Studie im Auftrag des Staatsschuldenausschuss

Long-run growth implications of government expenditures in Austria

Martin Zagler

Executive Summary

This project investigates the impact of four distinct public expenditure categories, education spending, research and development expenditures, public infrastructure investment, and investment subsidies on the long-run growth performance of the Austrian economy. After surveying the relevant theoretical and empirical literature, this study develops a rigid theoretical framework for the analysis. We find that government infrastructure and education should exhibit a direct impact on economic growth, whereas investment and innovation subsidies should foster growth indirectly through their impact on the innovation rate. We then discuss the data adopted for the empirical investigation, and point to potential data problems. We estimate the long-run relationship between economic growth and various government expenditure categories using co-integration analysis. We obtain a point estimator for the impact on the economic growth rate of a one percentage point increase in infrastructure investment of 0.32. We find a cumulated effect on the growth of a one percent annual increase in education expenditures of 0.25 over ten years and 0.63 over 25 years. A one percentage point increase in the share of public research and development expenditures increases output by 0.57 percent over the next ten years and 1.43 percent over the next 25 years, whereas a one percentage point increase in investment subsidies would only lead to a cumulated effect of 0.01 and 0.03 respectively. These results have to be treated with care for several reasons. First, the numbers indicated above are only point estimates, with range estimators given in the study. Second, it requires different fiscal costs to bring about a one percentage point increase in different expenditure categories. And finally, these figures have been obtained ignoring potentially distortionary effects when funding public expenditures.

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Introduction

Fiscal policy is predominantly viewed as a short run issue. By stimulating or dampening aggregate demand, various policy instruments, such as government expenditures, taxes, or public debt, are mainly designed to mitigate cyclical fluctuations in output and employment. The success of fiscal policy should therefore be evaluated by its ability to move the economy closer to potential output. Apart from its impact on the short run economic performance, fiscal policy is expected to affect the long run growth performance of an economy. This study investigates the long-run growth implications of fiscal policy. Whilst the ambition is to measure the long-run growth effects of various fiscal policy instruments, these results in no way pre-conclude normative policy suggestions.

In this study, we will focus on four particular expenditure categories, namely education spending, research and development expenditures, public infrastructure investment, and investment subsidies, which have received widespread attention in the theoretical literature and encouraging empirical evidence in several OECD countries. It is certainly one shortcoming of the proceeding study not to investigate the growth implications on the revenue side. From a theoretical perspective, we find a number of novel contributions focusing on the growth impact of taxation and government deficits. From an empirical perspective, our estimates of the impact of public expenditures on economic growth will ignore the potentially adverse effects caused through various forms of financing.

This study proceeds as follows. After surveying the relevant theoretical and empirical literature, we develop a rigid theoretical framework for the analysis. It is our belief that we cannot measure without profound theory. In particular, the inclusion or not of certain variables, the proper order of integration, and the correct formulation of the estimation equation(s) can best be derived from theoretical modelling, to be verified empirically thereafter. The study continues to discuss the data adopted for the empirical investigation, and points to potential data problems. We estimate the long-run relationship between economic growth and various government expenditure categories using co-integration analysis. The last section will then be devoted to discussing the implications of the results.

Literature Review[1]

The conventional wisdom suggests that there is no impact of fiscal policy on the long-run performance of an economy, or that fiscal policy is neutral. After all, Robert Solow (1956) has postulated that the long-run per capita growth rate of an economy is driven by increases in total factor productivity alone. Given that neither taxes nor expenditures can influence changes in total factor productivity, fiscal policy is neutral in the long-run according to the Solow-model.

This view has been challenged in recent years, and in the following this discussion will be summarized. On the expenditure side several fiscal policy instruments are known to exhibit long run growth effects. Since the stock of human capital acts as a key parameter in determining the growth rate of an economy, all public activities, which lead to an increase in the accumulation of knowledge and encourage an individual's education effort, also raise the growth rate. In his seminal paper Robert Lucas (1988) argues that investment into education increases the level of human capital. This expands the resource

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[1] This section draws heavily on Zagler and Dürnecker (2003).

base of the economy, and thus output. If the returns to education do not decline over time due to non-decreasing returns to scale in reproducible factors of production, education expenditure can be seen as the main source of long-run economic growth. Given credit market imperfections and human capital externalities, private agents have only partial incentives, and not enough means, to finance their own education. For these reasons, publicly provided education can reduce or eliminate the externalities in the human capital accumulation process. Thus any changes in the public provision of educational services, induced by a short-run change in fiscal policy, will alter the process of human capital accumulation and thus long-run economic growth. Even in the absence of credit market imperfections there is room for public education policy, if education is subject to congestion (Keuschnigg and Fisher, 2002)

Robert Barro (1990) has argued that infrastructure, which is non-rival and non-excludable in consumption and thus exhibits the character of a public good, can give rise to non-decreasing returns to scale with respect to reproducible factors of production. An increasing stream of government expenditure can thus induce long-run economic growth, thereby expanding the tax base of the economy, and thus permitting the required growth in public infrastructure expenditure.

Philippe Aghion and Peter Howitt (1992) have developed a theory of innovation-driven economic growth. As existing ideas, or knowledge in the economy, facilitate new innovations without a cost, there is an intrinsic externality involved in the growth process, hence any fiscal policy which allocates funds to the research and development process will exhibit a positive impact on economic growth.

Other examples for the influence of government expenditure on economic growth are investment subsidies (Romer, 1986), and health expenditures (Bloom et al., 2001).

On the revenue side, taxes are known to distort private agents´ decision making with respect to factor accumulation and supply. Insofar as distortionary taxes interfere in the private decision to save and invest, they may very well change the accumulation process of capital, and thus alter the growth rate of the economy (Milesi-Feretti and Roubini, 1998). Given that endogenous growth models intrinsically contain externalities, either in the accumulation of physical or human capital or in the innovation process, distortionary taxation can internalize the effect of the externality in private decision rules, and thus induce the efficient allocation (Turnovsky, 1996, and Fisher and Turnovsky, 1998).

Due to the focus of this study on the impact of some specific public expenditure categories on long run growth, we focus our introductive literature survey especially on the growth implications of public expenditure on infrastructure, research and development, education and private investment. However it should be mentioned that a comprehensive investigation of the impact of fiscal policy on long term growth can and should not ignore the manifold effects of distortive taxation and public debt. In a simultaneous investigation of the growth implications of taxes and expenditure it quickly becomes evident that the growth promoting effects of productive public spending can possibly be diminished by growth reducing effects by distortionary taxation.

Since its revival in the late 1980s, growth theory has produced a mass of theoretical and empirical literature which attempts to investigate the impact of public - and especially fiscal policy - on the long run growth rate of output. Notable theoretical contributions have been provided e.g. by Barro (1990), King and Rebelo (1990) and Turnovsky (1996). The major finding of this literature is that in general all kinds of taxes are expected to hamper growth due to their distortionary character. On the expenditure side, the effects of government spending are twofold, depending on the purpose they are used for. Investment into public infrastructure, education and research and development are in general considered to be productive. In contrast, many other expenditure categories, including government consumption, are assumed to be unproductive and therefore growth reducing. Recent articles which attempt to provide a comprehensive review of the recent literature on public policy and long run growth have been published e.g. by Agell et al. (1997), Tanzi and Zee (1997) and Zagler and Dürnecker (2003).

These theories have so far been tested, however unsatisfactory. Early work for the US dates back to Barro (1991) and Easterly and Rebelo (1993), who found a negative relation between growth and public consumption expenditure, no effect of public investment expenditure on economic growth, and a positive effect of education expenditures on economic growth. Contradictory evidence is from Levine and Renelt (1992), who found no robust correlation between fiscal indicators and economic growth. The issue remains heavily disputed in the literature, and is summarized by Slemrod (1995), who concludes that the current understanding of the link between real government activity and economic growth is far from satisfactory. Both Barro (1991) and Levine and Renelt (1992) and most of the subsequent literature are based on the Summers and Heston dataset, and typically only use cross-country regression, which is problematic, as we do not know whether different fiscal policy regimes are the result of inefficient policymaking or different national preferences. Some authors do estimate national time series, but apparently no study has yet been conducted for Austria. A profound empirical study, analysing the growth effects of a reduction in public expenditure in OECD countries, has been published by Heitger (1998). He does not present convincing evidence in either direction. It has to be mentioned at this stage that the relation between growth and taxation has received similar attention in the literature (cf. Engen and Skinner, 1996), but to follow this discussion is beyond the scope of this paper.

