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18. Kurzfassung

Die Abbildung des technologischen Wandels ist in den vorherrschenden umwelt-ökonomischen Modellen nicht adäquat. Technologischer Fortschritt ist in der Regel exogen, so dass Politiken ohne Einfluss auf Innovationen bleiben. Top-down Modelle überschätzen typischerweise die technologischen Substitutionsmöglichkeiten während technologie-orientierte bottom-up Modelle makroökonomische Zusammenhänge zu berücksichtigen.

In dem vorgestellten neuen Modellierungsansatz wird technologischer Fortschritt prozessspezifisch und politikinduziert abgebildet. Die Wahl zwischen limitationalen Produktionslinien (technologischen Paradigmen) wird für die Stahl-, Papier- und Zementherstellung in Deutschland explizit modelliert und in das makro-ökonometrische Modell PANTA RHEI integriert. Die Technologiewahl und die Entwicklung des technischen Fortschritts (in Form des Best-practice Energieeinsatzes) werden ökonometrisch geschätzt. Die Ergebnisse zeigen für die meisten Technologien einen empirischen Zusammenhang zwischen Energiepreisen und technischem Fortschritt. Mit Hilfe der neuen Modellierung lassen sich die Wirkungen von Politiken technologie-spezifisch analysieren sowie die Politikrelevanz langer Diffusionszeiten in energie-intensiven Sektoren empirisch darstellen. Simulationen mit einer aufkommensneutralen CO_2-Steuer zeigen, dass der herkömmliche Modellierungsansatz die Minderungskosten überschätzt, dass die Steuer keinen merklichen Einfluss auf das Sozialprodukt hat und dass – da die Einnahmen zur Senkung der Lohnnebenkosten verwendet werden – es zu deutlich positiven Arbeitsplatzeffekten kommt.

In zukünftigen Arbeiten könnte die neuartige Modellierung (i) auf andere Sektoren angewendet werden, (ii) die begrenzte Substituierbarkeit der technologischen Paradigmen stärker berücksichtigen, (iii) den Einfluss von (ggf. politik-induzierten) Nachfrageverschiebungen integrieren, und (iv) um weitere regulatorische Kontextfaktoren erweitert werden.

19. Schlagwörter

Endogener technischer Fortschritt, induzierte Innovationen, Nachhaltigkeit, umweltökonomische Modelle, bottom-up Modelle, top-down Modelle, Klimapolitik, CO_2-Steuer

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18. Abstract

In most environmental-economic models technological change is not modelled adequately. In particular, technological change is portrayed as exogenous leaving no role for policy intervention to affect innovation. Top-down models typically overrate the options for technology substitution while technology-based bottom-up models cannot account for macroeconomic effects.

A new modelling approach is developed which allows technological progress to be modelled as process-related and policy-induced. The choice between limitational production technologies (technological paradigms) is explicitly modelled and is implemented in the macro-econometric model PANTA RHEI for the German iron and steel, paper, and cement industries. Specifically, technology choice and innovation in terms of energy intensity of the best-practice technologies are estimated econometrically. Results imply, that energy prices induce innovation for most but not all technologies considered. The new approach allows for a technology-specific analysis of policy interventions and empirically highlights the policy relevance of long diffusion times for new technologies in those sectors. Simulation results for a revenue neutral CO_2-tax show that the conventional approach overestimates the costs of climate policy, that effects on GDP are small and – because tax revenue is used to lower labour costs – that employment increases significantly.

In the future, the new approach may be (i) applied to other sectors, (ii) deepened to capture limited substitutability between competing technological paradigms, (iii) extended to account for (policy-induced) demand shifts, and (iv) broadened to allow for other regulatory context factors.

19. Keywords
Endogenous technological change; induced innovation, sustainability, environment-economic model, bottom-up models, top-down models, climate policy, CO_2-emissions

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1 Introduction

The impacts of policy interventions on the economy and on the environment crucially depend – among other things – on how they effect technological change. Consequently, the results of policy simulations in environmental-economic models are decisively influenced by the modelling of technological change. For climate policies, Weyant (1993, 2000) and Jaffe et al. (2003) note that variations in the model results for the estimated costs of these policies can be traced back to a large extent to varying assumptions about how technological change is characterised. Nevertheless, most environmental-economic models treat technological change exogenous, that is, endogenous technological change such as induced innovations or learning effects are not captured by these models. In models where technological progress is portrayed as exogenous, policy interventions cannot affect the rate or direction of technological change.

