0.103980**	**0.032230**	**0.0024**	**LN_DE_INDIND(-1)**	**-0.007622**	**0.032269**	**0.8143**
C	-1.486521	0.495418	0.0044	C	4.347538	1.226297	0.0009
AR(1)	0.918118	0.044068	0.0000	AR(1)	0.978844	0.005367	0.0000
MA(1)	0.434467	0.142683	0.0039				
Dependent Variable: LN_VA_PRC_RETAIL				**Dependent Variable: LN_VA_QNTY_RETAIL**			
LN_EMPL_RETAIL	-0.113851	0.163955	0.4910	LN_EMPL_RETAIL	0.966269	0.211980	0.0000
LN_FA_RETAIL(-1)	0.630399	0.094964	0.0000	LN_FA_RETAIL(-1)	-0.393880	0.119906	0.0020
LN_BR_INDIND(-1)	**0.031844**	**0.024516**	**0.2006**	**LN_BR_INDIND(-1)**	**-0.012771**	**0.028354**	**0.6546**
LN_AR_INDIND(-1)	**-0.022202**	**0.031815**	**0.4889**	**LN_AR_INDIND(-1)**	**-0.005161**	**0.038039**	**0.8927**
LN_DE_INDIND(-1)	**-0.001510**	**0.057949**	**0.9793**	**LN_DE_INDIND(-1)**	**0.060780**	**0.069598**	**0.3871**
C	2.450089	1.366979	0.0798	C	-6.074065	1.462786	0.0001
AR(1)	1.049971	0.028465	0.0000	AR(1)	1.017838	0.009227	0.0000
Dependent Variable: LN_VA_PRC_UTILITIES				**Dependent Variable: LN_VA_QNTY_UTILITIES**			
LN_EMPL_UTILITIES	0.383091	0.372369	0.3091	LN_EMPL_UTILITIES	-0.255326	0.383086	0.5085
LN_FA_UTILITIES(-1)	0.779685	0.201405	0.0003	LN_FA_UTILITIES(-1)	-0.177525	0.164134	0.2852
LN_BR_INDIND(-1)	**0.038121**	**0.048537**	**0.4363**	**LN_BR_INDIND(-1)**	**-0.026043**	**0.044456**	**0.5609**
LN_AR_INDIND(-1)	**0.019696**	**0.068464**	**0.7749**	**LN_AR_INDIND(-1)**	**-0.038466**	**0.062190**	**0.5393**
LN_DE_INDIND(-1)	**0.086582**	**0.114619**	**0.4540**	**LN_DE_INDIND(-1)**	**-0.073549**	**0.108147**	**0.4999**
C	-4.866927	2.644771	0.0723	C	10.31217	2.545169	0.0002
AR(1)	0.953315	0.028542	0.0000	AR(1)	0.976052	0.008724	0.0000
Dependent Variable: LN_VA_PRC_WHOLESALE				**Dependent Variable: LN_VA_QNTY_WHOLESALE**			
LN_EMPL_WHOLESALE	0.163950	0.268137	0.5441	LN_EMPL_WHOLESALE	1.256963	0.332602	0.0005
LN_FA_WHOLESALE(-1)	0.399916	0.110606	0.0008	LN_FA_WHOLESALE(-1)	-0.528838	0.102246	0.0000
LN_BR_INDIND(-1)	**-0.015510**	**0.031240**	**0.6220**	**LN_BR_INDIND(-1)**	**-0.046017**	**0.040540**	**0.2622**
LN_AR_INDIND(-1)	**-0.030249**	**0.046534**	**0.5190**	**LN_AR_INDIND(-1)**	**0.105615**	**0.066888**	**0.1212**
LN_DE_INDIND(-1)	**-0.121981**	**0.076446**	**0.1177**	**LN_DE_INDIND(-1)**	**0.730905**	**0.074442**	**0.0000**
C	2.781498	2.252565	0.2235	C	-12.46071	2.707817	0.0000
AR(1)	0.819671	0.101739	0.0000	MA(1)	0.587099	0.137483	0.0001
MA(1)	0.326710	0.172848	0.0653				

Again if the estimated aggregate effects of employment and fixed assets are “far away” from 1.0 and 0.5, respectively, or “far away” from the previously estimated values, the estimated aggregate effects of the given variable tend to be insignificant. It might be the case that the estimated coefficients of variables in the regressions are “far away” from the previously estimated aggregate effects of these variables. Important is that the aggregate effects of variables shall be around the previously estimated values.
General remark is that in most of the sector price indices are elastic to fixed assets and quantity indices are elastic to employment and sometimes to fixed assets.