In order to examine the effects of government expenditure policy on long term economic growth, it is useful to disaggregate the total volume of expenditure into several categories and analyse them separately. A widely used approach has been to divide it into government consumption and investment. The former is in general considered to hamper and the latter to foster economic growth. It seems obvious that this classification is no longer sufficient, since certain categories of government consumption expenditures are expected to support growth, such as education and health expenditures. In contrast, not well targeted investment projects could create distortions which result in a welfare loss for the economy. Following Devarajan et al. (1996), we divide public expenditure into productive (or growth-enhancing) and unproductive (or purely consumptive) expenditure.

A central aim of government spending in order to raise the growth rate is to improve the marginal productivity of the private sector's physical capital and labour. Accordingly public expenditure would typically include the provision of a basic social and economic infrastructure. Aschauer (2000) discusses in detail the impact of public capital on economic growth. Physical infrastructure (roads and railways) and communication as well as information systems (phone, internet) are typical examples for publicly provided goods, which enter, in a productivity enhancing way, directly into the private production function (Feehan and Matsumoto, 2002). Although investment in this sort of infrastructure might not be profitable from a single firm's point of view (as private costs exceed private returns), the whole economy would nevertheless benefit enormously, which justifies public provision. Odedokun (1997) finds evidence for 48 developing countries that public infrastructure investment facilitates private investment and promotes growth. Using a pooled cross-section time series analysis, Andrews and Swanson (1995) investigate the effects of public capital on the marginal productivity of private capital for 48 US states. They find that the impact is small but positive. In line with these results Harmatuck (1996) estimates the elasticity of output with respect to public capital in the United States to be about 0.03. This is much less than Aschauer (1989) and Lau and Sin (1997) find in their works. Aschauer states that the stock of the core infrastructure such as streets, highways and airports has the largest explanatory power for productivity growth with an output elasticity of 0.39. There is widespread belief that, if government expenditure replaces private output beyond mitigating certain market failures, any additional spending is expected to reduce at least the level of output, if not economic growth (Morales 2001).

Beyond its influence on allocation decision of individuals, public spending affects the labour productivity mainly through two fairly obvious channels, knowledge accumulation and health care. Both in the case of education and health care the market allocation leads to sub-optimal solutions. This is mainly due to the occurrence of market imperfections such as externalities and non-excludability.

Due to the existence of imperfect credit markets (which may raise difficulties for individuals to borrow in order to finance education) and asymmetric information, individuals are often not able to acquire basic as well as advanced education. But since the average stock of human capital plays a decisive role in determining the long run growth rate of an economy, a reduced access to education is likely to have a negative growth implication. Publicly provided education through public schools and universities therefore ensures a continuous human capital accumulation process. In their work, Bils and Klenow (2000) find a positive correlation between schooling and economic growth. Barham et al. (1995) show that imperfect capital markets force individuals to borrow from their parents to finance schooling. But if parents´ savings are insufficient, a sub-optimal level of education is likely to exist. Early empirical works by Moonmaw and Williams (1991) show that apart from government spending on infrastructure, also expenditure on education is an important variable in explaining cross country differences in total factor productivity levels and growth rates. Hansson and Henrekson (1994) support this view in their analysis of several government activities in a sample of 14 OECD countries. While government transfers and consumption expenditures show significant negative effects, government spending on education is expected to promote private productivity growth. Temple (2000) surveys the recent empirical literature on the growth effects of education focusing mainly on OECD countries. Evans and Karras (1994) investigate the productivity of several government activities including educational services. They find evidence that educational expenditure is the only expenditure category which can be classified as productive. In a recent literature survey of 31 papers Glomm and Ravikumar (1997) identify two channels through which productive government expenditures affect the long run growth rate. Either through the above mentioned infrastructure spending or educational expenditure.

Public health expenditures may also have a large impact on long run growth. Similar to the effect of education on labour efficiency units, public spending can also affect the volume of labour supplied through its impact on the state of health. Expenditures on the health care system (which are not simply replacing private expenditures, but increasing the total amount of "the good health" consumed by individuals) are expected to reduce illness and absenteeism leading to an increase in the quantity of labour. Good health also affects the quality of labour, and tends to increase workers ability to acquire new knowledge and skills. Bloom et al. (2001) took up this idea in their study, and they found that health has a positive and statistically significant effect on economic growth. They claim that a one year improvement in population life expectancy leads to a 4 percent increase in output. In contrast Singh and Weber (1997) examine the effects of health care and educational expenditures on long run growth in Switzerland. Whilst they find a positive impact of spending on education on long run growth, they obtain a negative impact for health expenditures. Presumably, health expenditures do matter for developing economies, whereas additional health expenditures fall into the category of "luxury consumption" in advanced economies, and therefore exhibit little impact in economies such as Austria, which is why we have not been included it in our analysis.

Apart from one strand of endogenous growth literature, which identifies the accumulation of human capital as main engine of economic growth, as mentioned above, a second strand emphasises the continuous increasing variety of products caused by research and development activities. Starting with early works by Romer (1990), who finds that the growth rate of an economy crucially depends on the innovation activities[2], a vast literature

[2] This in turn depends on the fraction of labour employed in the R&D sector.

has recently emerged emphasising the importance of a well functioning R&D sector. An R&D sector is well functioning, if the externalities, which arise due to the non-excludability of generated ideas in a pure market allocation and result in an underproduction in the R&D sector, get internalized. Hence, any policy which ensures that economic actors are able to capture the full benefits of their research and development activities is expected to increase the growth rate of innovation and hence may stimulate output growth.

Although this fact has been heavily investigated, the existing literature is divided concerning the impact of public expenditures on R&D. Works of Romer (1990), Segerstrom et al. (1990) and Grossman and Helpman (1991) emphasise the importance of R&D subsidies in order to promote long run growth. Aghion and Howitt (1992) follow the Schumpeterian approach and employ a model of creative destruction, where they also find that subsidies have an unambiguously positive effect on output growth. In an interesting analysis, Frenkel and Trauth (1996) set up a research-driven growth model which is closely related to the Romer model, and examine the growth effects of different types of public subsidies, which aim at neutralising the occurring distortions. They find that growth effects depend predominately on the design of the subsidies, which yields different policy possibilities to achieve the optimal growth rate.

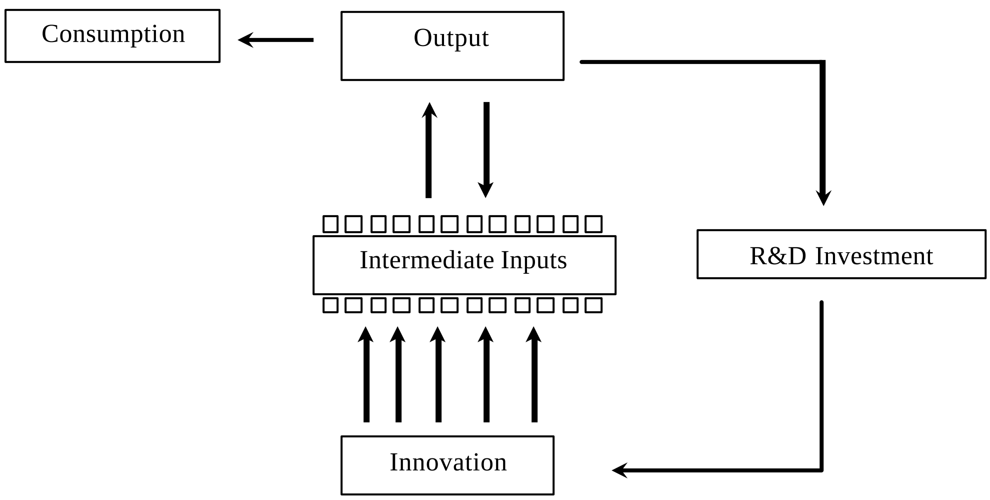
In contrast to this view, Jones (1995) argues that the scale effects of research and development, which are assumed to be the main engine of growth in the above cited models, are not consistent with empirical findings. He investigates a modified version of the Romer model, and finds that R&D expenditures only affect the relative size of the R&D sector, but have no consequences for long run growth, which is entirely determined by the population growth rate. However, Howitt (1999), who takes into account the non scale effects in R&D mentioned by Jones, rejects the assumption that R&D expenditures have no long run growth impact. Morales (2001) examines the effects of different types of research policies on economic growth. She finds that while basic research, performed at public institutions has positive effects, applied public research (which could also be done by private firms) has negative growth effects.