According to the theory of *induced innovation* developed originally by Hicks (1932), changes in relative factor prices will result in innovations which require less of the more expensive factor. Thus, policies, such as energy or carbon taxes, which increase the price of energy or carbon not only result in a different factor mix for the existing production set, but lead to the invention of new, more energy-efficient technologies.[1] From the hypothesis of induced innovation, conclusions can be derived for the effects of various policy instruments on innovation, in particular on the diffusion of new technologies.[2] Empirical work by Newell et al. (1999), Grupp (1999) and Popp (2002, 2003) support the view that higher energy prices induce innovation. Newell et al. (1999) develop an innovative approach to test the induced innovation hypothesis empirically using time series data on consumer durable goods. Analyses based on patent data tend to show an existing link between energy prices and innovations (Popp 2002, 2003, Grupp 1999). Similarly, Lanjouw and Mody (1996) and Jaffe and Palmer (1997) also find positive correlations between expenditures for pollution control and environmental innovation activities.

Arrow (1962) was the first to include learning effects in the analysis of economic growth. Such learning effects imply that the specific labour input per unit of capital decreases with the age of capital vintages. Investments not only improve the productivity of the present capital stock but, since they generate new knowledge, they also increase

1 Jaffe et al. (2003) provide an excellent overview on environmental policies and technological change.

2 See Fischer and Newell (2004) for a recent theoretical and stylized empirical assessment of various climate policy options. The few empirical studies on the benefits of market-based policy instruments include Kerr and Newell (2001) and Newell and Rogers (2003).

future productivity. In empirical economic models, this type of technological change is often captured through specific costs, which (negatively) depend on accumulated capacity. Here, accumulated capacity represents knowledge which was generated during production (learning-by-doing) and application (learning-by-using). In models based on the so-called "New Growth Theory", which has been developed by Lucas (1988), Romer (1990), Barro (1990) and Grossman and Helpman (1990), endogenous technological change emerges as the result of public and, in particular, private R&D investments. Investments in R&D not only benefit the investor firm, but increase the productivity or the product quality for other firms as well. Eventually, long-term economic growth is only feasible because of these so-called spill-over effects. Because of the high complexity, empirical models based on the "new Growth Theory" are rare.

Current modelling approaches for climate policy analyses can be distinguished in bottom-up and top-down models (Weyant 1999, 2000, IPCC 2001).[3] Bottom-up models are engineering-based partial equilibrium models of the energy sectors which explicitly model different technologies and their improvement over time to capture all energy saving possibilities. Bottom-up models calculate the least-cost combination of a set of available or expected technologies for given production and emission targets. Thus, technological change depends – to a large extent – on the set and the characteristics of the technologies included a priori in the database. In some dynamic bottom-up models endogenous technological change is included via experience curves, where – because of learning by doing effects – the unit production costs depend negatively on total historic production or installed capacity. Since bottom-up models neglect market failures, uncertainty and rebound effects (Binswanger 2001) - lower energy prices due to technological change will stimulate demand - the costs calculated for climate change policies tend to be biased downward.

By contrast, top-down models such as computable general equilibrium (CGE) models describe the general economy and all the economic effects of price changes, including income and substitution effects. In most top-down models, technological progress is typically captured through a trend variable. Hence, endogenous, policy-induced technological progress is not represented. As pointed out above, the modelling of technological change crucially affects the costs of policy interventions calculated by environment-economic models. If policy-induced technological change is not taken into account in these models, costs of climate policies will be overestimated, ceteris paribus (Popp 2002, 2004). For example, using the DICE model of global warming, Popp (2004) finds

3 For recent overviews on the modelling of technological change see, for example, Löschel (2002), Grübler et al. (2002), Edmonds et al. (2000) or Weyant and Olavson (1999).

in the case of a carbon tax that ignoring induced technological change overestimates costs to society by almost 10 %. As mentioned earlier, another form of endogenous technological progress results from so-called learning-by-doing effects. From a normative perspective, learning-by doing effects imply investments in reduction measures at an early stage (Van der Zwaan et al. 2002, Goulder and Matthai 2000).

