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Dynamic Effects and Structural Change under Environmental Regulation in a CGE Model with Endogenous Growth*

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Abstract:
In this paper, we use a CGE model with endogenous growth to study the interplay between environmental regulation, innovation and sectoral growth. We find that a stringent reduction target for carbon emissions combined with a CO_2-tax leads to structural changes. Under the assumption of a unilateral policy, the economy specializes in producing the energy-extensive good. Coupling the carbon tax with policies that aim at directly supporting sectoral capital accumulation significantly mitigates the negative impacts on competitiveness and growth. Finally, we identify two parameters that play an important role in applied energy policy analysis. First, the assumptions on the substitutability between fossil and non-fossil energy strongly affect the effectiveness of a given policy. When fossil and non-fossil energy are good substitutes, structural change in the economy is far less pronounced than under relative complementarity. Second, the rate of pure time preference has a pronounced impact on the investment incentives and thus on long-run development. Increasing the discount rate from 0.9% to 4.5% leads to a contraction in investments and to lower growth rates in all sectors.

JEL-Classification: C68, O31, O41, Q43
Keywords: Energy and Growth, CGE model, induced innovation, structural change

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1 Introduction

Despite the widespread consensus that the issue of climate change needs to be addressed with stringent and effective measures, environmental regulation is still frequently opposed, and the discussions on a follow-up agreement for the Kyoto-protocol are still ongoing. There are numerous reasons why it is a difficult task to reach an agreement on a global scale. Economic reasoning plays an important role in this discussion. A point often brought forward against environmental regulation and binding emissions constraints is that such policy intervention may negatively affect competitiveness and lead to undesirable structural effects in the sense that production and jobs are shifted abroad. This effect might be even stronger if the targets differ between countries. Higher constraints are then viewed as a comparative disadvantage that bring about negative economic effects, because they essentially make domestic production more expensive. This is a main concern of industrialized countries against stronger regulations as compared to developing countries.

Similar concerns are raised by certain industries when it comes to regulations at a country level. Fossil fuel and carbon intensive industries and related interest and lobbying groups usually oppose strict environmental regulations and emissions constraints, claiming that such regulations adversely affect their production costs and thus weaken their position on the market. In this respect, competitiveness may be affected both through lower profits (due to a decrease in sales) and through a decrease in output, leading again to a loss in employment and to a relocation of jobs and production.

This negative view is contradicted by the notion that environmental regulation is not necessarily harmful for the industries that are potentially most affected. It may even be beneficial and lead to a better outcome, not only on the level of the individual companies, but for the whole industry. Porter (1991) and Porter and van der Linde (1995) claim that the negative effects of policy measures aiming at reducing carbon emissions or energy use may be more than offset by the innovation activities triggered by these policy measures. More generally, the induced innovation hypothesis (first formulated by Hicks 1932) states that an increase in the relative price of a factor or an input may lead to innovative activities that aim at reducing the dependency on this factor in the production process. Applied to energy, this implies that an increase in the energy price, for example because of taxation, may spur innovation directed at a higher energy efficiency. For energy intensive sectors, environmental regulation may thus even be beneficial, because it leads to increased innovation aiming at reducing the dependence on energy or at increasing energy-efficiency. In an international context, this also implies that comparably stronger domestic regulation may lead to first-mover advantages. Countries with stricter targets may have higher innovation rates in the energy sector, which may lead to a faster increase in energy efficiency. Additionally, the earlier adoption of new technologies may be beneficial in the long run, especially if learning effects are important.

The conjecture of Porter and van der Linde has been criticized, e.g. by Palmer, Oates and Portney (1995), for various reasons. Two main points stand out in this respect. First, the argument of Porter and van der Linde is based on a number of case studies rather than on solid empirical foundation. And second, the notion that firm systematically overlook profitable investments seems to be at odds with economic reasoning. However, despite these criticisms, the Porter hypothesis has drawn considerable attention, and their argument has been investigated extensively.

In this paper, we aim at highlighting the dynamics and interrelations that drive the economic effects of environmental regulation. The analysis is conducted using a reduced version of the CITE (Computable Induced Technology and Energy) model. The CITE model is a one-region multi-sector model with fully endogenous growth[1]. In order to ensure compatibility with the original version of the model, we leave the formal structure unchanged, but we use a stylized simplified input-output matrix with only two sectors (plus an energy and an oil sector) that are heterogeneous with respect to their factor intensities. We thus study a model economy instead of applying the model to real data. This keeps the analysis tractable and reduces complexity considerably.

In particular, we are interested in the interplay between political intervention, innovation and investments, and sectoral and economic development. If the regulation creates strong investment incentives, the economy may even perform better than in the absence of policies, and induced innovation effects in the sense of Hicks or Porter may be present. We also analyze the influence of the variation of a couple of parameters that are particularly relevant in this kind of set-up.

We find that the implementation of a unilateral energy policy measure leads to pronounced structural effects. Compared to a business-as-usual path that abstracts from environmental regulation, structural change is clearly directed to the sector that is relatively less energy intensive. Sectoral capital accumulation plays a central role in this respect. Sectors that depend less on energy become more attractive for investors under a stringent energy policy regime and can perform even better than in the absence of political intervention. However, on the aggregate level, we find that the negative impacts of the policy cannot be fully compensated by the increased accumulation of capital.

Additionally, we identify two parameters that are particularly important in energy policy analysis. First, the elasticity of substitution between fossil and non-fossil energy is a key parameter in determining the effectiveness of a given policy. When the two sources are assumed to be good substitutes, a given reduction target can be achieved with much lower taxes than under the assumption of relative complementarity. Second, the intertemporal discount rate has a pronounced impact on the welfare effects of environmental regulation. Models using high discount rates usually find very moderate welfare effects even for strict reduction targets. We show that these very optimistic results may hinge on the assumption of high intertemporal discounting.

The paper is organized as follows. Section 2 discusses the related literature. Sections 3 and 4 describe the model structure, the data and the scenarios. The simulation results are presented in Sections 5, 6 and 7. Section 8 identifies two crucial parameter. Section 9 briefly discusses the role of knowledge intensities, and Section 10 concludes.

2 Literature

The interaction between environmental policy, innovation and economic development has been studied both theoretically and empirically. Simpson and Bradford (1996) claim that a general positive effect of stringent energy policy measures on competitiveness may be an exception (depending on numerous factors) that only emerges under certain conditions. Xepapadeas and de Zeeuw (1999) show in their model that stricter environmental regulation may lead to

[1]See Bretschger, Ramer and Schwark (2011) and Bretschger, Ramer and Schwark (2010) for a detailed description.

both a reduction and a modernization of the capital stock. These two effects jointly increase productivity, but this does not necessarily lead to a win-win situation in the sense of the Porter hypothesis. Ambec and Barla (2002) present a model where environmental regulation helps to overcome informational asymmetries with respect to productivity effects of R&D investments and thereby leads to higher profits (compared to a case without any regulation). In Smulders and de Nooij (2003), induced innovation can only mitigate, but not fully offset the reduction in per capita income resulting from energy conservation policies. Hence, their model does not confirm the induced innovation hypothesis. Lopez et al. (2007) present a two-sector model where structural change in the direction of the non-resource sector actually ensures sustainable growth, even in the absence of an environmental policy. Bretschger and Smulders (2010) also emphasize the role of structural change as a mechanism for obtaining sustainable development. Structural change (induced by rising energy prices) may promote investments and innovation rather than having a detrimental effect on the economy. They also highlight the importance of the substitutability between resources and labor as an input to production. Specifically, they show that poor substitutability is not necessarily harmful for innovation, or, put differently, that good substitution between the inputs is not a prerequisite for sustainable development.

Pittel and Bretschger (2010) develop an analytical model with two sectors with different resource intensities. They find that along the balanced growth path and in the absence of any policy, the resource intensive sector is more innovative, because innovation has to compensate for the drag on growth stemming from the reduction in the supply of the non-renewable resource input. This leads to faster efficiency gains in the resource intensive sector. Analyzing resource taxation, they find that a constant tax has no structural effects. However, if the tax is rising over time, growth effects are negative due to faster resource extraction, with a stronger impact on the resource intensive sector. These negative effects can be reversed if the tax rate is decreasing over time.

Bretschger (2010) shows both theoretically and empirically that a decreasing energy input may even stimulate growth through increased capital accumulation. In the theoretical model, a decrease in energy releases labor from final goods production and directs it to capital accumulation and thereby induces additional investments (which in turn increase productivity and therefore have a positive effect on growth). This implies that countries or sectors with a relatively low energy input can grow faster, because they will accumulate more capital. The condition for this effect to hold is that energy and labor are relatively poor substitutes[2]. The empirical estimations confirm that higher energy prices (and thus a lower energy input) do not have a negative impact on economic growth.

The larger part of the theoretical literature thus suggests that positive impacts of environmental regulation on innovation and competitiveness may only emerge under very specific conditions or assumptions. Slightly more encouraging is the empirical evidence. Jaffe et. al (1995), in their review of studies focusing on the U.S. manufacturing sector, find little evidence for a positive effect of environmental regulation on competitiveness, but similarly little support for a strict adverse effect. Jaffe and Palmer (1997) find a small positive relationship between stricter environmental regulation and R&D investments. Brunnermeier and Cohen (2003) report similar results. Popp (2002) on the other hand finds a strong positive relationship between energy prices and energy related innovation, measured by successful patent

[2]Empirical estimations show that this assumption seems indeed to be valid, see e.g. Kemfert (1998) or van der Werf (2007).

applications. Newell, Jaffe and Stavins (1999) also find a positive link between innovation and energy prices, but they also report that a significant fraction of energy efficiency improvements are due to autonomous technical change. Demailly and Quirion (2008) show that the European Emission Trading Scheme tends to have a positive influence on the competitiveness of regulated industries. In Lanoie, Patry and Lajeunesse (2008), positive impacts result only when dynamic effects are taken into account, and only less polluting industries are able to benefit from environmental regulation. Finally, Cadot, Gonseth and Thalmann (2009) look at industry level data from OECD countries. They find a negative direct effect of higher energy prices on total factor productivity, but also a positive indirect effect through R&D spending that outweighs the negative effect for almost 70% of the industries in the sample. Thus, while most studies find at least small positive effects of environmental regulation on innovation, the link between regulation and competitiveness is not so well established.

Several studies using integrated assessment models have also evaluated sectoral effects of energy policies. Focusing on Switzerland, Sceia, Thalmann and Vielle (2009) analyze different scenarios with a time horizon up to 2020. They find moderate and mostly negative (the only exception being metal products) effects on sectoral production in the year 2020. Ecoplan (2009) simulate different policies (again up to 2020), differing in stringency and the percentage of domestic reductions. Results are similar to Sceia et al. (2009), i.e. sectoral effects again are negative for most sectors. However, the chemical industry and a few machinery industries benefit from the regulations. Ecoplan (2008) evaluate Swiss policies with a model horizon up to 2030 and also report moderate sectoral effects with positive outcomes mostly for sectors included in the IETS (international emissions trading scheme). Ecoplan (2007), analyzing different oil price scenarios in a model abstracting from induced innovation, find negative effects for all sectors except for rail traffic.