The model

This section presents a simple model of innovation driven endogenous growth. Several public expenditure categories will be included in order to investigate the impact of fiscal policy on the growth rate of the economy. This approach includes subsidies, which are modelled as negative taxes.

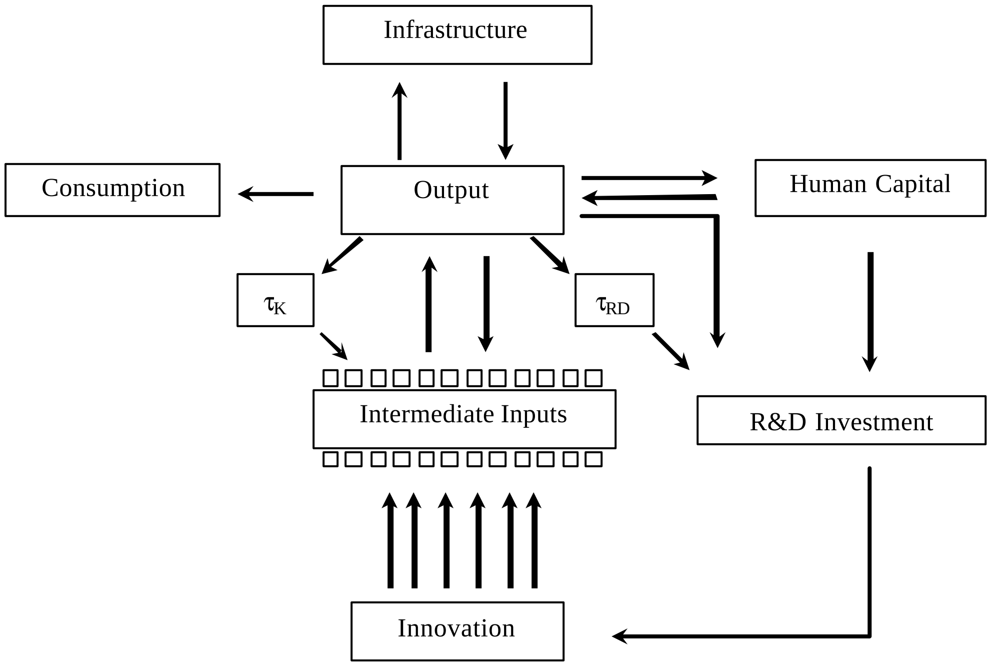
Figures 1 and 2 summarize the structure of the model economy. In figure 1, we show the economy without government. Output Y is used for consumption purposes, to build intermediate inputs, and to finance investment in R&D. Novel innovations add to the stock of innovations in the economy. Intermediate input producers (of which there are many) use an existing innovation and one unit of the output good to produce intermediate inputs (not unlike investment in the one product textbook economic model). These intermediate inputs are then used to assemble final output Y.

Figure 1: The structure of the economy without government



If we now add a public sector to the picture, as we do in figure 2, we must make several modifications. First, government uses final output to produce public infrastructure, which in turn enters as an input in the final output producing firm. Second, government uses final goods to finance education expenditures, which enter the production of final output, too. Third, education improves the quality of the workforce in the R&D sector as well, thereby fostering the rate of innovation. Fourth, government taxes output and subsidizes R&D activities, which directly foster innovation. Government also subsidizes investment, which will increase the demand for intermediate inputs, thereby creating an incentive to introduce new products, and thus indirectly encourage innovation or the adaptation of foreign innovations. This model structure will be laid out in detail below.

Figure 2: The structure of the economy with government



We can look at this model more formally, which we will do in the following. The stylized model economy comprises a competitive sector for final goods Y_t. These are produced using human capital H_t, composed of average human capital per worker h_t and labour L_t, specialized intermediate input goods $x_{i,t}$, which closely resemble physical capital, and publicly provided infrastructure G_t, according to the following Cobb-Douglas technology,

$$Y_t = G_t^{\beta} H_t^{1-\alpha} \int_0^n x_{i,t}^{\alpha} di \,. \tag{1}$$

This specification comprises the Solow model (1956) as a special case with $\int x_{i,t}di = K_t$ and $\beta = 0$, the Barro model (1990) with $\int x_{i,t}di = K_t$ and $\alpha + \beta = 1$, and the Lucas model (1988) with $\alpha = \beta = 0$. The inclusion of public infrastructure in the private production function has important implications for private sector productivity. The competitive firm minimises costs of production, C_t, subject to technology as indicated in equation (1), where costs are defined as,

$$C_t = w_t L_t + \int_0^n (1-\tau_K) p_{i,t} x_{i,t} di \,, \tag{2}$$

where w_t denotes the net wage. The purchase of intermediate input goods $x_{i,t}$ is subsidized with the investment subsidy rate τ_K on the net price $p_{i,t}$ of each individual intermediate input good.

A perfectly competitive final good manufacturer sets marginal costs equal to marginal revenues, where we normalize the gross price of output to unity and charge a revenue tax τ_Y on output (not unlike a value added tax) in order to finance all kinds of government expenditure programs, yielding the following first order conditions,

$$\frac{\partial Y_t}{\partial x_{i,t}} = \alpha(1-\tau_Y) G_t^{\beta} H_t^{1-\alpha} x_{i,t}^{\alpha-1} = (1-\tau_K) p_{i,t} \,, \tag{3}$$

$$\frac{\partial Y_t}{\partial L_t} = (1-\alpha)(1-\tau_Y) G_t^{\beta} h_t^{1-\alpha} L_t^{-\alpha} \int_0^n x_{i,t}^{\alpha} di = (1-\alpha)(1-\tau_Y) \frac{Y_t}{L_t} = w_t \,. \tag{4}$$

The first first-order-condition (3) states that the marginal product of each specialised input must equal the price for that particular input, taking the investment subsidy into account. This condition gives the demand function for intermediate inputs. The second first-order-condition (4) is the familiar condition that the marginal product of labour (which is equal to 1 - α times the average product of labour in the Cobb-Douglas case) must equal the wage. Rearranging both first order conditions, and adding both sides, we find that revenues equal expenditure on both factors, $(1 - \tau_Y)Y_t = C_t$, or that profits are zero for the competitive final good producer.

From the first-order conditions (3) and (4), we note that an increase in public infrastructure expenditure G_t will ceteris paribus raise the demand for every particular input $x_{i,t}$, and the demand for labour L_t, as an increase in government spending directly raises marginal productivity of private input factors. This encourages private factor accumulation and hence may induce output growth. Any public good, which is in a similar fashion capable of interfering with private allocation decisions, falls into this category of a productive public investment good (Aschauer, 1989). Although investment in public infrastructure might not be profitable from a single firm's point of view (as private costs exceed private returns), the whole economy would nevertheless benefit enormously, which justifies public provision. However, if government expenditure replaces private output beyond mitigating certain market failures, any additional spending is expected to reduce at least the level of output, if not economic growth (Morales 2001). The optimal level of government infrastructure provision is given when the marginal product of public infrastructure equals marginal costs,

$$\frac{\partial Y_t}{\partial G_t} = \beta(1-\tau_Y)G_t^{\beta-1}H_t^{1-\alpha}\int_0^n x_{i,t}^{\alpha}\,di = \beta(1-\tau_Y)Y_t/G_t = \Gamma'(G), \tag{5}$$

where Γ(G) is the cost function for the provision of public infrastructure investment. Any public infrastructure beyond that point could crowd out private investment, and thus indeed reduce the level of output.

Similarly, an increase in the provision of human capital would also augment the marginal product of labour and, more surprisingly, capital. Human capital accumulation is the consequence of private and public investment into education. Whilst we do consider private investment into education as exogenous (and treat it as residual), we assume that public expenditures on education per capita, b_t, lead to an increase in the level of average human capital h_t, according to,

$$\dot{h}_t = b_t - \delta h_t, \tag{6}$$

where δ is the depreciation rate of human capital, which would be lower in the case of an increase in private investment into human capital.