In the “low” sector (containing ACCOMM, ADMIN, MANAGEMENT, RETAIL and TRANSP(excluded)) only ADMIN has significant and plausible estimates for all types of regressors: employment (0.65), fixed assets (0.49) and total R&D expenditures (18%). These coefficients are almost the same as in the previous table. AR and DE turned out to be significant in this sector and they influence both the sectoral price and quantity indices. In other sectors R&D turned out to be insignificant – MANAGEMENT at 9% significance level R&D is significant and takes ca. 8.5% that is ca. 3% lower than previously. In sector ACCOMM the (aggregate) coefficients on labor (1.138) and capital input (0.59) seem to be plausible because they are close to the estimated values in the previous table. Furthermore they are plausible because the price (cost) of an “accommodational” service depend largely on the quality and quantity of kitchen (with foods), accommodation (e.g. hotel with more or less rooms) etc. and

quality is assumed positively related with prices. It means higher quality "costs" more money and hence higher quality of "accommodational" services costs more. Quantity of "accommodational" services shall be interpreted as the number of services offered (provided) to customers. Since the quantity of offered services depend/is determined by primarily by people, the estimated coefficient seems to be plausible. The quality of employment is not estimated in these regressions but in others and it has an impact on the price (cost, quality) of "accommodational" services on aggregate level. In sector MANAGEMENT the estimated coefficients on employment (1.07) and capital (0.49) are also not "far away" from the previous estimates (1.24 and 0.38, respectively), so they are plausible. In RETAIL the estimated labor (0.966) and capital (0.27) elasticities are a bit "far away" from the previous ones (about 0.82 and 0.43, respectively). Hence these estimates seem to be less plausible than the previous ones.
In the "high" sector (containing CONSTRUCTION, MANUFACTURING, PROFESSIONAL, REALEST, UTILITIES, WHOLESALE and OTHERSERV, EDUSERV) MANUFACTURING, PROFESSIONAL and UTILITIES turned out to be inelastic to R&D expenditures. In sector MANUFACTURING the estimated coefficients on employment (1.019) and fixed assets (0.35-0.54 – depends on the choice of significance level) seem to be plausible. I want remark here that the previously estimated coefficients on employment (0.61), capital (0.37) and R&D (0.33) in this sector suggest taking capital effect on value added as significant and plausible. The allocation of effects between employment and R&D seem to be plausible based on the previous estimates in this sector. Hence the last estimation result in this sector shows that the variable regressor "includes" the effects of R&D, i.e. the relevant R&D expenditures improve the effects of labor (efficiency) on sectoral produced quantity and value added. Negative effects of fixed assets on quantity can be seen as a simple technical result without any economic consequences or it refers to higher-than-required potential capacity of this sector. The latter means that reducing the overall capacity of this sector may improve the value added because of the expected lower (fixed) costs of fixed assets.
In case of PROFESSIONAL the estimated coefficients on employment (0.74) and capital (0.248) are about 0.23-0.25 lower than the sectoral estimates in the previous table (0.99 and 0.37, respectively). Based on the previous estimations these (last) estimates seem to a bit low and hence they tend to be implausible.
In sector UTILITIES the only variable that is significant is the fixed assets. Its effect on sectoral price index is about 0.78 that is close to the previous estimates 0.738. This result tends to be plausible based on the last two tables of estimations.
Sector CONSTRUCTION exhibits plausible results based on the all estimation results. Employment (0.85), capital (0.36) and R&D (0.20) elasticity are close to the previously estimated ones (0.82, 0.80 and 0.42, 0.36, and 0.20, 0.23 at 5% significance level, respectively). The only significant DE R&D expenditures affect only the price index.
The value added of REALEST has almost the same elasticity to labor (0.33) and capital (0.36) input as previously (0.41/0.379 and 0.358/0.385, respectively). However the estimated (DE) R&D elasticity (0.10) is much lower here than before (0.29/0.30) and it affects only the sectoral price index based on the last estimation. I take the previous two estimation results in this sector as plausible because in this sector (taking the 5% significance level) employment elasticity becomes 0.17 that is much lower than before.
EDUSERV's value added has the following elasticities: labor (1.19), capital (0.46) and R&D (5-10%, depends on the choice of significance level). Compared to the previous ones (1.08/(insignificant) for labor, 0.278/0.437 for capital and 0.28/0.35 for DE R&D and U&C R&D, respectively) the coefficients on labor and capital tend to plausible but R&D elasticity (BR and DE) is less plausible.
In sector OTHERSERV the estimated employment (0.54) and fixed assets (0.248) elasticities are much lower than in the previous table (0.98 and 0.61, respectively). R&D effects at 5%