3 Model overview and data

The main novelty of the CITE model, compared to other models used for similar purposes, is the inclusion of endogenous growth theory, with Romer (1990) being the main theoretical reference. The growth mechanism can be based on a complete microfoundation and does not include any exogenous elements[3]. In this paper, we take a more general perspective to investigate the dynamics of the model and to check for the presence of induced innovation effects in such a setting. We therefore focus on a model economy instead of applying real data. This helps to simplify the analysis and to reduce complexity. The basic data set (see the Appendix) includes two regular sectors (*Z1* and *Z2*) that produce final output, an energy sector and an oil sector. Final output of regular sectors is produced using output final good inputs[4] and an intermediate composite Q. The intermediate composite contains the individual intermediate varieties, whose number is measured by the sectoral capital stock, and therefore captures the sectoral endogenous growth dynamics. The intermediate varieties are in turn produced using energy, labor and non-accumulable capital. Figure 25 in the Appendix shows the nested production function for sector *Z1*, parmeter values are given in Table 1.

Total energy, produced in the energy sector EGY (see Figure 26 in the Appendix), consists

[3]The growth mechanism and an application to the model to the Swiss economy are described in detail in Bretschger, Ramer and Schwark (2011).

[4]Hence sector $Z1$ uses some of its own ouput and a fraction of the output of sector $Z2$ as an input and vice versa.

of non-fossil and fossil energy. Non-fossil energy is produced in the same way as the output of the two regular sectors, while fossil energy includes the output of the oil sector and (imported) natural gas (GAS). Finally, the oil sector (OIL) uses crude oil (CRU) as an additional input at the top level of the production function, while the rest of the nesting is again the same as in the two regular sectors. Non-fossil energy is carbon-free, while the use of fossil energy produces carbon emissions.

The model used here is a one-region-model, which implies that the policies under consideration are unilateral. The rest of the world is not explicitly specified, and all actions are therefore unilateral. Trade is modeled in the widely used Armington-fashion (Armington 1969), which differentiates goods by origin and implies that domestic and imported goods are imperfect substitutes. The degree of substitutability is measured by Armington elasticities.

The representative household chooses between consumption of energy and non-energy goods (i.e. output from sectors *Z1* and *Z2*) and investments in the sectoral capital stocks. Welfare is measured as overall intertemporal discounted consumption. The underlying rate of time preference is set to 0.9%. The role of this parameter is described in more detail in Section 8.2.

Parameter	Description	Value
σ_Y	Elasticity of substitution between Q and $Z_{1,2}$	0.8
σ_X	Elasticity of substitution between L, EGY and V	0.7
σ_I	Elasticity of substitution between I_P and I_N	0.3
σ_N	Elasticity of substitution between I_R and R	0.3
σ_E	Elasticity of substitution between E_{FOS} and E_{NFOS}	0.3
σ_C	Elasticity of substitution between energy and other goods in consumption	0.5
σ_W	Intertemporal elasticity of substitution in the welfare function	0.6
σ_A	Armington elasticity	2
σ_T	Elasticity of transformation	1
δ	Annual depreciation rate	4%
r	Nominal interest rate	1.565%
ρ	Implicit rate of pure time preference	0.9%

Table 1: Parameter values used in the model

For simplicity, we assume that the two regular sectors are identical with respect to most characteristics. Both regular sectors are initially of equal size, which means that both produce the same amount of output. We also assume that an equal share of total output of the sectors is used as an input in the other sector (at the top nest of the production function). Additionally, we set imports and exports equal in both sectors. This is mainly to exclude effects stemming from different degrees of dependency from foreign trade. With respect to capital accumulation, we assume that both regular sectors have equal initial total investments with the same shares of investments in physical and non-physical capital. Finally, we abstract from sector-specific elasticities of substitution and Armington elasticities and instead use a uniform parametrization for all sectors.

Regular sectors (*Z1* and *Z2*) differ in their energy intensities. Energy enters production at the level of the individual intermediate varieties. Thus, when we refer to a sectors energy intensity, we mean the input share of energy in the production of the intermediate varieties. By assumption, sector *Z1* has a relatively high energy share (16%) and uses less of the other two inputs. Sector *Z2* only uses little energy (0.5%), but has higher shares of labor and non-accumulable capital. A higher energy intensity in production implies a stronger exposure to environmental regulation. We can thus expect the sectors to react differently to energy policy measures.

Simulations are performed using the software GAMS/MCP. The model is formulated as a mixed complementarity problem. The system consists of three types of equations. Zero profit conditions determine quantities, requiring that each sector that supplies a positive amount of a good (or, more generally, each activity supplied at a positive amount) earns zero profits. Prices are determined by market clearance conditions, such that supply and demand are equalized in all markets. This includes both markets for goods (*Z1*, *Z2*, energy and oil in our case) as well as factor markets. Finally, income and trade are required to be balanced using the respective balance equations.

In the starting period, the model is calibrated to match the balanced input-output data, where row and column sums are equalized. Economic activity, or changes in quantities, is represented using so-called activity indices. The benchmark scenario is calibrated in a way that all activity indices are equal to 1 at any point in time. In our case, this is equal to a balanced growth calibration where all sectors follow a uniform growth path. Similarly, benchmark prices are calibrated to follow a reference path given by $P_t = (\frac{1}{1+r})^t$, with r denoting the constant nominal interest rate. In the policy scenarios, activity indices and prices deviate from their benchmark paths, which enables the identification of the effects of the policies.

4 Description of the scenarios

In what follows, we simulate different policy scenarios to investigate the dynamic effects of climate policies in a model framework with endogenous growth. The results of these policy scenarios are compared to a benchmark scenario (BAU), which is basically a business-as-usual scenario that abstracts from any political intervention, and thus implicitly also from possible negative effects of climate change. This may not come very close to a realistic business-as-usual scenario, as long-term costs of undamped climate change may be substantial (as shown by Stern 2007 in his report). However, given that we focus on a time frame of 40 years, the exclusion of negative effects of climate change is not a serious issue. Moreover, this simplification is common in energy policy analysis.

The benchmark scenario is calibrated to balanced growth, which means that all sectors grow at a uniform rate. Because the sectoral growth rates depend directly on the capital shares, capital shares have to be uniform in the benchmark. We set the capital share in each sector to 25%, which results in an annual benchmark growth rate of 1.34%. Consumption also grows at this rate in the benchmark. The time horizon of the model is 40 years. To simplify notation, we assume that the policy is implemented in the year 2010, and the model horizon thus ends in the year 2050.

In the first policy scenario (hereafter referred to as the "base scenario"), we implement a carbon tax that aims at reducing carbon emissions by 60% by the end of the model horizon (i.e. after 40 years). The tax is levied on the use of the two fossil energy inputs, refined oil and natural gas. We assume that the tax is rising steadily over time, so that the reduction target is approached gradually[5]. The revenues of the tax are redistributed to the household, entering its budget constraint as an additional source of income.

[5]Note that this is not an optimal policy. The initial level of the tax and its growth rate are chosen arbitrarily and are set so that they lead to the requested reduction.

Afterwards, we couple environmental regulation with policies that aim at supporting sectoral capital accumulation. We first implement a subsidy for R&D investments only, and then extend the subsidy to all capital types. This is particularly interesting in the context of the present model, because the accumulation of capital (both of physical and non-physical capital) has a direct effect on sectoral growth. The fact that capital accumulation has a positive effect on sectoral productivity causes a market failure in the sense that investors do not take this positive effect into account. Subsidizing investments will therefore help to come closer to the socially desirable level of capital accumulation. According to Hicks (1932) and the induced innovation hypothesis, policies that aim at reducing energy use may be positive in the sense that they spur innovation. Due to the direct correlation between innovation and growth in our model, this implies that sectors may benefit from the implementation of energy policies, because the additional innovative activities may lead to higher sectoral growth. It is therefore straightforward to couple the carbon tax with subsidization of capital build-up, because the subsidies may help to induce innovation, or they may amplify the positive impacts of regulation on sectoral innovation. Finally, we look at the effects of varying two important parameters (the elasticity of substitution between non-fossil and fossil energy and the rate of pure time preference).

Note that we will use the same tax profile in all sectors. Thus, while leading to a given reduction of carbon emissions in the base scenario, there is no quantitative target for emissions in the other scenarios. This allows us to investigate how effective a given tax profile is under different assumptions regarding the use of the tax revenues and the parametrization of the model, and how the incentives to reduce carbon emissions change.

5 Base scenario

In the base scenario, we set a reduction target for carbon emissions (-60% in 40 years), using a carbon tax (steadily rising over time) as a policy instrument. The carbon tax affects sectors through their use of energy as an input on the level of the production of the individual intermediate varieties. The tax is set so that the reduction target is met after exactly 40 years. Results are shown in Figures 1 to 8.

On the aggregate level, the tax leads to a contraction both in consumption and in total regular sector output (see Figures 1 and 2). Welfare, measured as total discounted consumption over the entire model horizon, is reduced by 1.4%. Compared to the benchmark scenario, both variables grow at slightly lower rates[6]. Innovation incentives are therefore not strong enough to compensate for the decrease due to the policy. However, growth rates are still positive, and the effects seem relatively moderate, considering the stringency of the policy.

The results on sectoral output show a clear and pronounced reallocation of production (see Figures 3 and 4). The energy-extensive sector (*Z2*) benefits from the introduction of the tax and increases its output compared to the benchmark scenario. The energy-intensive (*Z1*) sector on the other hand reduces its output. In percentage points, the reduction in the energy-intensive sector is larger than the increase in the energy-extensive sector, resulting in the contraction in total regular sector output shown in Figure 2. Hence, the tax leads to a shift towards less carbon intensive production, a finding that is consistent with other studies[7]. This result seems intuitive, and, at first sight, it confirms the concerns raised by

[6] Aggregate and sectoral growth rates for all scenarios are summarized in Table 3 in the Appendix.
[7] See e.g. Crassous, Hourcade and Sassi (2006).

energy-intensive sectors described in the introduction that binding constraints on emissions would affect them negatively. However, if we look at the growth paths of the sectors instead of percentage changes from the benchmark (see Figure 3), we see that even the energy-intensive sector still exhibits robust growth, albeit at a lower rate than in the benchmark. The "threat" coming from environmental policy for energy-intensive sectors is thus by no means existential.

Sectoral development is directly related to sectoral capital accumulation. Figure 5 shows that the tax leads to an increase in capital accumulation in sector *Z2*, and to a decrease in sector *Z1*, relative to the benchmark scenario. Effects on capital accumulation and on sectoral output are thus symmetric. Investment still takes place in both sectors, but a shift of investments in direction of *Z2* can be observed. This leads to the differences in sectoral growth shown in Figure 3. If we look at total investments (see Figure 6), we see that the path looks slightly different than in the benchmark. Total investments are higher in the first periods and lower later on. In general, the path is flatter than in the benchmark scenario, implying that investments are shifted to earlier periods and decreased towards the end of the model horizon. Total investments are slightly lower than in the benchmark. Thus, under the conditions set in the base scenario, the carbon tax does not lead to higher overall investment incentives, but it triggers two reallocation effects. First, from an intertemporal perspective, total investment is higher in earlier periods and lower later on. And second, more investment is taking place in the energy-extensive sector and less in the remaining sectors.