Each intermediate input is provided by a single monopoly supplier, who produces one unit of a specific intermediate input i, using one unit of the final good and her (private) knowledge on how to transform the final good into an intermediate good i. The normalisation that one unit of the output good produces one unit of the input good is similar to the conventional concept that an output good can be used both as a consumption and an investment good in a single good economy. Intermediate input providers maximise profits,

$$\pi_{i,t} = p_{i,t}x_{i,t} - x_{i,t}, \tag{7}$$

subject to the demand function for a particular input (3), resulting in a conventional mark-up pricing equation,

$$p_{i,t} = 1/\alpha. \tag{8}$$

Note that the net price of intermediate inputs does not depend on the investment subsidy. It is therefore not the sellers of intermediate inputs, but the buyers, who benefit. As it takes one unit of the final good at price one to produce one unit of the intermediate input, but intermediate input providers charge a price above unity (given that α is less than unity), we find that they charge a price above marginal costs. Combining equations (7) and (8) we find that profits of the intermediate input providers therefore equal,

$$\pi_{i,t} = \frac{1-\alpha}{\alpha} x_{i,t} . \tag{9}$$

Physical capital in this economy consists of the total amount of existing specialized input goods $x_{i,t}$. As all prices for intermediate inputs are identical due to the mark-up equation (8), all quantities of intermediate inputs will be identical as well, according to the demand function (3). We can therefore define the aggregate capital stock[3] as

$$K_t = \int_0^n x_{i,t} di = n_t x_t , \tag{10}$$

where n is the number of currently available differentiated intermediate inputs, and x_t is the average quantity of intermediate inputs. Substituting for the intermediate inputs in technology (1) yields,

$$Y_t = G_t^{\beta} (n_t h_t L_t)^{1-\alpha} K_t^{\alpha} . \tag{11}$$

This is a transformed production function in five arguments, the physical capital stock, government infrastructure expenditures, the average level of human capital per worker, the manufacturing sector labour force, and the number of available intermediate inputs. We can interpret the number of intermediate inputs as the level of technology. The output elasticity of the number of intermediate inputs n is identical to the output elasticity of labour, hence we can think of technology as labour-augmenting, in line with empirical evidence (Kaldor, 1961). The capital stock can at most be equal to output, as one unit of the final good produces one unit of the intermediate composite capital good, which would leave nothing for consumption. From the first order condition with respect to the intermediate input (3) and our definition of the aggregate capital stock (10), we find that the capital stock in the economy equals,

[3] Note that physical capital fully depreciates in this stylized model. This assumption is not critical in equilibrium, whereas it does unrealistically alter adjustment paths.

$$K_t = \frac{1-\tau_Y}{1-\tau_K}\alpha^2 Y_t. \quad (12)$$

Substituting the capital stock (12) and the equation of motion for education (6) into the transformed production function (11), and taking time derivatives, we find that the growth rate of the economy is given by

$$\hat{Y}_t = \frac{b}{1-a}\hat{G}_t + \hat{h}_t + \hat{L}_t + \hat{n}_t = \frac{b}{1-a}\hat{G}_t + \frac{b_t}{h_t} - d + \hat{L}_t + \hat{n}_t, \quad (13)$$

where chapeaus (^) denote growth rates. We have assumed that the investment subsidy and the revenue tax do not change over time. This implies that output growth is driven by an increase in the manufacturing sector labour force L_t, the growth rate of average human capital (which in turn is driven by human capital depreciation and schooling), the growth rate of public infrastructure spending, and the growth rate of available intermediate inputs.

This equation has several important implications. First, the literature on fiscal policy and economic growth has so far ignored the growth impact of innovations, which has only been discussed in theoretical work (Romer, 1990, Grossman and Helpman, 1991, and Aghion and Howitt, 1992). Looking at the first part only, we observe that taxation has only an indirect effect on economic growth, by financing the required level of government infrastructure and education. Early works (Barro, 1990) assume a proportional tax on output, thus implying that the growth rate of public infrastructure is identical to the growth of output. Solving for output using this rule, we find that output growth is less than population growth by a factor $(1 - \alpha)/(1 - \alpha - \beta)$, implying that per capita output will grow less than population by a factor $\beta/(1 - \alpha - \beta)$. As population grows, a larger number of manufacturing workers use a given public infrastructure. As the output elasticity of public infrastructure β declines, the growth rate of output approaches the growth rate of population. Public infrastructure is therefore subject to full congestion. Models with partial congestions have been discussed by Turnovsky (1996), Fisher and Turnovsky (1998), and Glomm and Ravikumar (1994). However, if and only if the output elasticity of public infrastructure β equals $1 - \alpha$, we have non-decreasing returns with respect to reproducible factors of production (1), and cannot solve for the above equation (13), but obtain long-run economic growth, as postulated by Barro (1990).

The second part of the above equation states that an increase in the share of per capita education expenditures as a fraction of human capital per worker has a positive and permant impact on long-run economic growth, which is in line with theoretical arguments of Lucas (1988) and empirical findings (e.g. Bils and Klenow, 2000).

In an open economy, a change in the number of available intermediate inputs can occur either because of a genuine domestic innovation, or by introducing foreign innovations to the domestic market. In the case of an innovation, someone invests time and effort into research and development activities. In accordance with the literature (Rivera-Batiz and Romer, 1991, or Todo and Miyamoto, 2002), we assume that it requires domestic resources to introduce foreign innovations to domestic markets as well, as foreign products need adaptation, marketing, and distribution. From now on, we will consider both genuine R&D and adaptation as a research activity. As the cost for an innovation usually has to be paid up front, whilst the revenues will only follow thereafter, both genuine R&D and the adaptation of foreign innovations in this economy have an investive character, and require funds to finance their projects. We use the old fashioned approach that agents save a constant proportion s of their disposable income Y^D, and that R&D firms use these funds to finance projects,

$$sY_t^D = (1-\tau_{RD})w_t E_t \,, \tag{14}$$

where the only cost in research and development is employment cost, given by $w_t E_t$ and a subsidy τ_{RD} for R&D expenditures is disbursed. We refrain from modelling the consumption-saving trade-off using intertemporal optimisation, as we are interested in growth and not welfare implications of fiscal policy. And, as Robert Solow (1994) has argued, we “see no redeeming social value in using this construction […]. It adds little or nothing to the story anyway, while encumbering it with unnecessary implausibilities and complexities.”

The R&D sector is perfectly competitive, so there are no dividends, and workers receive all revenues. Disposable income in the economy is then defined as income from employment in manufacturing, $w_t L_t$, income from employment in research and development, $w_t E_t$, and profit income from intermediate input providers, $\pi_{i,t}$,

$$Y_t^D = w_t L_t + w_t E_t + \int_0^n \pi_{i,t} di \,. \tag{16}$$

The labour market is assumed to be in equilibrium, where total labour supply N_t will equal labour demand from manufacturing, L_t, and labour demand from research and development, E_t. Given savings decisions modelled in (15), we find that R&D employment is proportional to total employment according to,

$$E_t = \frac{\alpha s + s(1-\tau_K)}{\alpha s + (1-\tau_{RD})(1-\tau_K)} N_t \,. \tag{16}$$

As employment in research and development is proportional to the total labour force, both grow at the same rate. Evidently, an increase in the saving rate fosters R&D employment, as does an increase in the share of intermediate inputs α, if the R&D subsidy is not too large. An increase in the R&D subsidy fosters R&D employment, as it allocates more funding to the R&D sector. An increase in the investment subsidy also increases R&D employment, as in this case quantity demanded in the intermediate input sector rises, thus creating revenues to finance research and development activities.

Innovation takes time, effort and knowledge. The latter is provided by the (public) education system, implying an arrival rate for new innovations according to

$$\dot{n}_t = \phi h_t E_t \,, \tag{17}$$

where ϕ is productivity in R&D and h_t again is the average level of human capital per worker. Dividing both sides by the number of available products n, and substituting the total labour force for R&D employment (16), we can solve for the innovation rate of the economy,

$$\hat{n}_t = \phi \frac{\alpha s + s(1-\tau_K)}{\alpha s + (1-\tau_{RD})(1-\tau_K)} \frac{h_t N_t}{n_t} \,. \tag{18}$$

The last term in the previous equation is the economy-wide level of human capital per innovation ($h_t N_t / n_t$). As the blueprints for intermediate inputs are the only marketable knowledge in this economy, this ratio postulates that the growth rate of the economy will increase (decline) if the growth in the level of human capital exceeds (falls short of) the growth rate of innovations. Note that output grows faster than the innovation rate (17) by $\beta/(1 - \alpha)$ times the growth rate of public infrastructure plus the growth rate of human capital. Thus, in a growing economy, we can ensure that the growth rate of human capital exceeds the growth rate of innovation even for constant tax rates. Alternatively, we can allow for the financing over other government activities, such as subsidies or public infrastructure investment.