significance level are about 17.3% that is close to the previous estimated R&D elasticity (18.6% at 5% significance level). Taking higher or lower significance level the aggregate R&D effect in this sector is about 8-9%. DE affects only the price index, BR and AR affects only the quantity index of this sector – if the significance level is appropriately defined.

As a short conclusion for the "low" and "high" sector one can state that DE seems to be the most significant R&D variable that affects the sectoral value added and sectoral price indices. Furthermore CONSTRUCTION and OTHERSERV "remained" highly elastic sectors w.r.t. R&D expenditures and ADMIN become also a highly elastic sector. The other sectors are inelastic or less elastic w.r.t. R&D. However these estimation results show only the R&D effects that are observable by these data and estimation methods.

In the other sectors (containing AGRIC, ARTS, FINANCE, HEALTHCARE, INFO, MINING and WHOLESALE) all sectors are more or less elastic to R&D. In sector AGRIC the only variable that seems to be plausible is the employment. Its aggregate effect is about 1.1 that is close to 1.0 and hence it seems to be plausible. The high sectoral R&D elasticity (0.36) of quantity is less plausible based on previous estimates but more plausible if one considers that machines-related-DE expenditures may improve the productivity of this sector through new (more efficient) agriculture-related-machines (e.g. tractor). However fixed assets as regressor is insignificant.

In sector ARTS the coefficient on employment (1.1) seems to plausible based on previous estimates (1.3 and 1.2). Fixed assets (0.179) affect only the sectoral price index. This suggests that the quantity of ARTS's products cannot be easily increased by supporting more capital to the sector. The main driver is hence the human capital in this sector. BR (0.21) influences the quantity – can be interpreted as new designs (findings) give enlightenment for the employees of this sector that improves their productivity. DE has about 13.6% impact on the sectoral price index. The aggregate R&D effect is about 34% that seems to be high compared to the previous one (0.234). Plausible estimates in this sector seem to be the labor and capital elasticities but not the R&D elasticities.

The value added of FINANCE has a 0.80 elasticity to employment and 0.429 to fixed assets that seem to be plausible. A 0.089 BR R&D elasticity is also acceptable with the following interpretation: new designs may increase the profits of firms and hence the profits of financial enterprises – new investments may require new credit. This not necessarily direct (i.e. indirect) effect of BR R&D may then affect the sectoral value added.

The estimated coefficients on labor and capital input in HEALTHCARE and INFO are too low, therefore they seem to be implausible. However, the estimated (DE) R&D elasticities (0.148 in HEALTHCARE and 0.136 in INFO) are significant and seem to be plausible because they affect the sectoral price indices – i.e. the use of new (more efficient) products may improve the level of service quality and by assumption it causes the increase of prices.

MINING exhibits plausible labor (1.29) and capital (0.549) elasticities given an appropriate significance level (>6%). The estimated R&D elasticity (23%) is for me a bit high. The significant DE R&D affects however the sectoral quantity index suggesting the following interpretation: using more efficient machines may increase the sectoral productivity and hence the value added.