Sectoral capital accumulation is driven by the profit opportunities of the individual monopolistic producers of intermediate varieties. In the benchmark scenario, profits are equal in all sectors, and therefore investment patterns are also equalized. Higher input prices (most notably a higher energy price because of the carbon tax) have a direct influence on these profits. The lower the profits, the lower the patent price in a given sector, and thus the lower the incentives for investing in new capital varieties. In a multi-sector economy, investments are therefore reallocated, with higher shares going to sectors with relatively better profit opportunities. This leads to the sectoral differences in capital accumulation shown in Figure 5 and, through the impact of capital accumulation on sectoral growth, to structural effects in final goods production. Adding to the divergence between the two sectors is the fact that more innovation takes place in the sector that becomes larger (i.e. that produces more) over time. The sector with the higher market share is relatively more attractive for investments, and given that the sector with a higher investment rate is growing faster over time, it is ensured that investment incentives do not cease over time[8]. In this two-sector setting, this amplifies the difference in sectoral development.

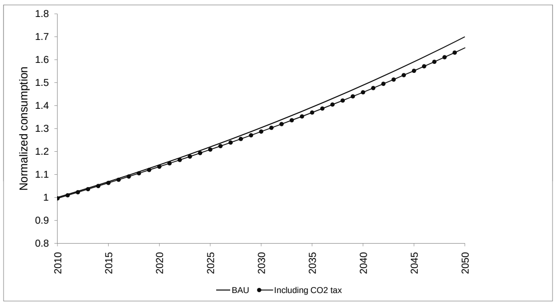
What happens in the energy sector? From Figures 3 and 4, it can be seen that total energy output decreases significantly as a result of the tax, even though the tax is only levied on fossil energy. This coincides with the hypothesis stated above that, given our nesting structure, a tax on fossil energy only also leads to a contraction in total energy production if we assume that non-fossil energy cannot easily be used as a substitute for oil and natural gas. The larger part of the decrease comes from a reduction in fossil energy use (mainly driven by a decrease in the oil sector, see Figure 7), but non-fossil energy is also reduced significantly. However, as Figure 5 shows, capital accumulation in the production of non-fossil energy does not decrease as much as capital accumulation in the oil sector. In fact, it still grows at a positive rate over

[8]This effect is also discussed in Bretschger and Smulders (2010). In their paper, the observation that more innovative sectors gain a larger market share over time and therefore help to keep investment incentives intact is identified as being crucial for sustainable development.

time. This shows that some effort is undertaken in non-fossil energy production to counteract the negative effects coming from the tax on fossil-energy, without being able to fully offset it.

The tax also leads to a shift in the distribution of the other production factors. As we assume that the size of the labor force is constant over time and that labor is inelastic in supply, labor can only be reallocated across sectors. In the case simulated here, labor is moved out of the energy and the oil sector and the energy-intensive sector and in to the energy-extensive sector. The same holds for non-accumulable capital. The decreased production in the energy-intensive sector and the downturn in energy use release production factors from these sectors and direct them to the energy-extensive sector. Incentives to substitute energy for labor and non-accumulable capital rise in both regular sectors due to the rise in the relative price of energy. Factor prices indeed indicate an increase in demand for labor and non-accumulable capital. However, because their availability is limited, the economy reacts with a relocation of production factors to the sector that is less affected by the policy. Labor demand decreases in energy-intensive industries, but this decrease is compensated by a corresponding increase in energy-extensive sectors, leaving total employment unaffected. Of course, these effects are also driven by simplified modeling of the labor market. In reality, labor is neither perfectly mobile across sectors nor is its supply completely inelastic. A more sophisticated representation of the labor market might lead to different effects in this respect. As indicated, the CITE model is a one-region model, and trade is modeled using the simplified Armington approach. Nonetheless, the simulations reveal some interesting effects on trade. Figure 8 focuses on the trade effects (measured by the difference between exports and imports) within the regular sectors $Z1$ and $Z2$. Exports of the energy-extensive sector increase considerably. At the same time, imports of the energy-intensive good rise sharply. This means that the carbon tax leads to an increasing specialization in the production of the energy-extensive good in the domestic economy. On the other hand, the demand for energy-intensive goods is covered to a much larger extent by imports, and domestic production decreases.

This also has some implications for the composition of total demand. The relatively conservative assumptions on the elasticities of substitution in the production process and in the nesting of investments imply a certain rigidity in total demand for final goods, i.e. there will always be a positive demand for goods from both regular sectors. The trade elasticities however state that it is of limited importance where these goods are produced. Foreign and domestic goods are not assumed to be perfect substitutes, but the elasticities are either equal to one (for the elasticity of transformation) or, in the case of the Armington elasticities, considerably above one. This leads to the change in the structure of domestic production. The sharp increase in the imports of the energy-intensive good indicates that total domestic demand of this good is not severely affected. The same holds for demand of the energy-extensive good, where a large part of the additional production (compared to the benchmark case) is exported. Thus, as Figure 2 shows, total demand for regular sector goods decreases slightly compared to the benchmark, but the trade effects suggest that its composition remains more or less similar. This also means that the changes in output (or production) of the two regular sectors are not driven by changes in domestic demand. They are mainly driven by an increased specialization of the economy in the production of energy-extensive goods and a change in trade patterns.



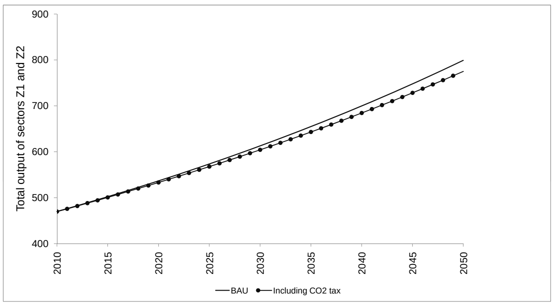
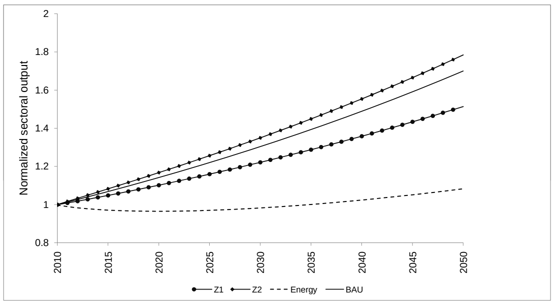


Figure 1: Aggregate consumption (base)

Figure 2: Total output of $Z1$ and $Z2$ (base)



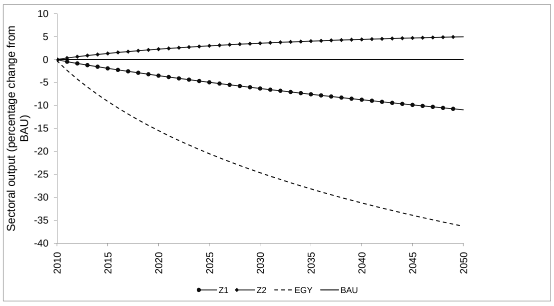
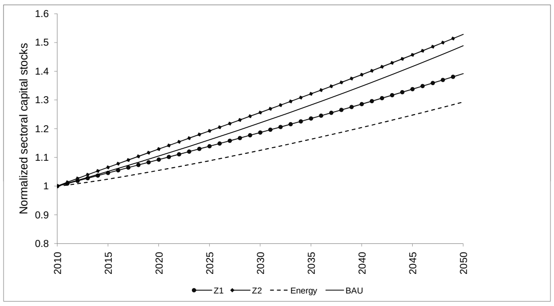


Figure 3: Sectoral output (base)

Figure 4: Output, %-change (base)



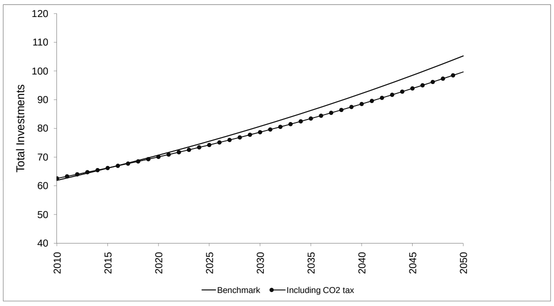
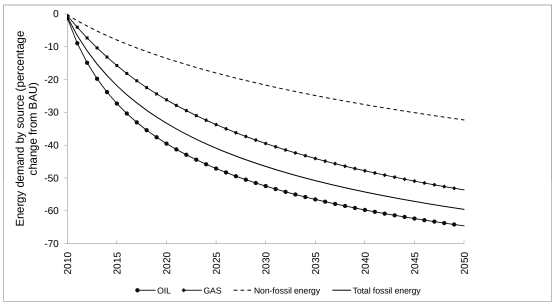


Figure 5: Capital stocks (base)

Figure 6: Total investments (base)



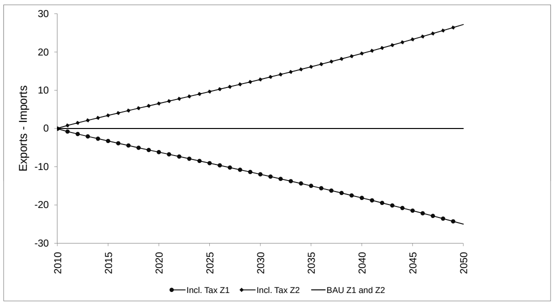


Figure 7: Energy demand by source (base)

Figure 8: Trade effects (base)

6 R&D subsidies

In the base scenario, the revenues of the carbon tax are redistributed back to the representative household and thus enter its budget constraint as a source of additional income. A more purposeful use of the tax revenues may be to use them to directly support the sectoral growth mechanism, which is capital accumulation. It is often argued that a combination of energy and research policies is more fruitful (e.g. in Massetti and Nicita (2010)). R&D subsidies increase the attractiveness of investments and thus even further decrease the difference of aggregate output and investments to the respective benchmark paths. Additionally, they may help to diminish the adverse effects on the energy-intensive sector. We use the same tax profile as in the base scenario to exclude additional effects that may come from a different profile. This tax profile leads to a lower decrease in carbon emissions than in the benchmark, but the difference is very small. Total reduction in 2050 is 59% and thus only slightly lower than the 60% in the base scenario.

If we look at aggregate effects (shown in Figure 9), there are two points worth noting. First, consumption in 2050 is a little higher than in the base scenario. Nonetheless, the increased investment activity leads to a higher welfare loss (1.9%). Second, the decrease in total output compared to the benchmark is considerably smaller (i.e. output in 2050 is higher than in the benchmark scenario). This indicates that the R&D subsidies i) lead to higher investments (and thus lower consumption) and ii) have a positive effect on competitiveness (compared to the base scenario) in the sense that the impact of the carbon tax on total output is smaller.

Structural effects are similar in direction compared to the base scenario. The energy-extensive sector increases its output, while the energy-intensive sector reduces its production. There is, however, an upward shift. The decrease in production of the energy-intensive sector is smaller, and the increase in the energy-extensive sector is larger (see Figure 10). Thus, while leaving the structural effects unchanged, the R&D-subsidies mitigate the negative effects (compared to the benchmark scenario) on the energy-intensive sector and help the energy-extensive sector to increase its production even more. In fact, this would still hold if we were to increase the tax to meet the reduction target formulated in the base scenario. In this respect, the R&D subsidies have a clear positive effect.