Even in models which allow for endogenous technical change such as Goulder and Schneider (1999) or Buonanno et al. (2003), there is no linkage to the actual technologies responsible for the technological development. Popp (2004, p. 743) rather criticizes that "none of the existing models make use of empirical estimates on the nature of technological change to calibrate the model".

Attempts to endogenise technical change via technical knowledge which is formed through accumulated research and development (R&D) expenditure fail because their impacts cannot be explicitly related to the complex input structures of the technologies. At most, more recent empirical work examines which influence R&D activities, recorded for example through patents or licence fees, have on the long-term production function (Jungmittag et al. 1999). In the predominant computable general equilibrium models, technical knowledge enters the production function alongside the other usual variables in the form of accumulated R&D expenditures. The R&D activities can then be endogenised via the system of factor demand functions derived from the optimisation.

Further criticism regarding the portrayal of technological change in general equilibrium models arises from the postulated type of production functions which imply unlimited factor substitution possibilities. Since in reality, substitution possibilities are limited, the assumption of unlimited factor substitution results in an underestimation of the costs of climate policies. This criticism holds in particular for the large industrial "energy consumers" such as the electricity sector, steel production, producers of non-ferrous metals, the cement industry or pulp and paper manufacturing which are better characterised by limited production relations of the "putty-clay" type. Gilchrist and Williams (2000) estimate the share of putty-clay technologies in total industrial production at 50 % to 70 % - and even higher in energy-intensive sectors. For production functions of this type, when making investment decisions, a choice can be made between different limitational processes, but the input structures of the existing plants are fixed.

To summarise, it can be concluded that, on the one hand, innovation and technological change are only represented superficially in the predominant top-down models.[4] In

4 For further discussion and criticism on the modelling of technological change see also Hemmelskamp (1999), Frohn et al. (1998) and FIU (1996).

addition the assumption of complete factor substitution does not correctly reflect the actual production processes in many production sectors. On the other hand, technology-based bottom-up models cannot account for macroeconomic effects and underestimate the cost of climate change policies.

In this research project, we have developed a new modelling approach, which addresses both lines of criticism. First, technological progress is modelled as process-related and policy-induced. Second the choice between limitational production technologies (technological paradigms) is explicitly modelled. This new modelling approach has been applied and implemented into the macro-econometric model PANTA RHEI (Meyer and Ewerhart 1998, Lutz 2000, Meyer 2001, Bach et al. 2002) for three energy-intensive industries in Germany:

- the iron and steel industry,
- the pulp and paper industry, and
- the cement industry.

The new integrated bottom-up/top-down modelling approach permits a process-specific analysis of the impacts of policy measures and changed frame conditions, where the choice of technology and technological progress can be described endogenous to the model.[5] The policy simulations allow for analyses of macroeconomic and environmental effects of climate policy, where the macroeconomic effects include the changes in sector output, investment, GDP or employment. In addition, while existing macroeconomic analyses focus on economic and environmental impacts of climate policy, we also consider the third "pillar of sustainability", social impacts. To do so, qualitative employment effects of environmental policy are explored, such as job qualification requirements, job characteristics, and working hours. Thus, in the sense of a comprehensive understanding of sustainability, the economic and social ramifications of policy instruments can be analysed in addition to its environmental consequences in an integrated and consistent policy framework.[6]

In chapter 2, the modelling framework and its integration into the existing macroeconometric model PANTA RHEI is presented in general, followed by a brief discussion of the concept of innovation applied in this project. Chapter 3 contains a descrip-

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5 Vögele (2000) has developed a detailed process-oriented model for the power industry in the federal state of Baden-Württemberg and integrated this model into a simple macroeconomic model.