WHOLESALE exhibits also significant and plausible estimation results regarding the employment elasticity (1.2 – close to 1.0) but not the fixed assets (-0.13 – too low) and R&D elasticities (0.73 – too high). However, based on previous regression results all of these coefficients tend to be implausible.

As a conclusion for the last group of sectors the labor and capital input elasticities are on average more significant and plausible than the estimated R&D elasticities. Similarly to the other sectors, these sectors are rather elastic to DE R&D.

In the total Private sector the estimated coefficients on labor (0.95) and capital (0.53) input are plausible based on previous estimates. However the estimated R&D elasticity (0.044 at high significance level) seems to be insignificant and implausible based on previous estimates.

Finally one can state based on these estimation results that DE R&D expenditures might be the most important and significant source from total R&D expenditures and for economic performance. DE may increase the quality of aggregate production process and products and hence the aggregate price level. This result seems to be plausible because DE R&D has the largest relative weight compared to BR and AR R&D.

2.5. Effects of economic performance on R&D expenditures:

The endogenous growth model presumes the endogeneity of technological progress and labor efficiency. This idea implies the endogeneity of the determination of R&D expenditures. It means the economic environment and performance determines the amount of R&D investments. Thus in the following I analyze whether this statement is true of false in the US economy.

I analyzed in the first step the link between the periods with higher-than-average growth rate of the economy and higher-than-average growth rate of R&D expenditures. The calculation method is the following: I calculated the average growth rate of each sector and of R&D expenditures in the sample and then I constructed dummies (1 for periods with higher-than-average growth rate, 0 for other periods). The table showed that the growth rate of R&D expenditures was usually higher-than-average in and 2-3 periods after the years with higher-than-average growth rate of the economy. This suggests the significance of the guessed link between R&D expenditures and economic growth.

As a next step I regressed the industrial and federal R&D expenditures on lagged industrial and federal R&D expenditures and aggregate economic performance. I have chosen these regressors because I expect based on the previous passage that economic performance affects the R&D expenditures and past R&D expenditures also determine the current stock of capital spent on R&D activities. (I corrected with AR(1) term for technical problems)
The following table shows the regression results:

Dependent Variable: LN_RD_IND				**Dependent Variable: LN_RD_FED**			
Variable	Coefficient	Std. Error	Prob.	Variable	Coefficient	Std. Error	Prob.
LN_RD_IND(-1)	**0.558281**	**0.217549**	**0.0135**	**LN_RD_FED(-1)**	**0.420536**	**0.143258**	**0.0051**
LN_VA_GDP(-1)	**0.435498**	**0.215768**	**0.0492**	**LN_VA_GDP_2(-1)**	**0.388804**	**0.089449**	**0.0001**
C	-1.614985	0.859613	0.0664	C	2.211796	0.764698	0.0057
AR(1)	0.542808	0.241601	0.0293	AR(1)	0.843656	0.068018	0.0000

These results show that in both cases current R&D expenditures are elastic to past R&D expenditures (0.558; 0.42) and economic performance (0.435; 0.388). Industrial R&D expenditures are a bit more elastic to the economic performance than federal R&D. It is not surprising because industrial R&D expenditures are primarily financed from industrial sources and secondarily from federal sources and the aggregate economic performance is primarily determined by industrial production. Hence federal R&D expenditures that are solely financed from federal sources (activities) are less sensitive to aggregate economic performance – federal activities accounts for ca. 10-15% of the US GDP.

Elasticity of current R&D expenditures to previous R&D expenditures may have the following interpretation: consider the R&D expenditures as an economic measure of R&D activities. It means if R&D activities are more intensive and successful, it costs more and the economic measure becomes higher. Consequently if R&D activities become more intensive and successful, there must be an incentive to exploit this potential of such activities, hence they must be financed with additional money. As a result R&D expenditures become higher. In the other way around if R&D activities are less intensive and successful, there is an incentive to withdraw capital from such activities and finance other, more successful projects.

Consequently technological progress and labor efficiency is partly determined by past economic performance as expected.