Most importantly, the R&D subsidies lead to a considerable increase in investment activity. As Figure 11 shows, investments are higher in this scenario than in the benchmark at any point in time. Moreover, they are considerably higher than in the base scenario where the tax revenues are redistributed lump-sum to the household. Capital stocks are higher in all sectors (see Figure 12), leading to the increase in production described above. The downside of this increased investment activity is the negative effect on welfare. As the household devotes more of his income to investments and less to consumption, welfare is lower than in the base scenario. This may indicate that the welfare measure used here (and that is used in a very similar way in many CGE models) may not be sufficient to measure the efficiency of a policy. Total production e.g. is affected much less than in the base scenario. Thus, in terms of competitiveness, R&D subsidies clearly lead to a superior outcome compared to a lump-sum redistribution.

In the energy sector, the picture (Figure 13) is very similar to the one in the base scenario. As indicated at the beginning of this section, the effect of the tax is a bit smaller in this scenario, meaning that the reduction in carbon emissions and thus also overall energy use is smaller. Hence, there is a shift upwards within the energy sector, similar to the one at the sectoral level. Reductions of the use of the individual energy sources are smaller compared to the base scenario. The largest difference can be observed in the use of non-fossil energy. Under the assumptions taken here, the R&D subsidy does not lead to any qualitative changes in the use of the different energy sources.

If we look at the effects on trade (Figure 14), we see that the R&D subsidy mitigates the relocation of production that takes place in the base scenario. The specialization in the production of energy-extensive goods is thus less pronounced. The effects are still relatively large in magnitude, but smaller than before, even though total domestic production is larger. Subsidizing R&D therefore has a certain stabilizing effect on domestic production in the sense that it reduces the impact of the carbon tax on the structure of the economy.

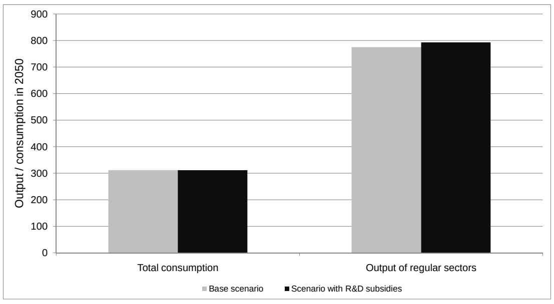


Figure 9: Output and cons. (base vs. R&D)

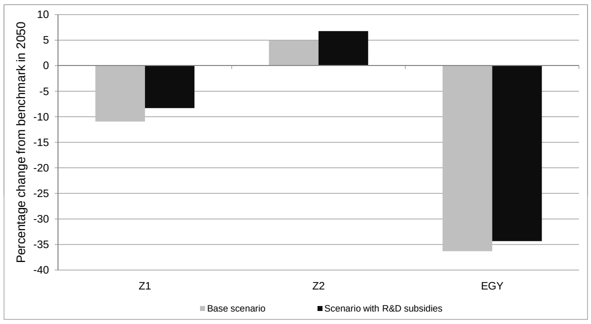


Figure 10: Output, %-change (base vs. R&D)

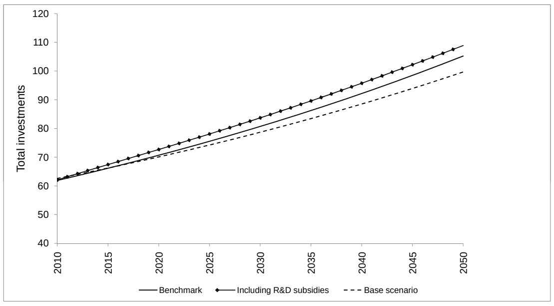


Figure 11: Total investments (R&D)

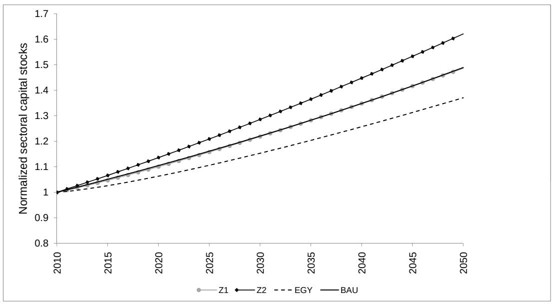


Figure 12: Capital stocks(R&D)

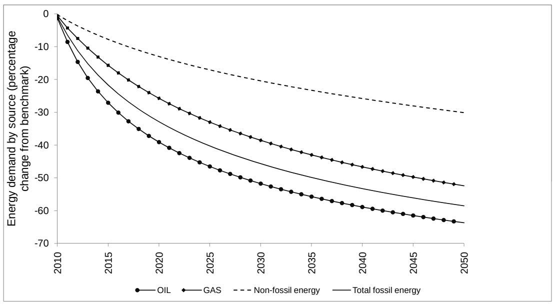


Figure 13: Energy demand by source (R&D)

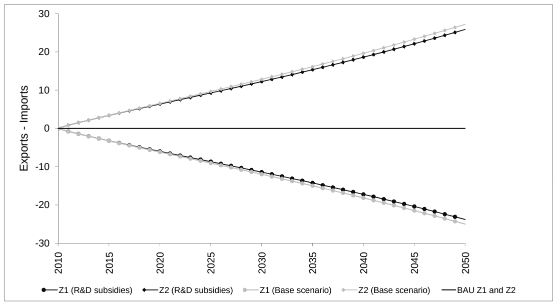


Figure 14: Trade effects (R&D)

An interesting question in the context of this scenario is whether or not subsidizing R&D can ever lead to a superior outcome in welfare terms compared to the base scenario. It may be that the positive effects of the increased investments on welfare can only be exploited in a more distant future. The productive effects of additional capital accumulation may emerge only in later periods or when a longer time horizon is considered. Indeed, this seems to be the case. Extending the time horizon from 40 to 90 years and using the same tax profile for this longer time interval leads to a welfare loss of 3.2% if the tax revenues are redistributed back to the representative household (as in the base scenario) and to a welfare loss of 3.1% if the revenues are used as R&D subsidies. The turning point (i.e. the point in time when R&D subsidies become superior to the lump-sum redistribution) is around the year 2090, i.e. after about 80 years. The exact turning point is sensitive to choices of parameter values and to the tax profile. It highlights that R&D subsidies should be viewed as a long term investment whose benefits (at least in welfare terms) cannot be reaped in the short run. The positive effects on capital accumulation and production emerge even within short time horizons, but it takes more time until this policy also leads to a better outcome as far as consumer welfare is concerned.

7 Capital subsidies

An important assumption of the CITE model is that investments in all capital types have a positive effect on sectoral productivity. Hence, it may make sense not to restrict the subsidies to investments in R&D (and therefore in non-physical capital) only, but to support also the build-up of physical capital. Investments in more efficient machines and in infrastructure (e.g. better insulation of buildings) can contribute significantly to a reduction of fossil energy use and to a decrease in carbon emissions. In this scenario, we model a subsidy that supports both physical and non-physical capital.

The two capital types are summarized to one aggregate capital stock using a nested CES function. We assume that the two capital types (physical and non-physical capital) are imperfect substitutes. Hence, the corresponding elasticity of substitution σ_I is set below unity (the exact value is 0.3). The underlying conjecture is that the two capital stocks are interdependent in the sense that one stock can hardly be increased without a corresponding progress in the other stock. For example, the development of new, more energy-efficient machines (and thus an increase in the physical capital stock) presupposes research and the accumulation of related knowledge. In this sense, the two stocks are complementary to a certain degree. This assumption has important implications for the modeling of policies related to R&D and capital build-up. A subsidy to R&D as in the previous scenario is, due to the assumption of relatively strong complementarity, also indirectly a subsidy to the build-up to physical capital. As a result, the capital stock cannot rise by an increase in the non-physical capital stock alone. The increase in the non-physical capital stock has to be accompanied with an increase in the physical capital stock (however, not in fixed proportion, because the two stocks are not perfect complements). The same would hold, of course, if capital accumulation decreases.

Thus, in comparison to the scenario with R&D subsidies, we expect no big difference in the results if the accumulation of both capital types are explicitly subsidized. The results confirm this hypothesis. Aggregate output, consumption and investments (see Figure 15) are almost identical in the two scenarios. In accordance with these results for aggregate variables, the effects at the sectoral level are also virtually the same.

If we drop the assumption of relative complementarity and instead assume that physical and non-physical investments are good substitutes[9], there is only a slight additional upward shift, both at the sectoral and the aggregate level. Hence, the similarity of the results of the two different types of capital subsidies does not depend only on the degree of substitutability between the two capital types. A simplifying assumption in our stylized data set is that the

[9] The corresponding elasticity of substitution is increased from 0.3 to 1.3.

two regular sectors have equal total initial investments and equal shares of physical and non-physical investments. In reality, sectors are obviously heterogeneous in this respect. If we assume heterogeneity in the shares of physical and non-physical investments on total sectoral investments, it may be relevant for the results whether the subsidies are restricted to R&D investments or include both types of investments.

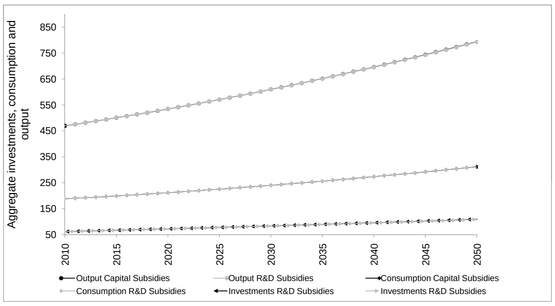


Figure 15: R&D subs. vs. capital subs.

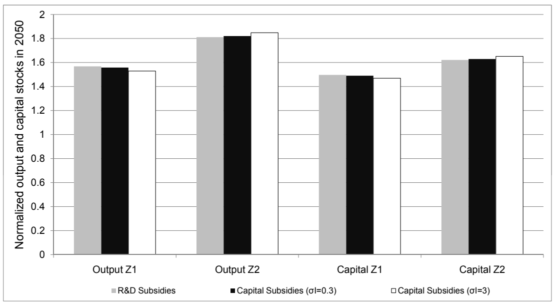


Figure 16: Output and capital stocks

In the following, we assume that both sectors still have equal total investments, but that the shares of physical and non-physical investments are different. To be more precise, we assume that the energy-intensive sector (*Z1*) relies mostly on non-physical investments and only has a small amount of physical investments. In the energy-extensive sector (*Z2*), the opposite holds. In comparison to the scenario where only R&D investments are subsidized, aggregate effects are virtually the same as shown in Figure 15, even if we relax the assumption of relative complementarity between the two capital types. However, the capital subsidy does affect sectoral reactions (Figure 16). First, as one would intuitively expect, an expansion of the subsidy to both capital types favors the sector with high physical investments (*Z2*). Both the capital stock and output are higher than when only R&D is subsidized. On the other hand, sector *Z1* is better off when the subsidy is restricted to non-physical investments. These sectoral effects are amplified when we assume that the two capital types are good substitutes. Hence, with heterogeneous shares of physical and R&D investments, the two policies do have different impacts on sectoral development, despite the interrelations and dependencies of the two capital types explained at the beginning of this section. Given these results, sectorally differentiated policies with subsidies supporting the capital types that are relatively more "important" may be advisable, even if we assume a high degree of complementarity between the two types.