6 However, no attempt is made to evaluate (weigh) the trade-offs between the different dimensions.

tion of the technologies and the modelling approaches chosen for the German steel, paper and cement sectors. Those descriptions are summaries of more detailed sector reports.7 Policy simulations for individual sectors are presented in chapter 4.[8] For the steel sector, it is also analyzed whether – because of investment cycle dynamics - there was or will be a "window of opportunity" for a new steel-making technology[9]. In chapter 5 the effects of a tax on CO_2-emissions and on GDP are simulated. In addition, results of the new modelling approach are compared to the conventional modelling approach. In chapter 6 qualitative employment effects of a CO_2-tax are also analysed for the new modelling approach.[10] Chapter 7 summarizes the main results, concludes and points to open research questions.

7 For the steel sector, see Schleich et al. (2002), for the paper industry see Nathani et al. (2003), and for the cement industry see Angerer et al. (2003).

8 Simulation results for the steel sector are published as Lutz et al. (2005a) and for the paper sector as Nathani et al. (2004).

9 The section on „windows of opportunity" is a brief summary of the paper by Lutz et al. (2005b).

10 Simulation results for all sectors have been published as Lutz et al. (2004).

2 General modelling framework

In this section we provide a general overview of the modelling approach used. Further details on the actual implementation as well as results of the econometric analyses for the three industry sectors can be found in section 3.

The new modelling approach was implemented into the econometric input-output model PANTA RHEI. PANTA RHEI implies - in contrast to general equilibrium models based on CES functions - limitationality of the input factors in the individual branches.[11] The input coefficients are modelled as price-dependent, which is then interpreted, not as the result of substitution, but of cost-/profit-induced technological progress, which results in changes in the choice of process.

In the new modelling approach developed in this project, economic variables be linked to actual production processes. In this sense the new modelling approach allows for an integrated bottom-up/top-down analysis. To do so, among others, investments, production amounts, detailed input structures and the process-specific input demand of the respective best-practice technologies (*trajectories*) are determined for the historical observation period 1980-2000 for the different process lines (*paradigms*) (Dosi 1982, 1988) in the German steel, paper and cement sectors. Based on these data, the paradigm-specific investments, i.e. the choice of technology and the development of technical change in the model can be estimated econometrically for each paradigm. The correlations found then serve as the basis for the policy simulations as described in section 4 and 5.

In terms of innovation, the taxonomy developed by Pavitt (1984) and the analyses carried out by Pavitt et al. (1989) imply, that the conditions for technological change and its implications for the sectors in the economy differ considerably (Rahmeyer 1993). Following Pavitt (1984) the steel, pulp and paper and the cement industry may be best characterized as being "supplier dominated" that is, these types of sectors contribute relatively little to process innovation itself. Instead, technical progress, which tends to be primarily process-integrated, is primarily realized via new capital goods. Dosi (1988) stresses, that in such sectors, innovation proceeds through the adoption and diffusion of best-practice technologies (also Silverberg 1988). Thus, technological progress is incorporated in the capital goods. To briefly illustrate, the technological paradigms, which will be presented in more detail in section 3, are briefly described.

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11 A detailed description of PANTA RHEI can be found in Annex A.

For the production of steel, two most important paradigms for crude steel production in Germany are (i) blast oxygen furnace (BOF) steel production, i. e., the process of producing primary materials following the route sintering plant (ore concentration) / coking plant - blast furnace (iron making) - converter (steel production), and (ii) electric arc furnace (EAF) steel production, i. e. processing steel scrap primarily in electric arc furnaces (to a lesser extent in induction furnaces). The production of electric arc furnace steel is more attractive from an energetic viewpoint, since it requires less than half the primary energy demand of the BOF steel route.