Conclusions

In the theoretical part I presented briefly the evolution of growth models including the exogenous and endogenous models. I used in the first step the idea of endogenous growth theory, i.e. technological progress is (can be) endogenously determined, influenced in order to make the presentation of R&D expenditures plausible in the regression models. Otherwise, i.e. in case of exogenous technological progress, the plausibility of R&D expenditures as determinants of economic growth seem to be inacceptable because exogeneity means there is no (external) effect, determinant that would influence the technological progress. In the next step I separated the quantitative and qualitative characteristics of products and production processes from each other as well as the state of technology and labor efficiency from each other. This idea had the following intuitions: in my opinion the growth models generally emphasizes the quantitative growth, characteristics of production factors and the importance (role) of qualitative characteristics are not explicitly expressed in growth models. Furthermore the values (as economic measures of qualities and quantities of products, production processes, etc.) do not make directly observable the qualitative and quantitative characteristics of aggregate economic performance. It is important because economic growth happens also if the quality of products increases but their quantity not, by assumption. Furthermore one can then analyze whether the quality or quantity of given production factors have more or less impact on the qualitative or quantitative growth of the economy. However, an additional transformation of the data (value) is required for such separation of characteristics – Fisher price and quantity indices.

The separation of state of technology and labor efficiency is an important idea because using this idea one can interpret or explain why in several empirical studies the exogenous growth model "performs" better than endogenous one. There are countries, firms that "buy" or obtain the technological progress by buying licenses, copy or steal new designs (knowledge) from other companies and countries. Consequently they take technology as exogenous but they have significant and important role in the distribution of new technologies. Hence knowledge or technology diffusion, distribution is endogenously determined by the economic infrastructure for knowledge distribution.

Consequently the success of R&D expenditures depends on the quality of researchers and on the quality of national and international knowledge distribution possibilities. These ideas serve as a presentation of how R&D expenditures may exert impact on economic performance.

In the empirical part I analyzed the (short-run) relationship between the US economy and US R&D expenditures between 1953 and 2006. I used yearly nominal data (transformed by taking the natural logarithm) and Fisher indices in order to separate the quantitative and qualitative characteristics of aggregate products, production processes. Consequently the estimated coefficients show an elasticity of value added with respect to the given regressor. So I analyzed the R&D effects in 4 steps. In the first step I wanted to know which variables are the most significant and plausible determinants of (yearly) sectoral value added in the sample. The first table showed that EMPL, FIXED ASSETS and industrial RD expenditures turned out to be the most significant ones. Federal R&D and U&C R&D seemed to be insignificant determinants of economic performance in the short run. The estimated R&D effect on value added was about 15% that is plausible based on other studies on this topic. In the second step I analyzed how the industrial and U&C R&D affects the sectoral value added. Based on these estimation results 3 groups of US economic sectors can be built concerning the level of sectoral R&D elasticities. First of all I want to mention here that about 1.0 estimated coefficient on employment and about 0.5 on fixed assets turned out to be the general case in most of the sectors – little (sectoral) deviations from these values are possible and plausible. Concerning the R&D

elasticity in this table, the “low” sector (containing ACCOMM, ADMIN, MANAGEMENT, RETAIL and TRANSPORTATION) exhibits less than 17% effect of R&D on value added. The “high” sector (containing CONSTRUCTION, MANUFACTURING, PROFESSIONAL, REALEST and UTILITIES) exhibits more than 0.30 R&D elasticity. In other sectors R&D elasticity turned out to be insignificant. In the third group of estimations EDUSERV and OTHERSERV turned out to be highly elastic with respect to R&D expenditures (>18-20%). In the “low” sector varies the estimated R&D effects between 11% and 19%, in the “high” sector between 19% and 38%. ACCOMM and TRANSP show low elasticity or inelasticity to R&D expenditures. Finally I analyzed how the sectoral price and quantity indices are affected by the given regressors. The regression results state that sectoral quantity indices are primarily affected by employment and sectoral price indices primarily by fixed assets. Furthermore DE R&D turned out to be the most significant and plausible R&D type that primarily influences the sectoral price index. The estimated R&D elasticities confirm more or less the previously estimated R&D effects but in some cases it is lower than before or insignificant – ADMIN, CONSTRUCTION and OTHERSERV have about 0.18-0.20 elasticity with respect to R&D. In other sectors the estimated R&D effect is lower or insignificant or implausible.
On the aggregate Private level the following estimates seem to be plausible: 0.99-1.05 on employment, 0.51-0.53 on fixed assets and 0.12-0.15 on industrial R&D.
As a last step I analyzed whether past economic performance and past efficiency of researchers affect the current R&D spending. The estimation results show that this relationship between the variables is significant.