8 Important parameters in applied policy analysis

8.1 The elasticity of substitution between fossil and non-fossil energy

In energy policy models that differentiate between various sources of energy, choices for the values of the elasticities of substitution between these different energy sources are obviously very important. As usually only some energy sources are subject to policy intervention (typically fossils or carbon-intensive energy sources), the degree of substitutability between the inputs whose use should be reduced and alternative energy sources may have a pronounced influence on the effectiveness of the policy and thus on the results. If we assume that the energy sources that are subject to policy intervention can easily be replaced, the policy should be relatively more effective than in a case where the substitution potentials are limited. Of course, other constraints such as adjustment costs or learning rates may also play a role in this context. To a certain degree, the importance of such other factors can be captured by the elasticity of substitution. Abstracting from other influences is a simplification that is, however, widely used, because most of these impacts are hard to estimate. On the other hand, this also means that the role of the elasticity of substitution is even more substantial.

In the CITE model, the energy sector is represented in a relatively aggregated and simplified way. We differentiate between non-fossil and fossil energy. Fossil energy is further divided into two energy sources (natural gas and oil). Additionally, we assume that fossil and non-fossil energy do not enter sectoral production directly. Instead, the production sectors use an energy aggregate that consists of both fossil and non-fossil energy. Hence, the carbon tax on fossil energy use we implement as a policy measure directly affects the energy sector and only has an indirect effect on the two regular sectors. Our hypothesis is thus that the better fossil and non-fossil energy can be substituted, the smaller should be the impact on the regular sectors. If they are good substitutes, we should see mainly composition effects within the energy sector, but only relatively small changes in overall energy use. On the other hand, if they are poor substitutes (as we assume in the two scenarios discussed above and also in the original version of the CITE model), the effects on the two regular sectors should be more pronounced, because overall energy use should contract along with the decrease in fossil energy use.

Given its importance, it seems rather surprising that there are (at least to our knowledge) no empirical estimates available for this parameter. The values commonly used in energy policy models rely either on "guesstimation" (i.e. on a more or less reasonable guess) or on values taken from existing studies rather than on solid empirical foundation. This leads to a large variation of values used in different models[10]. The time horizon considered often plays an important role in justifying the choice of a specific value for this parameter. If we look at short run policies, it may be reasonable to argue that fossil fuels cannot be readily replaced with non-fossil energy, e.g. because of the limited maturity of certain green technologies, or simply because of financial constraints. In the original CITE model, time horizons are relatively short (25 or 40 years), which is why we use the assumption of limited substitutability. In the long run, however, this may be different. As clean energy becomes more and more competitive, the assumption of poor substitutability may no longer be valid.

Acemoglu et al. (2010) argue that the case of good substitutes is even relevant when shorter time horizons are considered, because clean technologies must be able to fully replace dirty technologies once they enter the market. If they were not able to fully substitute for conventional fossil energy, they would not be competitive and would not be employed at all. The validity of this argument seems a bit doubtful, since clean technologies are being used despite the fact that they are in some cases either more expensive or less efficient than dirty technologies, which would in fact make them an imperfect substitute. Nonetheless, we take up the argument from Acemoglu et al. (2010) in this variation of the base scenario and set the elasticity of substitution between fossil and non-fossil energy (σ_E) to 1.3 instead of 0.3, which implies good substitutability between the two energy sources. Other than that, we leave all the assumptions from the base scenario as well as the data unchanged.

The results show that the variation of σ_E has quite a large effect on the results. As

[10] Gerlagh and van der Zwaan (2003) assume that fossil and non-fossil energy are good substitutes by setting a value of 3 for the corresponding elasticity, while Ecoplan (2007) sets a value for 0.2.

expected, the effects on production of the regular sectors are much smaller in the case of good substitutes (see Figure 17). The increase in production of the energy-extensive sector is now only minimal, and also the decrease in the energy-intensive sector is much smaller. Sector *Z1* reduces its output only by about 5% in 2050 (compared to the benchmark). In the base scenario, the decrease in 2050 was more than 10%. Similarly large is the difference in sector *Z2*. Production in 2050 is only about 1% higher than in the benchmark, which is considerably less than the increase of about 5% in the base scenario. As a consequence, total output is also higher than in the base scenario (shown in Figure 18). This confirms our hypothesis that better substitutability between fossil and non-fossil energy leads to a smaller impact on total production. Additionally, the effect on aggregate consumption and on welfare is smaller as well. Welfare decreases by only 0.9%, and the growth path of consumption is only minimally below the benchmark path.

Another positive effect of good substitutability between fossil and non-fossil energy is that carbon emissions can be reduced much faster and at a lower cost. With the same tax profile as in the base scenario, carbon emissions can be reduced by 90% until 2050. The 60% reduction target from the base scenario could thus be reached with a much lower tax, which would reduce the welfare loss and the effects on production even more.

The case of good substitutes also leads to different effects on investment incentives and on sectoral capital accumulation (shown in Figure 19). The main difference compared to the base scenario is the substantial increase in capital accumulation in the energy sector. To be more precise, given our nesting structure, this corresponds to an increase in capital accumulation in non-fossil energy. Hence, if fossil and non-fossil energy are good substitutes, non-fossil energy becomes increasingly attractive for investors and attracts even more capital than in the benchmark scenario. In fact, capital accumulation increases even more than in the energy-extensive sector. Capital accumulation in the two regular sectors is only moderately affected. In the energy-extensive sector, there is a marginal increase (compared to the benchmark scenario), while capital accumulation in the energy-intensive sector is slightly lower than in the benchmark. The range in the effects and therefore the degree of reallocation of capital in regular sectors is considerably smaller than in the base scenario.

In the energy sector (see Figure 20), the picture is also drastically different from the base scenario. The impact of the tax is almost fully restricted to fossil energy. Thus, rather than dragging down non-fossil energy use as well, the tax almost exclusively affects fossil energy, leading to a much larger decrease in the use of both natural gas and oil. Non-fossil energy use on the other hand even increases slightly compared to the benchmark. As a result of this, overall energy use contracts only by about 11%, which is significantly less than in the base scenario.

Finally, trade effects are also present in the case of good substitutes, but they are less pronounced than in the base scenario. The tax still leads to a specialization in the production of non-energy goods, but to a lesser degree than before. This again mirrors the smaller impacts of the carbon tax on the two regular sectors.

These results also highlight the need for research on the elasticity of substitution between fossil and non-fossil energy. Robust and profound estimates for this parameter would increase the credibility of energy policy modeling significantly and reduce the uncertainty about the reliability of the results. Whether or not we assume fossil and non-fossil energy to be good substitutes has a significant impact on the investment incentives and on the degree of structural change, and therefore leads to different policy implications.

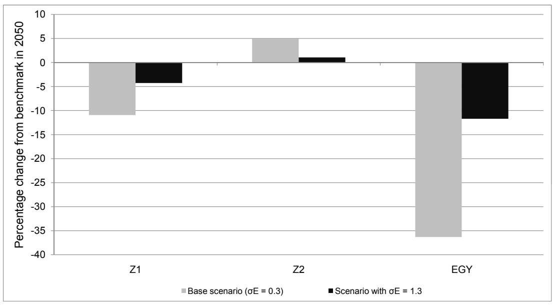


Figure 17: Output, %-change (high vs. low σ_E)

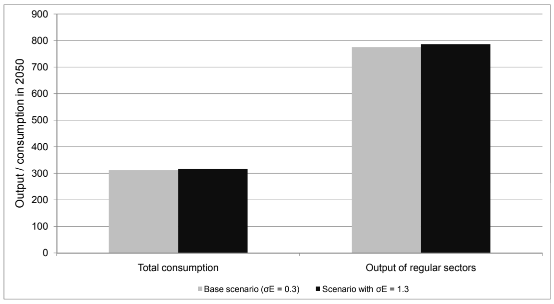


Figure 18: Output and cons. (high vs. low σ_E)

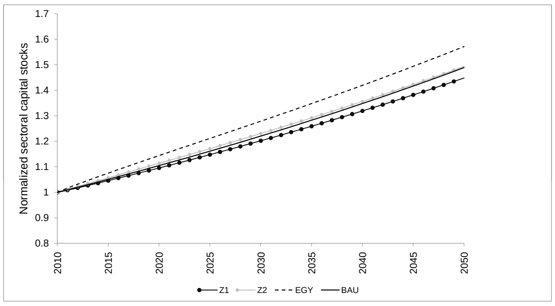


Figure 19: Capital stocks (high σ_E)

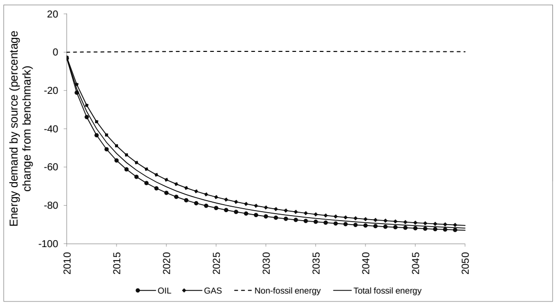


Figure 20: Energy demand by source (high σ_E)

8.2 The intertemporal discount rate

Another important parameter in intertemporal models and, more specifically, in endogenous growth theory and its application in CGE modeling, is the rate of time preference (denoted ρ from here on, see Frederick, Loewenstein and O'Donoghue (2002) for a detailed discussion). In an energy policy context, this measure of discounting over time is obviously very important. First of all, climate change and its side effects are long-term issues. Hence, it requires policies with a long time horizon. For the evaluation of such policies and their possible costs, it is important to what extent future costs and their effects on utility are taken into consideration. Second, it is also important when calculating the costs of undamped climate change. As Stern (2007) points out, the costs of climate change if no political action is taken rise at an exponential rate over time and may augment up to a loss of 35% of GDP per capita in 2200. Several authors (e.g. Nordhaus (2007) or Weitzman (2007) claim that these results depend crucially on Stern's assumption of very low discounting (at a rate of 0.1% per annum Stern). With higher intertemporal discounting, they argue, the results of the review would be far less clear-cut. Moreover, as showed by Nordhaus (2007), near-zero discounting can imply an unrealistically high willingness-to-pay of current generations to reduce damages in the far future. This discussion highlights that ρ indeed plays a central role in this context, especially when longer time horizons are considered.

In the original CITE model, and also in the scenarios discussed so far, ρ is (implicitly) set to 0.9% (see the Appendix for the derivation). In this scenario, we investigate the effects of using a significantly higher rate of pure time preference and set ρ to 4.5%. An intuitive hypothesis would be that a higher discount rate mitigates the effects of the carbon tax. We again use the same tax profile as in the base scenario, meaning that the tax is rising over time. Political intervention is therefore more severe in later periods. However, with a higher intertemporal discount rate, these later periods have a lower weight in the determination of welfare. The welfare loss should thus be considerably lower than in the base scenario. As we expect the overall effects of the tax to be less severe than in the base scenario, sectoral effects should also be less pronounced. Results are shown below in Figures 21 to 24.

As expected, the effects on overall welfare are mitigated with a higher value for ρ. Welfare decreases by only 1.2%. However, carbon emissions are reduced by a smaller amount than in the base scenario. To reach the same reduction target, a higher tax would be needed[11]. Still, the 60% reduction could be attained with a lower welfare loss. Varying the tax profile so that carbon emissions are effectively reduced by 60% leaves the welfare loss unchanged at 1.2%.