Paper is usually manufactured in a two-step process. In a first step the main resource inputs, wood and waste paper, are mechanically or chemically processed into three different kinds of pulp. Mechanical and chemical pulp are processed from wood, whereas recycled pulp is processed from waste paper. According to the desired paper characteristics, a specific mixture of the different kinds of pulp, added by other mainly mineral substances (e.g. fillers and coatings), is further processed in a second step to paper. Energy consumption is highly process specific. The manufacturing processes need electricity and steam which are either generated on-site or – especially in the case of electricity – purchased (from outside). In the German paper industry a significant share of heat and electricity is delivered by co-generation. We chose a "composite technology" approach, distinguishing between two alternative process lines, (i) paper based on primary fibres (PFP) and (ii) paper based on secondary or recycled fibres (RCP). These process lines include the respective pulping and paper manufacturing processes and with regard to energy demand also an average energy supply technology.

In the production of cement, different raw materials are used, the most important one is limestone. These materials are prepared in either wet or dry processes. The German cement industry uses almost completely the dry processes. Then the raw materials are processed in rotary kilns under very high temperatures. The product of this process is called cement clinker. This process is the most energy intensive part of cement production. Coal is the most important energy source for this process, but the share of waste-based fuels has increased drastically in the last two decades.

To integrate the new modelling approach into PANTA RHEI the following modelling steps are implemented: Firstly, production levels for steel, paper and cement are econometrically estimated from the gross output of the respective industry. In PANTA RHEI gross output of an industry is explained by the demand of the 59 sectors. Next, production shares of the paradigms are regressed on a set of variables which generally includes material and energy input prices, the relative capacity share of both process lines. Splitting the production is then done proportionally to the capacity development of the paradigms. Then, real gross investments in the technological paradigms are estimated as a function of the real rate of interest, energy and material input prices, demand and relative production capacities. This modelling step makes it possible to describe the changes in the production structure and thus the input consumption of the production of the various paradigms resulting from a change in the process lines used via the choice of technology. In the next two sub-sections we will focus on the "key ingredients" of the new approach, the modelling of technology choice and of technological change.

2.1 Choice of technology in the steel, pulp and paper and cement industry

The choice of technology (adoption and diffusion) takes place in the new modelling approach via the new investments in alternative process lines (technological paradigms). In the conventional form of PANTA RHEI, the industry sectors are part of the 59 sectors described. To enlarge the model and explicitly describe the various paradigms for the steel and the paper industry, these are modelled in technical and economic detail and linked to the driving parameters of PANTA RHEI in a consistent way. In particular, technology choice is modelled as investments in the technological paradigms. Investment data are regressed on a set of variables which generally includes material and energy input prices, in the case of steel the prices of electricity and coke, as well as the ratio of production to capital stock The modelling approach applied, however, does not imply that energy prices are the only determinants for technology choice. Other cost factors such as costs for labour may also affect technology choice, but their impact is less direct. In PANTA RHEI costs for labour are also determined endogenously and they affect unit production costs and thus total production. Total production, in turn, affects capacity use of the competing technological paradigms which in turn is one of the determinants for technology choice.

For cement, the approach is simpler since there is only one technological paradigm, rotary kilns. At the same time parameters of PANTA RHEI such as energy input coefficients of the industries under consideration depend explicitly on the weighted energy input structures of the alternative technological paradigms. The same approach is applied to investment and prices. As pointed out earlier, in the conventional form of the model assuming a homogenous good for every product group including iron and steel or pulp and paper, specific technology information cannot be used.