Finally I want to mention that the regression models I presented and used in the empirical part have the similar form like the CBO’s model. It implies that my models and estimation results are (or might be) exposed to the disadvantages of models like the CBO model – detailed in section 2.1. For instance some of the significant variables in the estimation results might have no impact on value added in reality.
Furthermore the short run relationship between R&D expenditures and value added can be criticized because R&D projects take usually more periods of time. For instance in the car industry the firms introduce in about every 5 or 6 or more years new models of given type. Only the testing of new products before the introduction on the market takes plenty of time. However, if the estimation results and the estimated coefficients are significant the interpretation of estimation results shall be modified according to this idea: it means the estimated coefficients on R&D do not show only how the R&D expenditures influence the value added through (realization of) new designs but additionally they show how R&D expenditures influence the value added through budgeting. It means higher R&D expenditures give incentives to improve the profits in order to be able to finance R&D projects and other projects of firms. It might be independent of the success of R&D projects and products.
Consequently R&D expenditures might affect economic performance differently in the short run and in the long run. In the long run R&D (might) have impact on economic productivity (primarily) through new designs (R&D products); in the short run budgeting effects and temporary demand effects of R&D expenditures might prevail according to the above explained idea.

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Annex

Zusammenfassung und Schlussfolgerungen der Diplomarbeit

Meine Diplomarbeit besteht aus zwei großen Teilen: einem theoretischen und einem empirischen Teil. Der theoretische Teil beschäftigt sich mit verschiedenen Wachstumsmodellen und deren Entwicklung im Laufe der Zeit. Ich habe mich für das endogene Wachstumsmodell entschieden als Grundlage für mein Wachstumsmodells. Endogenität des technologischen Fortschrittes spielt wichtige Rolle in dieser Arbeit, weil ansonst die F&E (Forschung und Entwicklung) Ausgaben theoretisch irrelevant erscheinen würden. In einem endogenen Wachstumsmodell können die F&E Ausgaben sowohl die Anzahl der neuen Erfindungen („invention“) und Neuerungen („innovation“) erhöhen und als auch die Produktivität der Wirtschaft steigern. In meinem Modell ($A^K K A^L L$) spielt die Trennung des technologischen Fortschritts von der Steigerung der wirtschaftlichen Produktivität wichtige Rolle neben der Trennung der qualitativen Eigenschaften von den quantitativen. Die Intuition hinter diesen Trennungen sind die Folgenden: das technologische Niveau einer Wirtschaft ist eine Liste aller Erfindungen und Neuerungen die jemals von Menschen „erzeugt“ wurde; d.h. alle Elemente dieser Liste ist verschieden. Wirtschaftliche Produktivität oder Effektivität („labor efficiency“) hängt jedoch von den verfügbaren neuen Produkten („new designs“) an den Wirtschaftsakteuren ab. Demzufolge können F&E Ausgaben die Wirtschaftsleistung beeinflussen wenn der F&E Projekt erfolgreich war (d.h. es hat zum neuen Produkt geführt) und die F&E Produkten erfolgreich in der Wirtschaft realisiert werden konnten (d.h. jeder relevanter Wirtschaftsakteur verfügt über die relevanten neuen Produkte). Infolgedessen beeinflussen unterschiedliche Faktoren diese Prozesse. Laut Annahme beeinflussen externe Effekte (wie z.B. F&E Ausgaben) den technologischen Fortschritt aber die Produktivität der Wirtschaft hängt in erster Linie von der Struktur der Wirtschaft (d.h. von der Qualität und Quantität der Produktionsfaktoren und von der Qualität der Organisierung von Produktionsprozessen) ab. Wegen dieser Idee betone ich in meinem Modell die Qualität von Produktionsfaktoren neben deren Quantität.
Leider sind die qualitativen Merkmale von Produktionsfaktoren und Produktionsprozessen auf nationaler und sektoraler Ebene nicht direkt beobachtbar. Ich setze daher voraus, dass die Preise auf qualitative Merkmale der Produktionsfaktoren hinweisen. Daher benutze ich nominelle Daten und Fisher Preis und Ideal Mengenindizes in der Analysis.
In dem empirischen Teil habe ich analysiert welche Typen der US-F&E Ausgaben beeinflussen signifikant auf kurze Sicht die Wirtschaftsleistung der Vereinigten Staaten (US). Es hat sich herausgestellt, dass staatliche und akademische F&E Ausgaben keine oder sehr geringe Effekten auf die sektorale Wirtschaftsleistung ausüben. Die Regressionsresultate zeigen, dass die industriellen F&E Ausgaben, insbesondere die Entwicklungs-bezogene industrielle F&E Ausgaben die größten Wirkungen auf die sektorale Wertschöpfung ausüben. Anhand der Graphiken und der angeführten Studien sind die Resultate erwartet. Die geschätzte Elastizität der sektoralen und nationalen Wertschöpfung in Bezug auf F&E Ausgaben schwankt um ca. 0.15. Das bedeutet: ein 1% Steigung in relevanten F&E Ausgaben induzieren eine 0.15% Steigung der Wertschöpfung. Eine weitere Konsequenz ist, dass die Mehrheit der Sektoren der US-Wirtschaft elastisch auf F&E Ausgaben ist.
In dem letzten Punkt der empirischen Analysis habe ich festgestellt, dass die aktuelle F&E Ausgaben von der vergangenen Wirtschaftleistung (Wertschöpfung) abhängig sind.