However, the effects on welfare are surprisingly small. Figure 21 shows that the path of consumption in the scenario with a higher discount rate lies even slightly below the path from the base scenario. It seems that there are two forces at play. On the one hand, higher discounting reduces long-run effects on consumption by putting a lower weight on future generation. But on the other hand, a higher discount rate also reduces the incentives to invest in new capital varieties, leading to lower total output and thus to lower consumption. Figure 21 indicates that the second effect dominates.

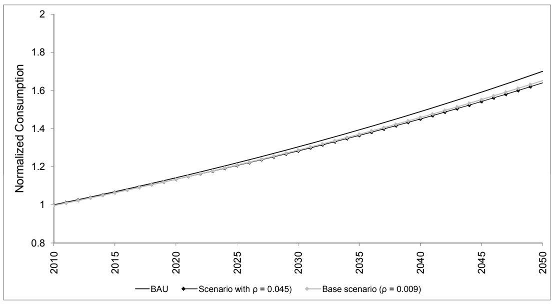


Figure 21: Consumption (high vs. low ρ)

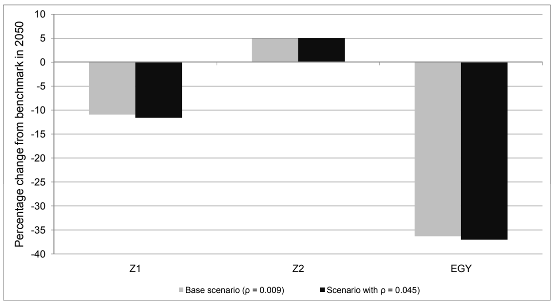


Figure 22: Output, %-change (high vs. low ρ)

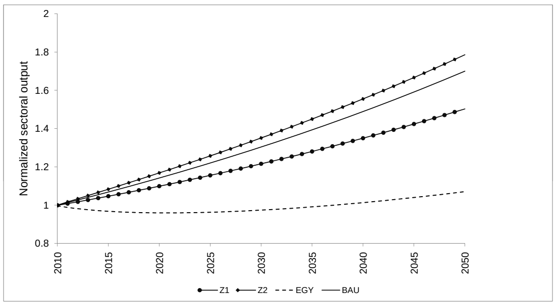


Figure 23: Sectoral output (high ρ)

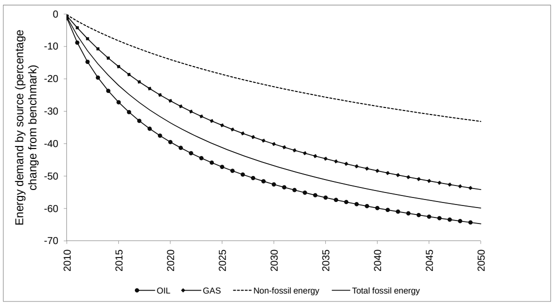


Figure 24: Energy demand by source (high ρ)

On a sectoral level, results are quite similar compared to the base scenario. Structural change remains similar in direction (see Figures 22 and 23). The energy-extensive sector increases its production in comparison to the benchmark, while the energy-intensive sector slightly reduces its output. Total output decreases slightly more than in the base scenario.

[11]This is in line with the results of Stephan and Mueller-Fuerstenberger (1998), who find that higher discounting leads (ceteris paribus) to significantly lower emission reductions.

This highlights the importance of investments for sectoral and aggregate development.

In the energy sector (Figure 24), effects are similar in direction compared to the base scenario, but a bit less pronounced. As indicated above, the carbon tax has a lower impact on carbon emissions in the case of higher intertemporal discounting. Hence, there is a smaller reduction in fossil energy use. The same holds for non-fossil energy.

Hence, a higher intertemporal discount rate tends to mitigate the welfare impact from the carbon tax. Too high discount rates may thus lead to an underestimation of the welfare losses of a given policy. Especially when we assume a rising tax profile over time and thus an increasing tax burden on later generations, results may depend notably on the value used for ρ. In case of high discounting, these higher future costs have a lower weight in the determination of the overall effects, which drives the welfare losses down.

However, the effects of a higher discount rate on investments, consumption over time and sectoral output indicate that there is another force that may be especially relevant in models including endogenous growth. By reducing investment incentives considerably, a higher discount rate may even lead to amplified (rather than to mitigated) effects. Due to the direct link between investments in capital varieties and sectoral growth, higher discounting and a reduced innovation rate do not necessarily reduce the long-term impacts of environmental regulation. When investments are the driving force behind sectoral growth, total output and thus consumption may even be lower in case of higher discounting despite the lower value placed on future generations and on future costs of regulation.

This modification of the base scenario illustrates that the value for the intertemporal discount rate plays a crucial role, and that different values may lead to different conclusions for policy. In contrast to the elasticity of substitution between fossil and non-fossil energy (a parameter that could be based on empirical estimations if available), the discussion on reasonable value for ρ is more complex. As indicated at the beginning of this section, moral and ethical arguments are also important in this context. In applied policy models that aim at delivering advice to decision makers, high discounting seems not appropriate, because there is no obvious reason why the welfare of future generation should have a lower weight. In this sense, an annual discount rate of e.g. 5%, as it is used in comparable studies focusing on the Swiss economy, such as Ecoplan (2007) seems to be an extreme assumption, and it is an important part of the explanation for the relatively low welfare effects they find, even in the case of stringent policies. It is reasonable to assume that welfare losses under the assumption of high discounting may be underestimated. Hence, from our point of view, relatively low discounting at an annual rate of 1% or even lower, as it is done in the original CITE model seems to be more appropriate in the context of applied energy policy analysis.

9 The role of the knowledge intensity

In this section, we briefly investigate the role of the knowledge intensity. The knowledge intensity refers to the "size" of the sectoral research labs, i.e. the relative importance of non-physical capital in the different sectors. Given our modeling of capital accumulation, this may be particularly relevant if the energy policy is coupled with an R&D subsidy, as in the scenario discussed before. In such a case, a knowledge intensive sector may benefit from a subsidy simply because non-physical capital has a high and relevant share in its capital accumulation process. In sectors where R&D is only a minor factor, the positive influence of supporting research is supposedly smaller. When the subsidy is expanded to support the build-up of all capital types, heterogeneity in the shares of physical and non-physical capital indeed proved to be relevant.

So far (except for parts of the subsection on capital subsidies), we have assumed that both regular sectors are equally knowledge intensive and that both sectors have identical total investments. As long as no R&D policy (or generally a policy that affects capital accumulation) is in place, this assumption has no distorting effect on the results. Since we assume that both investment types (i.e. physical and non-physical investments) are equally productive in capital accumulation, shares are not important if total investments are equal. This can easily be confirmed by dropping the assumption of equal shares of capital types in the base scenario. Whether we assume that both sectors have an equal share of non-physical investments or one of the two sectors is more knowledge intensive is almost irrelevant for the results.

When the carbon tax is coupled with an R&D policy and the tax revenues are used to subsidize to build-up of non-physical capital, the sectoral knowledge intensities are more relevant. If we assume that the energy-extensive sector has a higher knowledge intensity, this increases the gap between the two sectors, i.e. the sector *Z2* benefits slightly more than in the case with equal knowledge intensities, and output from sector *Z1* decreases a bit further. The reason for this is that the energy-extensive sector attracts more capital in this case if R&D is more relevant. This leads to a small amplification of the effects observed in Section 5. The opposite holds if R&D is relatively more important in the energy-intensive sector. In this case, the negative effects on the energy-sector are slightly mitigated, and generally the range of effects gets smaller.

However, in both cases, the knowledge intensity does not have a big impact on the results. A reason for this is that the productive effects of capital accumulation are essentially effects on total factor productivity. Investments directed at a specific factor, most notably at energy, are not included in our setting. Hence, even if R&D is subsidized, a sector that is both knowledge-intensive and energy-intensive cannot offset the negative impacts from a carbon tax, it can only mitigate the effects to a limited degree.

If we drop the assumption that sectors are unequally energy-intensive and instead assume that sectors *Z1* and *Z2* are identical in every aspect except for the size of their research lab, a higher knowledge intensity can be a comparative advantage. In this case, if R&D is subsidized, the sector with the higher knowledge intensity is relatively better off when a carbon tax is implemented. More investments are directed at the knowledge intensive sector, which results in higher output. Thus, when sectors are similar with respect to their factor shares, the knowledge-intensity can be a decisive factor in determining the structural effects resulting from policy intervention.

10 Conclusions

The central aim of this paper is to highlight and to identify the dynamics and some key parameters that are particularly important in applied energy policy modeling. By reducing the complexity of the original CITE model and removing numerous sectoral heterogeneities, we are able to point out the characteristics that are most important for a better understanding of the observed effects.

Implementing a long-term oriented unilateral policy that aims at reducing carbon emissions, the results show a pronounced structural shift in favor of the less energy-intensive sector. The driving force behind the resulting growth patterns is the impact on sectoral capital accumulation. After the implementation of the carbon tax, investments in the energy-extensive sector rise and decrease in the energy-intensive sector, leading to diverging growth patterns. Hence, environmental regulation spurs capital formation in one sector and decreases it in the other. This indicates that environmental policy does indeed affect innovation, but whether or not the effects are positive depends on the characteristics of the sectors. If R&D is directly subsidized, the negative effect on the energy-intensive sector (compared to the business-as-usual case) can be mitigated, but not fully offset. In the long run, R&D subsidies can lead to a superior outcome in welfare terms. Expanding the subsidy to include all capital types can make a difference (compared to research subsidies) if the sectors have unequal shares of physical and non-physical capital and if the the two capital types are good substitutes. Additionally, we showed that the model results and thus the recommendations for policy and decision makers are somewhat sensitive to the assumptions on the elasticity of substitution between fossil and non-fossil energy and the rate of intertemporal discounting ρ.

The positive and encouraging result of the model is that both sectors are able to grow even if a stringent policy is put in place. However, induced innovation effects in the sense of the Porter hypothesis are restricted to certain sectors, and they can at best mitigate the negative effects in sectors that are heavily affected by the regulation. A few points are important in this context. First, the sectoral structure is obviously highly simplified. Special characteristics of sectors or even firms (e.g. high adaptive capacities or learning rates with respect to new innovations) with respect to technologies are not modeled here. Hence, it is possible that individual firms in a given sector do benefit from a regulation, even if the sector at the aggregate is negatively affected. The lack of data prohibits a detailed analysis in this direction. Second, it needs to be noted that it is in fact an aim of a carbon-reducing policy to change the structure of the economy in a way that the share of sectors with high emissions is reduced. In this sense, the direction of the resulting structural change in the CITE model is consistent with one of the purposes of the policy. Third, on the aggregate level, effects are very moderate. Hence, in an international context, competitiveness is only minimally affected. And finally, the policy we implement here (and also in the original version of the model) is by no means optimal. The initial rate of the tax and its profile over time are chosen arbitrarily in a way that leads to the planned reduction of carbon emissions. However, the results indicate that even with an optimally chosen policy, it is unlikely that induced innovation could reverse the effects explained above.