2.2 Modelling technological change

Starting from the best-practice trajectories of the technological paradigms, it is possible to endogenise technical progress in the model. To do so, the relations between the time path of the best-practice fuel and the best-practice electricity consumption of the technological paradigms is regressed on a set of determinants which are supposed to reflect factors affecting the costs and benefits of new technologies to the adopters as well as factors affecting the technical development of energy efficiency. Thus, the determinants generally include relative energy and material input prices and R&D expenditures by the industry sectors and by the main technology suppliers, i. e. the mechanical engineering and electrical engineering sectors. In addition indices reflecting industry concentration in the production of steel, paper or cement in Germany were included. From a theoretical point of view, the impact of firm size or industry concentration on the adoption of new technologies is ambiguous (Hall and Kahn 2003, p. 9 or Hall 2004, p. 22). On the one hand, large firms or firms with a larger market share may use market power to appropriate the costs associated with the adoption of new technologies. Such up-front costs not only include investment costs, but also training of workers, marketing, or expenditures for research and development. Similarly larger firms are more likely to have internal financial resources available, and have better access to capital markets to finance the adoption of new technologies. In addition, larger companies may spread the potential risks associated with the new technologies easier because they tend to be more diversified in terms of the technologies installed. Thus, they may rather be in a position to test new technologies while keeping the old one operating as a safety cushion (at lower production levels). Finally, larger firms may capture economies-of-scale effects associated with the implementation of new technologies faster and they may spread the fixed costs of adoption across more production units. On the other hand, larger firms may be more bureaucratic and suffer from so-called X-inefficiencies. Such inefficiencies may be the result of complex and time-consuming decision processes, or of agency-related problems, such as lack of observability of individual behavior. Similarly, the degree of concentration of providers of new technologies may also have an impact on innovation and diffusion. Since highly concentrated providers tend to charge higher prices, they may slow diffusion, but they may also be in a better position to determine a common standard, increasing the benefits of adoption (Hall 2004, p. 21). Since no data is available for the industry concentration of suppliers to the steel, paper and cement producing sectors, this aspect could not be explored.

2.3 Summary of concept of innovation applied

Following Schumpeter (1942), the literature traditionally distinguishes between three separate stages of technological change: invention, innovation (= first application) and diffusion. Subsequent authors developed a finer disaggregation into five phases consisting of: recognition, invention, development, implementation, and diffusion (Modesto 1980). In recent years, this linear approach has been challenged and technological change is rather perceived as an evolutionary process where the different stages are interlinked via multiple feedback loops (Kemp 1997, Montalvo 2002). This research project captures, in particular, the impact of climate policy on the development, first application and the diffusion of technical innovations, that is energy efficient technologies in major energy-consuming industry sectors in Germany.[12] Thus, other types of environmental innovations such as organisational innovations, institutional innovations (reorganisation of social boundary conditions, legal relations and organising principles) or social innovations (changes in governing norms, behaviour or lifestyles) are neglected.[13] Based on actual historical data, we look at the determinants of technological change in terms of energy use as observed in the best-practice technologies in the German steel, paper and cement industry. Since the model used is based on econometric estimations, only determinants (or proxies) could be included which could be expressed as variables and where data was available. In summary, the following types of determinants for technical progress are used: fuel input prices, material input prices, R&D expenditure of case study industry, R&D expenditure of the supplying industries (e.g. mechanical and electrical engineering sectors), market structure (industry concentration, share of imports), product demand and existing production capacities, real interest rate (reflecting the costs of capital), and policy changes described as scenarios.

12 For further details see Schleich et al. (2004).

13 See Klemmer et al. (1999) for a systematic overview on the types of environmental innovations.

3 Modelling technological change in three energy-intensive industry sectors in Germany

In this section, the technological context and the concrete modelling of the German steel, paper and cement industry are described. The summaries presented are based on more detailed sector reports by Schleich et al. (2002), Schleich et al. (2003) Nathani et al. (2003) and Angerer et al. (2003) for the steel, paper and cement industry, respectively. As can be seen from Table 3-1, the sectors chosen combine for more than one third of final energy consumption in the German manufacturing sector.

Table 3-1: Sectoral final energy consumption in the German manufacturing sector in 1999[14]

Sector	Final energy consumption		Fuel consumption		Electricity consumption	
	PJ	Share in %	PJ	Share in %	PJ	Share in %
Minerals	216.3	9.1	187.2	11.3	29.1	4.0
Iron and steel	552.5	23.2	487.0	29.3	65.5	9.1
Non-ferrous metals	132.3	5.6	61.1	3.7	71.2	9.9
Basic chemicals	364.3	25.3	222.1	13.4	142.3	19.7
(other chemicals)	(110.6)	(4.6)	(78.1)	(4.7)	(32.6)	(4.5)
Pulp and paper	172.9	7.3	111.2	6.7	61.8	8.5
Glass and ceramics	98.0	4.1	79.0	4.8	18.9	2.6
Food	185.4	7.8	137.4	8.3	48.0	6.6
Others	551.4	23.1	297.7	17.9	253.7	35.1
Total[1)]	2383.9	100.0	1660.9	100.0	723.0	100.0

[1)] Manufacturing sectors including other mining, without oil processing industry

Source: German Energy Balances (1999)

14 For more recent years there is no official data on final energy use available at the level of industry sectors.

3.1 Modelling the steel industry

Before the main elements of the concrete implementation in the model can be presented for the steel sector, the technological correlations of crude steel production are explained which are relevant for the modelling.