We will estimate a log-linearized version of the innovation equation (18), which we obtain by first computing elasticities of equation (18) with respect to changes in the R&D subsidy and the innovation subsidy,

$$\varepsilon_{RD} = \frac{\partial \hat{n}_t}{\partial \tau_{RD}} \frac{\tau_{RD}}{\hat{n}_t} = \frac{(1-\tau_K)\tau_{RD}}{[\alpha s + (1-\tau_{RD})(1-\tau_K)][\alpha s + s(1-\tau_K)]},$$

and

$$\varepsilon_K = \frac{\partial \hat{n}_t}{\partial \tau_K} \frac{\tau_K}{\hat{n}_t} = \frac{\alpha s \tau_K (1-\tau_{RD} - s)}{[\alpha s + (1-\tau_{RD})(1-\tau_K)][\alpha s + s(1-\tau_K)]},$$

which are both strictly positive, leading to a log-linearized version of the innovation equation,

$$\hat{n}_t = \Omega + \varepsilon_{RD}\tau_{RD} + \varepsilon_K \tau_K \, . \qquad (18')$$

Government expenditures exhibit two channels through which they impact on the growth rate of the economy. First, they directly influence the growth rate through public infrastructure expenditures and education expenditures, as indicated by equation (13). Second, they indirectly influence the growth rate of the economy by altering the innovation rate, using innovation and investment subsidies, as indicated by equation (18'). Note that the tax on output Y_t has no direct effect on the growth rate of the economy, as it appears in neither of the two fundamental growth equations. It does, however, have an impact on the current level of output.

The model contains two fundamental equations, which explain the long-run growth implications of government expenditures, a growth equation (13) and an innovation equation (18'). In the following, we will test these two equations empirically using Austrian data.

The data

We will estimate the two equations (13 and 18) that explain long run economic growth as presented in the previous section using Austrian data. We will use data on government infrastructure expenditures, education expenditures and innovation to estimate the growth equation (13), and data on innovation and investment subsidies to estimate the innovation equation (18). The purpose of this section of the paper is therefore to describe the relevant data we have used in the estimation process. In doing so, we sort the data not only by source, observation period and similar characteristics, but we will also mention different kinds of data intrinsic problems that either come up in the data collection process or that may arise in the estimation procedure due to a possibly inadequate explanatory character of several data series.

The dependent series in our analysis is economic growth, measured as the growth rate of real GDP per capita. If we do expect specific policy instruments to exhibit a long term growth effect, we would best observe it in a change in the long-run GDP growth rate. For a valid and especially meaningful empirical analysis it is necessary to work with long and contiguous data series.

There is a theoretical and a technical problem using GDP data. The theoretical is that GDP data contain information on both the long-run trend of economic growth and the business cycle. On possibility to eliminate business cycle components is to either use potential GDP as the dependent series, or to apply a Hodrick-Prescott-Filter to the data, which in theory should also eliminate cyclical components from the data. We use a different methodology, by letting the data themselves reveal this information in the estimation methodology, to be described below.

The technical problem is the availability of GDP data. We have obtained the corresponding data for GDP from the European Commission for the period 1954 – 2003. This time series has the major advantage that it has already been adjusted for structural changes which occur due to changes in the underlying accounting methods. Especially in Austria the calculation procedure for the GDP has changed three times in the past decades. The European System of National Accounts (ESA) was introduced in 1979, replacing the system of national accounts (SNA) which was used since 1968. This new method made international GDP more comparable due to the harmonised character of the calculation methods. The ESA 79 was then replaced in 1995 in favour of the ESA 95 which is in force till this day. The GDP data which we have received by the European Commission were in nominal units. For our purpose it was necessary to convert them into real terms using the GDP deflator which we have obtained from the Commission as well. We have chosen 1995 as our base year. The resulting real GDP was then divided by the total Austrian population in order to get it in per capita terms as desired. Note there is a difference between GDP per worker, Y_t/N_t, as modelled in the theoretical part of this study (13), and GDP per capita, as used in the empirical analysis. The difference arises when labour market participation changes over time. We have still chosen to use GDP per capita in the empirical analysis, as our focus remains to analyse the growth implications of government policy, which are typically measured in GDP per capita. The time series we have obtained after these calculations was highly correlated with a comparable series of the Austrian Institute of Economic Research (WIFO). Given the length of some of the independent series in the growth equation (13), we had to resort to GDP data for the time period of 1976 to 2000, giving us 25 observations. This time span coincides with the GDP series according to the ESA 95 classification, and therefore is free of structural breaks due to revisions in data definitions[4]. The model suggests to use GDP in growth rates, which we have obtained by taking logs and first differences of the GDP series in levels. The log of GDP is stationary in first differences. Table 1 summarizes the statistical properties of our data.

The first independent series in the growth equation (13) is government spending on public infrastructure or simply public investment. For completeness of our exposition we consider it as necessary to include not only pure public investment, but also spending on ongoing maintenance of existing public capital. Measuring public infrastructure is a problematic issue for several reasons. First, public infrastructure is provided both directly through the public sector and indirectly through public companies (e.g. railways, electricity or telephone lines). Second, public infrastructure is provided both by central government, but in a large extent also by local government. Therefore we had to rely on national accounting data to obtain a series for public infrastructure investment, which is available only since the ESA 79 classification for a time period from 1976 to date. In order to capture the impact of infrastructure investment by public companies, we use subsidies paid by government bodies to public companies as an approximation, as we assume that in order to finance infrastructure investment projects, these firms have to rely on funding. In this approach we ignore the fact that public companies have access to outside finance, but the subsidy series from the ESA 79 and ESA 95 respectively are the only data we had available. Data for public infrastructure investment were obtained from the Austrian Statistics Agency (ST.AT) for the period 1967 – 1999. Due to the fact that these data were also in nominal terms we had to convert them into a real series using the above mentioned

[4] We are well aware that this limited number of observations may generate problems when invoking large sample properties in the econometric analysis to follow, in particular when adopting time series methods. However, due to a lack of available data and limited funding, this was the best we could do.

GDP deflator. Data for subsidies to public firms were provided by the Staatsschuldenausschuss and was also deflated with the GDP deflator.

We use data for education expenditures per capita in order to approximate the impact of public schooling on the change of human capital (6). The intention is that since publicly provided or funded education accounts for a large share of total education, as it is the case in Austria, it can be seen as a reliable measure for the total supply of education. Education expenditures according to our analysis comprise all kinds of spending towards different types of schools including the salaries paid to teachers. We have received the adequate data for this variable from ST.AT for the period 1957 – 1999. Note that the data preclude expenditure towards universities, which leads to an insufficient illustration of the volume of public education expenditure.

Table 1: Summary statistics for the growth equation

	GDP (in Euro per capita)	Infrastructure (in Mio. Euro)	Education (in Euro per capita)
In levels	17,919.18 (3195.095)	11,051.65 (973.237)	843.6292 (191.121)
In growth rates (logs and first differences)	0.023 (0.017)	0.009 (0.045)	0.0413 (0.066)

Comments: Numbers correspond to the mean of the series, numbers in parenthesis are standard deviations.

A main feature of the theoretical model we have presented in the previous section is that the growth rate of the economy crucially depends on the arrival rate of new innovations. We have created a measure which adds up the total number of patents and trademarks which have been applied for, and the number of registered designs at the Austrian Patent Office, which should give a good proxy variable to measure the innovation rate as precise as possible. Given that both domestic and foreign innovators register at the Austrian Patent Office if they intend to make business in Austria, this should be a good measure for the number of innovations introduced in the Austrian market, whether by genuine domestic innovators or by importing foreign innovations. As more and more firms resort to the European Patent Office in Munich for registration, we tend to underestimate the rate of innovation. This problem has gotten more severe over the years. However, this does not include the registration of designs and trademarks, which have taken over as the primary means of innovation protection, given that e.g. computer software code cannot be patented, but registered.

Note that we do not take into consideration the number of patents which were actually registered, which is less than the number of patent applications. This is due to the intention that every research effort should be taken into account no matter if it leads to a new patent or not. We had to resort to the volume of registered designs, as the number of applications were not available for this case. We have collected data for the specific variables, mentioned above, from the annual statistical yearbooks published by ST.AT.

We have generated a cumulative time series, where we have used a 10 percent depreciation rate, to obtain an indicator of the existing stock of innovations in the Austrian economy. We have cover the period from 1976 to 2000, which we have already used for national accounting data.