Given the fact that many countries still do not have stringent and long-term oriented environmental regulation and binding targets in effect, the results indicate that reducing energy abundance and emissions before such a policy is put in place seems to make sense. This reduces the vulnerability to carbon and energy policies and increases competitiveness, not only on a domestic level, but also internationally. Investments in energy-saving technologies and related research and early adaptation of such technologies can thus be crucial as a "preparation" for future regulations. A model with a more sophisticated representation of the relevant technologies, and possibly also including learning rates, could be useful to highlight these effects.

11 Literature

Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D. (2010): *The environment and directed technical change*, NBER Working Paper No. 15451.

Ambec, S., Barla, P. (2002): *A theoretical foundation of the Porter hypothesis*, Economic Letters, 75, pp. 355-360.

Armington, P. S. (1969): *A theory of demand for products distinguished by place of production*, International Monetary Fund Staff Papers, 16, pp. 159-78.

Bretschger, L. (2010): *Energy prices, growth, and the channels in between: theory and evidence*, CER-ETH Working Paper 06/47.

Bretschger, L., Ramer, R., Schwark, F. (2010): *Impact of energy conservation policy measures on innovation, investment and long-term development of the Swiss economy: results from the Computable Induced Technical Change and Energy (CITE) model*, Final project report prepared for the Swiss Federal Office of Energy, Bern.

Bretschger, L., Ramer, R., Schwark, F. (2011): *Growth Effects of Carbon Policies: Applying a Fully Dynamic CGE model with Heterogeneous Capital*, Resource and Energy Economics, doi:10.1016/j.reseneeco.2011.06.004.

Bretschger, L., Smulders, S. (2010): *Sustainability and substitution of natural resources: How structural change affects long-term R&D-investments*, mimeo.

Brunnermeier, S. B., Cohen, M. A. (2003): *Determinants of environmental innovation in US manufacturing industries*, Journal of Environmental Economics and Management, 45, pp. 119-132.

Cadot, O., Gonseth, C., Thalmann, P. (2009): *The effect of energy efficiency enhancement on innovation and competitiveness*, Energie Trialog Schweiz, Lausanne.

Crassous, R., Hourcade, J. C., Sassi, O. (2006): *Endogenous structural change and climate targets modeling experiments with Imaclim-R*, The Energy Jorunal, Endogenous Technological Change and the Economics of Atmospheric Stabilisation Special Issue, pp. 259-276.

Demailly, D., Quirion, P. (2007): *European Emission Trading Scheme and competitiveness: a case study on the iron and steel industry*, Energy Economics, 30, pp. 2009-2027.

Ecoplan (2007): *Auswirkungen langfristig hoher Oelpreise*, Bern.

Ecoplan (2008): *Volkswirtschaftliche Auswirkungen von CO2-Abgaben und Emissionshandel fuer das Jahr 2020*, Bern.

Ecoplan (2009): *Volkswirtschaftliche Auswirkungen der Schweizer Post-Kyoto Politik*, Bern.

Gerlagh, R., van der Zwaan, B. (2003): *Gross world product and consumption in a global warming model with endogenous technological change*, Resource and Energy Economics, 25, pp. 35-57.

Frederick, S., Loewenstein, G., O'Donoghue, T. (2002): *Time discounting and time preference: a critical review*, Journal of Economic Literature, 40(2), pp. 351-401.

Jaffe, A. B., Peterson, S. R., Portney, P. R., Stavins, R. N. (1995): *Environmental regulation and the competitiveness of U.S. manufacturing: what does the evidence tell us?*, Journal of Economic Literature, 33(1), pp. 132-163.

Jaffe, A. B., Palmer, K. (1997): *Environmental regulation and innovation: a panel data study*, The Review of Economics and Statistics, 79(4), pp. 610-619.

Kemfert, C. (1998): *Estimated substitution elasticities of a nested CES production function approach for Germany*, Energy Economics 20, pp. 249-264.

Lanoie, P., Patry, M., Lajeunesse, R. (2008): *Environmental regulation and productivity: testing the Porter hypothesis*, Journal of Productivity Analysis, 30, pp. 121-128.

Lau, M. I., Pahlke, A., Rutherford, T. F. (2002): *Approximating infinite-horizon models in a complementarity format: A primer in dynamic general equilibrium analysis*, Journal of Economic Dynamics and Control, 26, pp. 577-609.

Lopez, R. E., Anriquez, G., Gulati, S. (2007): *Structural change and sustainable development*, Journal of Environmental Economics and Management, 53, pp. 307-322.

Massetti, E., Nicita, L.(2010): *The optimal climate policy portfolio when knowledge spills across sectors*, Fondazione Eni Enrico Mattei, Nota di Lavoro 2010.96.

Newell, R. G., Jaffe, A. B., Stavins, R. N. (1999): *The induced innovation hypothesis and energy-saving technological change*, The Quarterly Journal of Economics, 114(3), pp. 941-975.

Nordhaus, William D. (2007): *A review of the Stern Review*, Journal of Economic Literature, 155, pp. 686-702.

Palmer, K., Oates, W. E., Portney, P. R. (1995): *Tightening environmental standards: the benefit-cost or the no-cost paradigm?*, The Journal of Economic Perspectives, 9(4), pp.119-132.

Paltsev, S. (2004): *Moving from static to dynamic general equilibrium economic models (notes for a beginner in MPSGE)*, MIT Joint Program on the Science and Policy of Global Change, Technical Note No. 4.

Pittel, K., Bretschger, L. (2010): *The implications of heterogeneous resource intensities on technical change and growth*, Canadian Journal of Economics, forthcoming.

Popp, D. (2003): *Induced innovation and energy prices*, The American Economic Review, 92(1), pp. 160-180.

Porter, M. E. (1991): *America's green strategy*, Scientific American, 264(4), 168.

Porter, M. E., van der Linde, C. (1995): *Toward a new conception of the environment-competitiveness relationship*, The Journal of Economic Perspectives, 9(4), pp. 97-118.

Romer, P. (1990): *Endogenous technical change*, Journal of Political Economy, 5(2), pp. 71-102.

Rutherford, T. (2004): *Dynamic General Equilibrium with GAMS/MPSGE*, UNSW Workshop, Sydney, Australia.

Sceia, A., Thalmann, P., Vielle, M. (2009): *Assessment of the economic impacts of the revision of the Swiss CO2 law with a hybrid model*, REME-Report-2009-002, Lausanne.

Simpson, R. D., Bradford, R. L. III (1996): *Taxing variable cost: environmental regulation as industrial policy*, Journal of Environmental Economics and Management, 30, pp. 282-300.

Smulders, S., de Nooij, M. (2003): *The impact of energy conservation on technology and economic growth*, Resource and Energy Economics, 25(1), pp. 59-79.

Stephan, G., Mueller-Fuerstenberger, G. (1998): *Discounting and the economic costs of altruism in greenhouse gas abatement*, Kyklos, 51(3), pp. 321-338.

Stern, N. (2007): *The Stern Review report: the economics of climate change*, Cambridge University Press, Cambridge.

Xepapadeas, A., de Zeeuw, A. (1999): *Environmental policy and competitiveness: the Porter hypothesis and the composition of capital*, Journal of Environmental Economics and Management, 37, pp. 165-182.

A Appendix

A.1 Calculating r and ρ

In what follows, we explain how the equations for the interest rate r and the implicit intertemporal discount rate ρ (as used in section 8.2 of this chapter) can be derived. We follow Lau, Pahlke and Rutherford (2002) and Paltsev (2004) and their method of calibration for dynamic models. We first aim at expressing the parameter r as a function of other model parameters and benchmark values that can be taken from the data. Then we derive an expression for the implicit rate of pure time preference ρ.

We start by assuming that a representative consumer maximizes his lifetime utility according to

$$max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t U(C_t), \tag{1}$$

with ρ denoting the rate of pure time preference and $U(C_t)$ being the utility function. In each period, the consumer allocates his income between consumption and investments (both by physical and non-physical investments), i.e. total output is either consumed or invested. Thus, we have

$$C_t = F(K_t) - I_t, \tag{2}$$

where F denotes the production function, and K_t is capital. For simplicity, we abstract from other inputs to production (such as labor or energy). Capital is increased by investments and is assumed to depreciate at a given rate δ. Between two periods, it therefore evolves in the following way:

$$K_{t+1} = K_t(1-\delta) + I_t, \tag{3}$$

The consumer has one decision variable (C_t), and the capital stock in $t+1$ (K_{t+1}) is determined by investments in period t. This means that there are two constraints, one for C_t and one for K_{t+1}. To set up the Lagrangian, we first combine equations 2 and 3 to obtain

$$K_{t+1} = K_t(1-\delta) + F(K_t) - C_t, \tag{4}$$

as a side condition for the maximization problem. The Lagrangian then looks as follows

$$\mathfrak{L} = \left(\frac{1}{1+\rho} \right)^t U(C_t) + \lambda_t \left(K_t(1-\delta) + F(K_t) - C_t - K_{t+1} \right) \tag{5}$$

Maximization of equation 5 over C_t considering the evolution of the capital stock yields the following first order conditions:

$$\left(\frac{1}{1+\rho}\right)^t \frac{\partial U(C_t)}{\partial C_t} = \lambda_t, \tag{6}$$

and

$$\lambda_t = \lambda_{t+1} \left((1-\delta) + F'(K_t)\right). \tag{7}$$

Under the assumptions of perfect competition and constant returns to scale, price equals marginal cost. In the case here, this means that the prices of consumption and capital have to be equal to the corresponding marginal costs. We can then reformulate equations 6 and 7 in the following way:

$$P_t = \left(\frac{1}{1+\rho}\right)^t \frac{\partial U(C_t)}{\partial C_t} \tag{8}$$

and

$$P_{K,t} = P_{K,t+1} \left((1-\delta) + R_{K,t}\right), \tag{9}$$

where we also assumed that the marginal product of capital equals its rental rate. As capital can either be bought or rented, this means that there are actually two prices for capital: The purchase price P_K and the rental price R_K. The underlying assumption here (again considering two time periods) is that the household purchases the capital stock in period t at $P_{K,t}$, then rents it to the firms at a rate $R_{K,t}$ and sells it again at $t+1$.

When calibrating the model to a steady state where all variables grow at constant rates, we also need to assume a benchmark price path. Because we calibrate the model to a base year, we express future prices in terms of present value. Between two periods t and $t+1$, prices in these two periods are then related in the following way:

$$P_{t+1} = \frac{P_t}{1+r}, \tag{10}$$

with r being the nominal interest rate and hence the parameter we are looking for. For convenience, we will assume that prices in the base year at $t = 0$ are equal to 1 (so we have that $P_0 = 1$). Equation 10 can then be generalized to express prices in any future period τ as

$$P_\tau = \left(\frac{1}{1+r}\right)^\tau, \tag{11}$$

Note that this formulation essentially implies a decreasing price path over time. In this sense, the expression of future prices in terms of present value also prevents output from growing without bound. In a growing economy, nominal output must be bounded for reasons of numerical optimization. Without this restriction, the model would be unable to find a solution. We can interpret this price path as being the result of some sort of monetary policy that aims at stabilizing future development.