Schließlich möchte ich bemerken, dass die Regressionsresultate verschiedenen Problemen ausgesetzt sein können. Im Punkt 2.1. habe ich diese Probleme detailliert. Sie können zum

Beispiel verursachen, dass die signifikanten Variablen in der Tat keine Wirkung auf die US-Wirtschaftleistung ausüben.
Außerdem kann es kritisiert werden, dass F&E Ausgaben kurzfristig durch F&E Produkte die Wirtschaftsleistung beeinflussen. Im Allgemeinen dauern F&E Projekte mehrere Jahre, deshalb üben die aktuellen F&E Ausgaben ihre Effekten auf die Wirtschaftleistung erst in einer späteren Periode der Zeit aus. Kurzfristig beeinflussen F&E Ausgaben die Wertschöpfung eher durch die Budgetierung (von Firmen und der Staat) und durch temporäre Nachfrageneffekte. Daher zeigen die geschätzten Koeffizienten auch temporäre, nicht-F&E-Produkt-bezogene Effekte der F&E Ausgaben auf die Wirtschaftsleistung.
Folglich kann man schließen, dass F&E Ausgaben die Wirtschaftleistung in Abhängigkeit des Zeitraumes unterschiedlich beeinflussen. Langfristig setzen sich eher die Effekte der F&E Produkte durch und kurzfristig eher die temporäre Nachfrageffekte und Budgetierung-Effekte.

Curriculum Vitae (short version)

I was born in Hungary and absolved there the school leaving examination. Since October 2004 I have studied Economics at the University of Vienna. In the centre of my scientific interests are economic theory (particularly macroeconomics, financial markets and contract theory), applied economics, econometrics and finance. According to my interests I have chosen my courses during studies. At present I am taking doctorate courses in Economics at the University of Vienna.

Lebenslauf (gekürzte Version)

Ich bin in Ungarn geboren und habe dort maturiert. Seit Oktober 2004 studiere ich Volkswirtschaft an der Universität Wien. Im Zentrum meines wissenschaftlichen Interesses liegen die ökonomische Theorie (insbesondere Makroökonomie, Finanzmärkte und Kontrakttheorie), angewandte Ökonomie, Ökonometrie und Finanzwirtschaft. Dementsprechend habe ich die zu absolvierenden Kurse ausgewählt. Derzeit mache ich Doktoratskurse aus dem PhD-Studium der Volkswirtschaftslehre an der Universität Wien.