The innovation rate was used as the endogenous or dependent series in the second key equation of our model (18). As the independent series in estimating the innovation rate, we have resorted to innovation subsidies and investment subsidies. The latter should capture public expenditures which flow towards private firms aiming at increasing the private investment activities. We have modelled this aspect as a subsidy to private investment. Any increase in the subsidy rate can be considered a reduction in total tax payments leading to an increase in the private marginal value product of investment (cf. equation 3), and will in turn stimulate private investment.

To quantify the tax burden of companies with respect to capital, several techniques are mentioned in the literature. These techniques can be structured in nominal tax rates, tax quotas and effective tax rates. Due to the fact that the first two categories are only crude measures of the tax burden and hardly used in empirical investigations, we do not give them any further consideration. Effective tax rates, however, are the standard tool for measuring the tax burden. They can be distinguished between ex-post and ex-ante tax rates, whereby the latter can further be divided into average and marginal tax rates. For the purpose of our analysis, we decided to take ex-post average effective tax rates. We have chosen these tax rates from an ECFIN paper published by Martinez-Mongay (2000, p. 75) for the period 1970 – 2001. These rates have the characteristics that they are calculated in per cent of gross operating surplus rather than net operating surplus – depreciation of private capital is therefore ignored - and they exclude the wage income of the self employed. As noted above, we can interpret any reduction in these tax rates as a subsidy to private capital.

The second independent series in the innovation equation (18) were R&D subsidies, which we have obtained from spending on science, research and development. In our model this kind of expenditure enters as a subsidy, and can broadly be interpreted as publicly provided basic research (performed e.g. by public universities) that both reduces private research costs and raises private marginal productivity. For our empirical analysis we have used data which we have received from ST.AT for the period 1967 – 1999. Alternatively we could have taken the data which have been published by the Austrian ministry of education, science and culture. The reason why we refrain from taking this time series is that it contains too few observations, which would lead to imprecise and invalid estimation results.

Table 2: Summary statistics for the innovation equation

	Innovation (Flow per annum)	R&D subsidy (in % of GDP)	Investment subsidy (in % of gross operating surplus)
In levels	14,400.14* (1118.068)	0.668 (0.065)	-17.205 (1.328
In growth rates (logs and first differences)	0.097* (0.008)	0.018 (0.050)	-0.004 (0.077)

Comments: Numbers correspond to the mean of the series, numbers in parenthesis are standard deviations. Note (*): The annual gross flow of patents, designs and trademarks is presented under "levels", whereas the net growth rate of innovation (using a 10% depreciation rate) is indicated under "growth rate".

We have refrained from including the average level of human capital in estimating equation (18) for three reasons. First, much of the human capital formation for the research and development sector would occur in universities, which have already been included in the share of R&D expenditures mentioned above. Second, time series for human capital are not readily available. The level of human capital predominately depends on the time individuals have spent on acquiring knowledge and skills. Due to the fact that appropriate data, which describe these activities, are hardly available, we decided to look for alternative measures that approximate the missing values as precisely as possible. In the existing empirical literature, we found three alternative methods to estimate the level of human capital. A widely used approach is to use the average years of schooling of the total or the working population (see for instance Barro and Lee, 1993, and Bassanini and Scarpetta, 2001). Although this technique is often used in the empirical literature, we refrain from adopting this approach as it is not applicable for our purposes. The treatment of primary, secondary and tertiary education as perfect substitutes implies that an additional year in primary school would exhibit the same growth impact as an additional year in tertiary school, which is problematic. And even if we would have data, the average level of human capital is bound to be high in research and development, so that we will get little variation in the data, which in turns makes estimation difficult.

An improvement of this technique would be made to differentiate various levels of education. In the spirit of this approach Koman and Marin (1999) augment the standard Solow model with human capital and test it for Austria and Germany. They construct figures for five levels of educational attainment beginning at compulsory education up to the university. However, they had to rely on data from the population census, which are available in five year intervals only. Missing data were entered using information of school completion. As a consequence the resulting data series was pieced together of a variety of sources which significantly increases the estimation error rate, and we therefore had to refrain from adopting it.

Methodology

The model presented in the theoretical section of this study clearly indicates the existence of a long-run relationship both in the growth equation (13) and the innovation equation (18). For convenience, we repeat these two equations here,

$$\hat{Y}_t = \frac{b}{1-a}\hat{G}_t + \hat{h}_t + \hat{L}_t + \hat{n}_t = \frac{b}{1-a}\hat{G}_t + \frac{b_t}{h_t} - d + \hat{L}_t + \hat{n}_t, \qquad (13)$$

and

$$\hat{n}_t = \Omega + \varepsilon_{RD}\tau_{RD} + \varepsilon_K \tau_K . \qquad (18')$$

We therefore have a clear economic model, which is empirically testable. The naïve approach would be to estimate the system using ordinary least squares. We refrain from this method, as we are interested in a long-run relationship between the respective series.

As these long-run relationships may and will be overshadowed by short-run relations, as explained in more detail around figure 3 below, we need to resort to co-integration techniques. Econometrically, a long-run relationship between time series should yield a co-integrating relationship. According to the definition, "The components of a vector x_t are co-integrated of order d, b, denoted $x_t \sim CI(d, b)$, if (i) all components of x_t are I(d); (ii) there exists a vector α ($\neq 0$) so that: $z_t = \alpha' x_t \sim I(d-b)$, $b > 0$. The vector α is called the co-integrating vector." (Engle and Granger, 1987). We therefore have to establish first the order of integration of our time series, before progressing to running a co-integration test. In principle we can test for the presence of co-integration, using the conventional Johansen Maximum Likelihood Test (Johansen, 1995). Before performing this test, we need to test for stationarity of the series and make an assumption on the number of lags to be included.

Therefore, our first methodological concern is stationarity of the time series presented above. We will now explore the order of integration, i.e. the minimal number of times a series has to be differenced until it is stationary. Assume that a time series y_t can be described by a simple autoregressive process,

$$y_t = C + r y_{t-1} + e_t, \qquad (19)$$

where C is a constant, r is the autocorrelation coefficient, and e_t is an error term. If r would be unity, then equation (19) would no longer be stationary, and any test on the properties of r would be biased. We can avoid the problem of non-stationarity simply by subtracting the lagged dependent variable from equation (19), resulting in,

$$y_t - y_{t-1} = C + (r - 1) y_{t-1} + e_t. \qquad (19')$$

Equation (19') presents the bases for a formal test of stationarity, the so-called Dickey-Fuller test (Dickey and Fuller, 1979), which tests the null hypothesis whether $r - 1 = 0$.

Agiakoglu and Newbold (1992) have noted that the size and power properties of the Dickey-Fuller tests change as different lags of the dependent variable or the error term enter the estimation of equation (19'). Without any prior knowledge from theory on the distribution of residuals, autocorrelation of the error term may be present in our estimation in the form of moving average terms. If some of the deep parameters of the model are related to past values of the dependent series, way may even observe autoregressive components in equation (19'). The literature therefore suggests to include further lagged values of the dependent series in the estimation, known as the Augmented Dickey-Fuller test (Said and Dickey, 1984).

This implies that we face a choice of the optimal number of lags to be included in the Augmented Dickey-Fuller test. As the inclusion of an additional lag increases the power of the test, but reduces the parsimonious use of additional regressors, we face a tradeoff, which enables us to select an optimal number of lags. Schwert (1989) proposes a rule based on the total number of observations, and suggests to use $(12T/100)^{1/4}$ lags, where T is the number of observations. Maddala and Kim (1998, p. 77f) suggest to weigh parsimony against power directly and suggest to minimize the following objective function,

$$\log \sigma^2(k) + k\frac{C}{T}, \tag{20}$$

where s^2 is the sum of square residuals in the estimation of equation (19') upon inclusion of k lags, and C is based on an information criterion, where the Akaike Information Criterion chooses $C = 2$, and the Schwarz Baysian Criterion would select $C = \sqrt{T}$. Table 3 presents Dickey-Fuller tests for our time series both in levels and first differences, with the critical values in parenthesis, and with the optimal lag length according to the above discussed criteria in square brackets. If the indicators have pointed to different lag lengths, we have chosen the lag length favoured by the majority of indicators. If this did not lead to a solution, we have used the shortest lag length suggested by any of the above criteria.