According to equation 10, we have $P_{K,t} = P_{K,t+1}(1+r)$. This can be used to remove $P_{K,t+1}$ in equation 9. This yields

$$R_{K,t} = \delta + r \tag{12}$$

as an expression for the rental rate of capital. Equation 12 can be interpreted as a no-arbitrage condition. If capital and other loans or bonds are perfect substitutes (which is a prerequisite for no arbitrage), the two returns have to be equalized. When investing in other loans, the household receives an interest rate r. The return on capital is $R_{K,t}$ minus the depreciation rate. We can rearrange equation 12 to obtain $r = R_{K,t} - \delta$, which is exactly the no-arbitrage condition just described.

We need to consider two further relations. First, the data given in the input-output table represents values and not stocks. As far as capital is concerned, this means that the entries in the data refer to the value of the capital stock at period t (denoted V_t), which is simply given by

$$V_t = K_t * R_{K,t}. \tag{13}$$

Second, in a steady state, all capital grows at a constant rate (which we define by grk). Between two periods, capital then evolves according to:

$$K_{t+1} = (1 + grk)K_t. \tag{14}$$

We can then use equations 3 and 14 to derive investments in the steady state. The following equation results:

$$I_t = (\delta + grk)K_t. \tag{15}$$

This is also a familiar condition. It says that in a steady state, actual investments I_t and break-even investments $(\delta + grk)K_t$ have to be equal.

Replacing K_t using equation 13 and implementing equation 12 yields the following expression for investments in the base period (at $t = 0$):

$$I_0 = \frac{(\delta + grk)V_0}{\delta + r}. \tag{16}$$

This can then be rearranged to obtain the equation for the nominal interest rate r shown in the main text:

$$r = \frac{(\delta + grk)V_0}{I_0} - \delta. \tag{17}$$

Hence r is given as a function of initial investments and the value of the capital stock, the depreciation rate and the benchmark growth rate.

Steady state calibration is also the basis for the derivation of the implicit rate of pure time preference ρ. Remember that ρ does not have an explicit representation in the model. We can, however, derive the value of ρ implied by parameters that are used in the model. The utility function used in the model reads

$$U(C) = \left[\sum_{t=0}^{T} \left(\frac{1}{1+\rho} \right)^{t} C_t^{1-\sigma_W} \right]^{\frac{1}{1-\sigma_W}}. \tag{18}$$

Preference orderings are defined by the marginal rate of substitution. Again given two periods t and $t+1$, the marginal rate of substitution between these two periods is given by

$$\frac{\partial U \backslash \partial C_{t+1}}{\partial U \backslash \partial C_t} = \frac{1}{1+\rho} \left(\frac{C_t}{C_{t+1}} \right)^{1-\sigma_W}. \tag{19}$$

In equilibrium, the marginal rate of substitution must be equal to the relation of prices in periods $t+1$ and t (i.e. it is equal to $\frac{P_{t+1}}{P_t}$). According to equation 10, P_{t+1} and P_t are related in the following way:

$$\frac{P_{t+1}}{P_t} = \frac{1}{1+r}. \tag{20}$$

In the steady state, consumption grows at a constant rate $1+gr$. We therefore have

$$C_{t+1} = (1+gr)C_t. \tag{21}$$

Given this and equations 19 and 20, we get

$$\frac{1}{1+\rho} \left(\frac{1}{1+gr} \right)^{1-\sigma_W} = \frac{1}{1+r}, \tag{22}$$

which is the standard Keynes-Ramsey rule. This can then be rearranged to obtain the implicitly defined rate of pure time preference ρ, which is a function of r, the steady state growth rate of consumption $1+gr$ and the intertemporal elasticity of substitution θ:

$$\rho = \frac{1+r}{(1+gr)^{1-\sigma_W}} - 1. \tag{23}$$

These calculations highlight that both r and ρ depend on other model parameters. In particular, r depends on investments and the capital stock, which are both given by the data. In combination with the depreciation rate δ and the benchmark growth rate of capital grk, we can derive the value for r that is to be used in the model. In accordance with other studies, we set δ to 4%. The benchmark growth rate of capital is set to 1%, which reflects the average growth rate of capital in Switzerland in the past 30 years. This gives us a value of 1.57% for r. Given r, we can derive the value for the implied rate of pure time preference ρ. According to equation 23, ρ is then equal to 0.9%.

A.2 Nested production functions, data set and growth rates

The following figures show the nested production functions of the regular sectors (using the example of sector $Z1$ and of the energy sector. The benchmark data set is shown in Table 2, growth rates resulting from the different scenarios in Table 3.

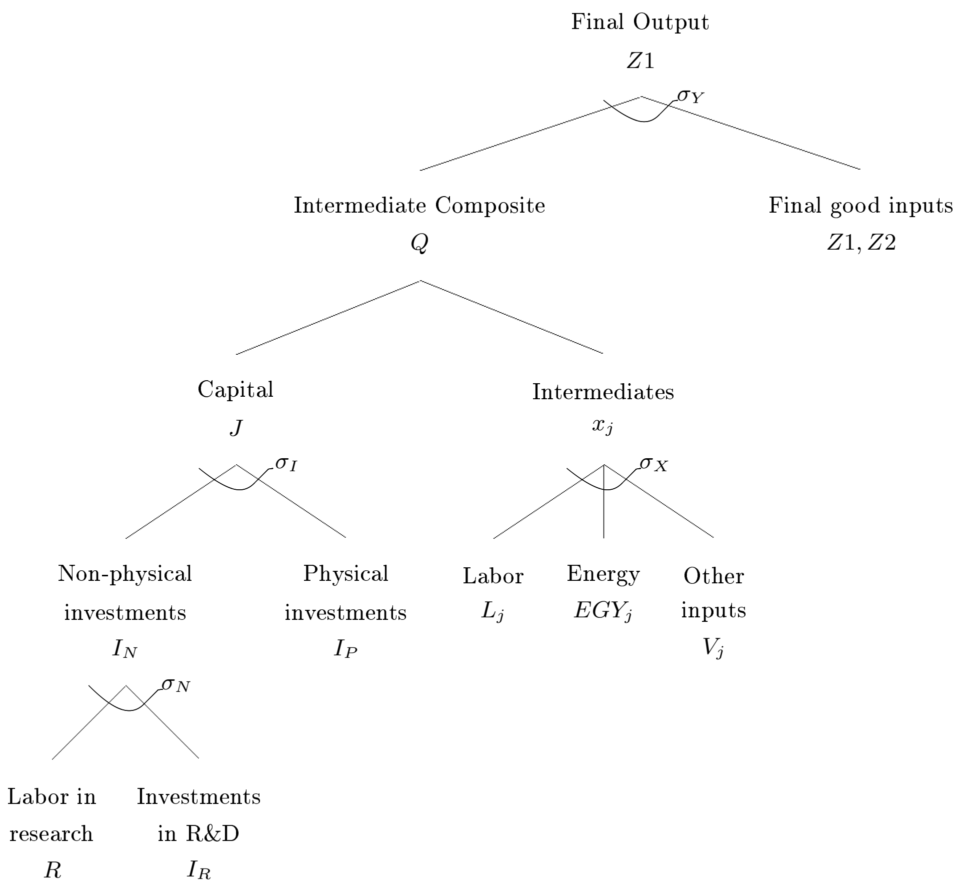


Figure 25: Nested production function of regular sector Z1

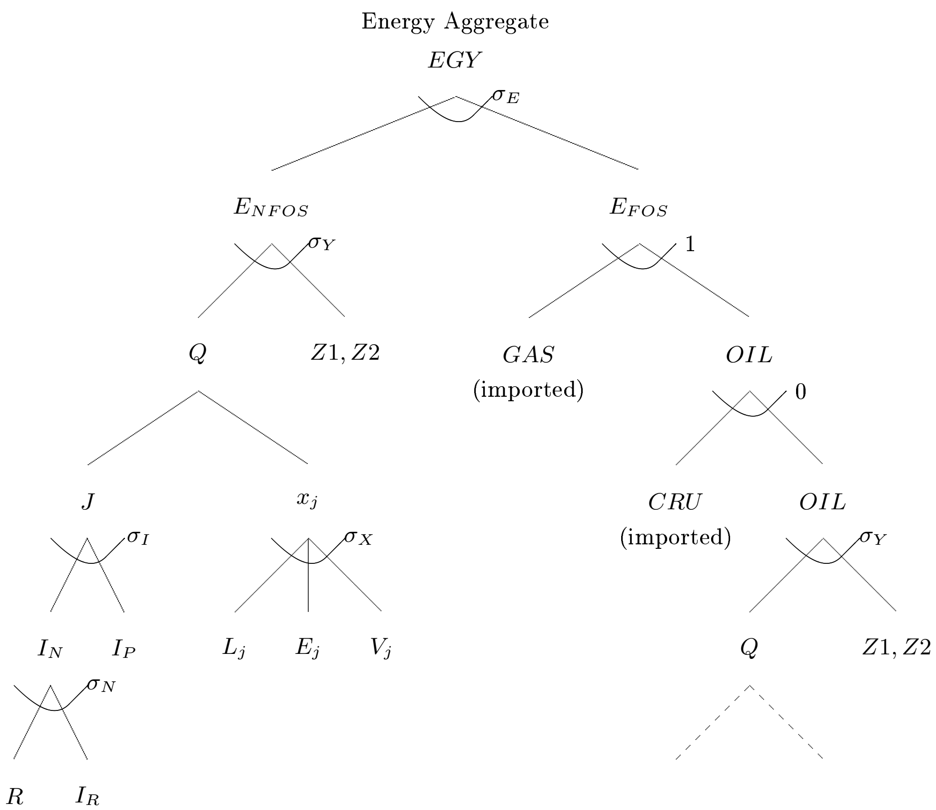


Figure 26: Nested production function of the energy sector

	$Z1$	$Z2$	EGY	OIL	CRU	GAS	C	I_P	I_N	Exp	**SUM**
$Z1$	60000	50000	2000	200	0	0	92800	25000	5000	100000	335000
$Z2$	50000	60000	2000	200	0	0	92800	25000	5000	100000	335000
EGY	15000	500	10000	100	0	0	3000	900	500	1940	31940
OIL	0	0	1040	0	0	0	0	0	0	3510	4550
CRU	0	0	0	50	0	0	0	0	0	0	50
GAS	0	0	1000	0	0	0	0	0	0	0	1000
R									500		500
L	65000	69500	7000	150	0	0					141650
K	31250	31250	6250	150	0	0					68900
V	13750	23750	1750	200	0	0					39450
Imp	100000	100000	900	3500	50	1000					20540
SUM	335000	335000	31940	4550	50	1000	188600	50900	11000	205450	1163490

Table 2: Benchmark data set

	Scenario					
Variable	BAU	Base	R&D subs.	Capital subs.	High σ_E	High ρ
$Y(Z1)$	1.34%	1.04%	1.13%	1.12%	1.23%	1.03%
$Y(Z2)$	1.34%	1.46%	1.50%	1.51%	1.36%	1.46%
$Y(EGY)$	1.34%	0.20%	0.28%	0.28%	1.03%	0.18%
$Y(Z1+Z2)$	1.34%	1.26%	1.32%	1.32%	1.30%	1.25%
C	1.34%	1.27%	1.27%	1.27%	1.31%	1.25%

Table 3: Annual growth rates in the different scenarios

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