Table 3: (Augmented) Dickey-Fuller test for the growth equation

	GDP	Infrastructure	Education
In levels	-0.86 (-2.98) [1]	-2.97 (-2.98) [1]	-1.42 (-2.99) [3]
In first differences	-4.14 (-2.99) [1]	-4.82 (-2.99) [1]	-3.53 (-2.98) [1]

Comments: Numbers are the t-values of the Dickey-Fuller test with one lag. Numbers in parenthesis are the critical values for stationarity at the 5 % significance level. Numbers in square brackets are the optimal lag length according to the above discussed criteria.

Table 4: (Augmented) Dickey-Fuller test for the innovation equation

	Innovation	R&D subsidy	Investment subsidy
In levels	-2.43 (-2.98) [1]	-1.16* (-1.96) [3]	0.14* (-1.96) [1]
In first differences	-3.11 (-2.99) [1]	-2.21* (-1.96) [1]	-5.16* (-1.96) [1]

Comments: Numbers are the t-values of the Dickey-Fuller test with one lag. Numbers in parenthesis are the critical values for stationarity at the 5 % significance level. Numbers in square brackets are the optimal lag length according to the above discussed criteria. Note (*): due to the limited number of observations, we have dropped the constant in the ADF test for the R&D and investment subsidy.

We find that all series are stationary in first difference and therefore are integrated of order I(1), which ensures stationarity of the vector auto-regression. We estimate the model as presented in equations (13) and (18') in first differences. We therefore had to difference some series more than statistically necessary. However, using the correct order of integration according to the model makes economic sense, and overdifferencing is less a problem than running regressions with non-stationary time series, as this may give spurious results.

Before testing for co-integration, we need to make an assumption on the number of lags to be included. In principle, the number of lags to be included depends on the number of lags in the moving average processes of the error terms in our two fundamental equations. As theory gives no clear indication on the order of the MA process, we investigate the optimal number of lags empirically.

Maddala and Kim (1998, p. 164f) suggest to select the model with the lowest information criterion. The two most common information criteria are the Akaike Information Criterion and the Schwarz Baysian Criterion, which are both based on log-likelihood and penalize the inclusion of additional regressors.

Alternatively, the literature suggests the use of a likelihood ratio test. The test statistic is generated by dividing the likelihood of the restricted model by the likelihood of the more general model, where the later contains a larger number of lags. We then take logs and multiply by -2. The resulting test statistic is χ^2 distributed, with the degrees of freedom equal to the number of zero restrictions. For three variables and one lag, the total number of zero restrictions on coefficients in the estimation of the VAR system to reduce the general model to the restricted model is eight. Every additional lag and every additional variable doubles the number of zero restrictions. We would reject the restricted model for the more general model if the test statistic exceeds the critical value at the 5 % significance level, or if the p-value is above the 5 % critical value. Starting from a lag length of 4, we choose the number of lags at the level when we first reject the restricted model for the more general model. Table 5 below summarizes these results by presenting the optimal lag length in an unrestricted VAR for the growth and the innovation equation.

Table 5: Optimal Number of Lags in an unrestricted VAR for the growth equation and the innovation equation

	Growth equation (13)	Innovation equation (18)
Akaike Information Criterion	3	1
Schwarz Baysian Criterion	2	1
Likelihood Ratio Test Criterion	2	1

Comments: Numbers in parenthesis correspond to local minima.

For both equations, the Schwarz Baysian and the Likelihood Ratio Test Criterion agree on the optimal number of lags to be included in a VAR. The optimal number of lags is typically longer for the Akaike Information Criterion, as it penalizes additional regressors less then the Schwarz Baysian Criterion. We therefore conclude that we have to include 2 lags in the growth equation and one lag in the innovation equation.

This now brings us to test for a long-run relationship in our data according to equations (13) and (19), using co-integration analysis. Consider the first order dynamic system of two equations in two variables in vector representation, as given below,

$$\dot{x}_t = (\rho - 1)(1 \quad - a)'(1 \quad - b)x_{t-1} + A\dot{x}_{t-1} + u_t \,. \tag{21}$$

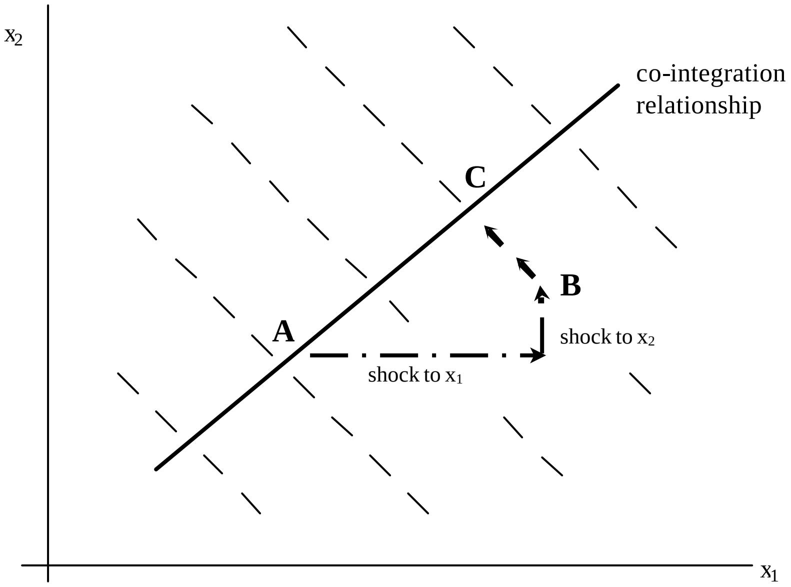
where x_t is a vector of time series, a and b are coefficients, A is coefficient matrices, and u_t is a vector of error terms.

If all time series are difference stationary as suggested by tables 3 and 4, all elements in equation (21) are stationary, with the exception of the first element on right hand side, the vector of the lagged dependent variable in levels, which is integrated of order one. One possibility for equation (21) to remain consistent would be that $\rho = 1$. Both series would then be integrated of order one, without any co-integrating relationship between them. The other possibility for equation (21) to remain consistent would be if the matrix $M = (\rho - 1)(1, -a)'(1, -b)$ is not of full rank. If ρ is different from unity, equation (19) is stationary, and hence so is $(1, -b)x_{t-1}$. The later, of course, is the co-integrating relationship, and (1, -b) is the co-integrating vector. This co-integration relationship would represent our long-run equilibrium depicted in equations (13) and (18), whereas the system in equation (21) would represent a short-run relationship between the variables.

We can think of the functioning of the dynamic system in the following manner: If we plot two variables x_1 and x_2 in a two-dimensional graph, shown in figure 3, we can draw the co-integrating vector as an e.g. upward sloping line, which represents the long-run equilibrium relationship between the two variables. If the system gets hit by a shock to either variable (and moves from point A to point B), it will slowly converge back to the equilibrium relationship (but not necessarily to the same point A) along an adjustment path, which is represented by the downward sloping arrows in figure 3 (where it moves from point B to point C). Evidently, we can expand the system to include more than two variables, as needed for the growth equation (13) or the innovation equation (18), but not graphically.

This picture also indicates why simple ordinary least square regression, as discussed in the introduction of this chapter, would fail. Given that our observations will lie on some convergence path (indicated by the arrows) most of the time, we would not observe a positive correlation, as indicated by co-integration, but more likely a negative correlation, as suggested by the adjustment path. Given that shocks will frequently shift the observations away from one to another adjustment path, the results will most likely be statistically insignificant, due to a high volatility in the data. And finally, as the past of an observation determines much of its present state, we should see a high degree of autocorrelation. All this is true with our data, and gives further prove for the existence of a co-integration relationship.

Figure 3: A graphical representation of the vector error correction method



In order to determine the rank of the matrix *M*, Johansen (1991) suggests a likelihood ratio test, which tests the restrictions implied by the reduced rank matrix against an unrestricted model, where the matrix *M* is assumed to be of full rank. The trace test for the number of co-integrating relations suggests to estimated the following likelihood ratio statistic for the hypothesis of rank zero, or equivalently no co-integrating relation,

$$LR_0 = -T[ln(1 - l_1) + ln(1 - l_2)], \qquad (22)$$

where l_1 is the smaller and l_2 is the larger eigenvalue of the matrix *M*, and *T* is the number of observations. Similarly, the likelihood ratio statistic for the hypothesis of rank one or equivalently a single co-integrating relation is equal to,

$$LR_1 = -T[ln(1 - l_1)]. \qquad (22')$$

To determine the number of co-integrating relations, we can proceed by sequentially comparing the likelihood ratio test statistic against the critical values as tabulated in Osterwald-Lenum (1992), until we fail to reject. We would assume the matrix to be of full rank if we reject all hypotheses. Table 6 summarizes the co-integration tests for both equations and the different lag lengths suggested by the VAR method (see tables 4 and 5).

Table 6: Johansen Co-integration Test

	Growth equation	Innovation equation
Hypothesis: Rank = 0 (No Co-integrating Relation)	59.93* (54.46)	49.15* (41.07)
Hypothesis: Rank = 1 (1 Co-integrating Relation)	**24.84** **(35.65)**	**21.80** **(24.60)**
Hypothesis: Rank = 2 (2 Co-integrating Relations)	8.74 (20.04)	1.69 (12.97)
Hypothesis: Rank = 3 (3 Co-integrating Relations)	0.74 (6.65)	

Comments: Numbers are the likelihood ratio test statistic as presented in equation (22) and (22') for the Johansen co-integration trace test. The benchmark (unrestricted) model is of full rank. * implies that we reject the hypothesis at the 1% significance level. Numbers in bold indicate the number of co-integration relationships.

We find that we can reject rank zero, or that all variables are integrated but that there is no co-integration in both equations. However, we find that we cannot reject rank one, or one co-integrating relation for each equation, but do reject more than one co-integrating relationship.

The results

The purpose of this study was to estimate the long-run growth implications of four distinct public expenditure categories, education spending, research and development expenditures, public infrastructure investment, and investment subsidies for the Austrian economy. After surveying the literature for guidelines to accomplish this task, we have been able to derive a theoretical framework to analyse these growth implications. In particular, we have been able to derive a growth equation, which presents a long run relationship between economic growth per capita, public infrastructure investment, education expenditures, and the innovation rate (13). Moreover, we have been able to obtain a long-run relationship between the innovation rate, R&D subsidies and capital investment subsidies.

After a strenuous search for applicable time series, and testing these data for stationarity, lag length and co-integration in the previous two sections, we are now able to present our findings. Equation (23) gives the empirical estimates for the co-integrating vector in the growth equation (13), with t-values in parenthesis,

$$\hat{Y}_t - \hat{N}_t = 0.185 + \underset{(5.49)}{0.323}\hat{G}_t + \underset{(2.66)}{0.025}b_t + \underset{(3.72)}{0.388}\hat{n}_t . \tag{23}$$

We find all parameters exhibit the correct sign according to the model that we have presented in a previous chapter, and all are statistically significant. We find that an increase in the long-run growth rate of public infrastructure investment by one percentage point fosters the rate of output growth by 0.323 percentage points. In the theoretical model, the coefficient was $\beta/(1 - \alpha)$. With a share of capital of one third, we obtain an output elasticity of public infrastructure investment of 0.215, which is slightly less than the value Aschauer (1989) has obtained for the US.

Given that we have used the log of public education expenditures in our estimation, we can conclude that a one percent increase in the level of education expenditures increases the long-run growth rate of the economy by 0.025 percentage points every period. In contrast to the simulated change of infrastructure indicated above, this effect builds up over time, so that we get a cumulated increase in the growth rate per capita of 0.250 percentage points over ten years and 0.625 over 25 years from a one percent increase in the level of education expenditures.

Finally, a one percentage point increase in the innovation rate leads to a 0.388 percentage point increase in the economic growth rate. We can in turn explain the innovation rate according to equation (18'), which yields the following empirical results[5],

$$\hat{n}_t = \underset{(2.58)}{0.056} + \underset{(3.71)}{0.147}\tau_{RD} + \underset{(2.31)}{0.004}\tau_K . \tag{24}$$

Once again, all coefficients exhibit the right sign according to the theory suggested previously, and are statistically significant. A one percentage point increase in R&D subsidies fosters the innovation rate by 0.147 percentage points, whereas a one percentage point reduction in the marginal effective tax rate on capital (which we have used as a proxy for the investment subsidy) only leads to a 0.004 percentage point increase in the innovation rate. Whilst we do not find direct effects of investment or innovation subsidies on economic growth, they do exhibit a positive indirect effect by promoting innovation.

[5] It should be mentioned at this point that we have included the real GDP per capita growth as an exogenous in the estimation in order to account for the fact that consumption smoothing may alter the savings rate and thereby change the adjustment paths. No change to the co-integration relation itself has been undertaken.

We have undertaken a series of robustness tests, such as changing the time horizon, using different definitions for our time series etc., but have both qualitatively and quantitatively received very similar results. It has to be clearly stated, however, that the above mentioned coefficients are point estimates. In order to give a fuller picture, table 7 below gives range estimators for the 90% significance interval, given in the third and fourth column.

We have computed the indirect effect of investment and innovation subsidies as the product of the coefficient in the innovation equation and the innovation coefficient in the growth equation, given in the second column. The range estimates were computed adding the variance on the coefficients in the innovation equation and on the innovation coefficient in the growth equation[6].

Table 7: Instantaneous policy impact on economic growth

	Coefficient	Lower bound	Upper bound
Infrastructure	0.323	0.265	0.382
Education	0.025	0.015	0.034
R&D subsidy	0.057	-0.054	0.169
Investment subsidy	0.001	-0.103	0.106

Comments: The coefficient is the direct, respectively indirect, effect of economic policy changes on economic growth. The upper and lower bound indicate the 90% confidence interval.

We find that the point estimates fare rather well for infrastructure and education, whereas the lower bound turns negative in the case of the two subsidies. The latter is not surprising, given that we did not measure a direct effect on economic growth in the first place. In comparing these four coefficients, we must also take care in interpreting them correctly. A permanent one percentage point increase in infrastructure expenditures is not the same as a one percent increase in the level of education expenditures, neither economically nor fiscally. Therefore the reader is advised to refrain from directly

[6] This is imprecise, as the variance of the product of two coefficients is the sum of variances minus the covariance between the two indicators.

comparing these estimates. Moreover, the instantaneous effect does not necessarily carry over to the long-run, as shown in table 8 below.

Table 8: Long-run policy impact on economic growth

	1 year	10 years	25 years
Infrastructure	0.323	0.323	0.323
Education	0.025	0.250	0.625
R&D subsidy	0.057	0.570	1.425
Investment subsidy	0.001	0.010	0.025

Comments: The coefficient is the direct, respectively indirect, effect of economic policy changes on economic growth after 1, 10 and 25 years respectively.

Whilst a permanent one percentage point increase in infrastructure investment leads to a permanent increase in the growth rate of 0.323 percentage points, a level shift in education expenditures exhibits little instantaneous response. However, the effect builds up and already contributes 0.250 to the growth rate in 10 years, and 0.625 to the growth rate in 25 years.

Even more dramatic, a one percentage point increase in the R&D subsidy (this corresponds to more than doubling public R&D expenses) would yield a higher growth rate of 0.57 already after 10 years. By contrast, a one percentage point increase in investment subsidies (or a one percentage point decline in the marginal effective capital tax) only contributes mediocre 0.025 percentage points to economic growth after 25 years, and is therefore economically insignificant.

These estimates have to be treated with care. First, the quality and length of the data available was not optimal, leading to potentially large measurement errors (Leamer, 1993). Second, it requires different fiscal costs to bring about a one percentage point increase in different expenditure categories. Third, these figures have been obtained ignoring potentially distortionary effects when funding public expenditures. A broader approach would certainly attempt to model growth implications of government revenues and then discuss different policy scenarios, where the financing aspects of public expenditures are explicitly included. Finally, these effects will only set in the long run. In the short run, they may be overshadowed from cyclical movements in the data and unforeseeable policy reactions on part of the economic actors. It has to be mentioned that the beneficial effects of growth promoting policies depend on individual economic actors to adopt their behaviour accordingly, which they will probably do in the long run (at some point higher R&D subsidies should lead to more research), but may refrain from implementing at short notice. We have therefore also refrained from modelling or estimating the short-run adjustment paths of the economy.

With these caveats in mind, the results nonetheless give encouraging evidence that public finance is capable of fostering the national rate of growth, even for a small open economy. Given that growth is always consumption forgone, there is a drawback to our findings, namely that distributional justice deteriorates at least intertemporally. And if the primary focus of economic policy is balancing the budget, which has to be achieved on the expenditures side (Brandner, Frisch and Hauth, 2001), economic policy may have the means, but not the willingness to promote domestic economic growth.

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