3.1.1 Steel manufacturing

The two most important paradigms for crude steel production in Germany are (i) oxygen steel production, i. e., the process of producing primary materials following the route sintering plant (ore concentration) / coking plant - blast furnace (iron making) - converter (steel production), and (ii) electric arc furnace steel production, i. e. processing steel scrap in electric arc furnaces (to a lesser extent in induction furnaces) .[15]

The subsequent steps consist of ladle metallurgy to treat the liquid crude steel (adjustment of the material features and alloy composition) and the casting and rolling process which – for lack of data – cannot be explicitly included. The production of electric arc furnace steel is more attractive from an energetic viewpoint, since it requires less than half the primary energy demand of the blast furnace-oxygen steel route. Following the notation of, for example Kim and Worrell (2002, p. 829) or Ruth and Amato (2002), we refer to basic oxygen furnace (BOF) for oxygen steel production and to electric arc furnace (EAF) for electric steel production. The output development by the two technologies in Germany is shown in Figure 3-1. The share of EAF in Germany is about 27 % which is much lower than in the US where the share of EAF amounts to 43 % (Ruth and Amato 2002, p. 548).

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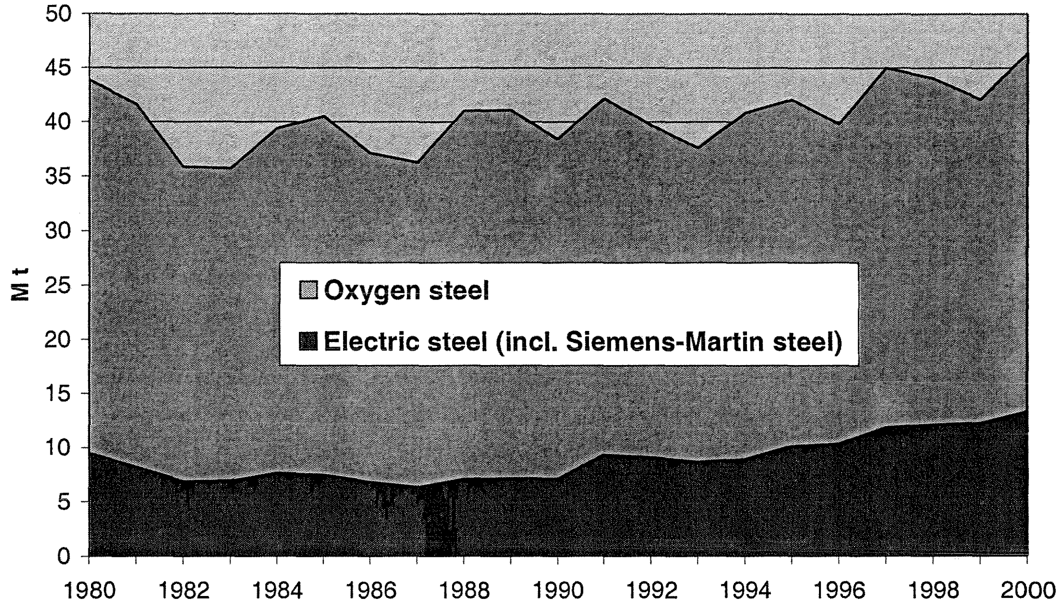
15 The scrap available to German steel producers may come from several sources: (i) circulatory scrap as own discards from the steel production at steel words, or from casting at foundries; (ii) left-over material from the steel processing industries (mechanical engineering, vehicle construction, steel and container construction etc.); (iii) old scrap from products that are no longer used; or (iv) scrap imports, in particular from the former Soviet Union.

Figure 3-1: Process lines of crude steel production in Germany

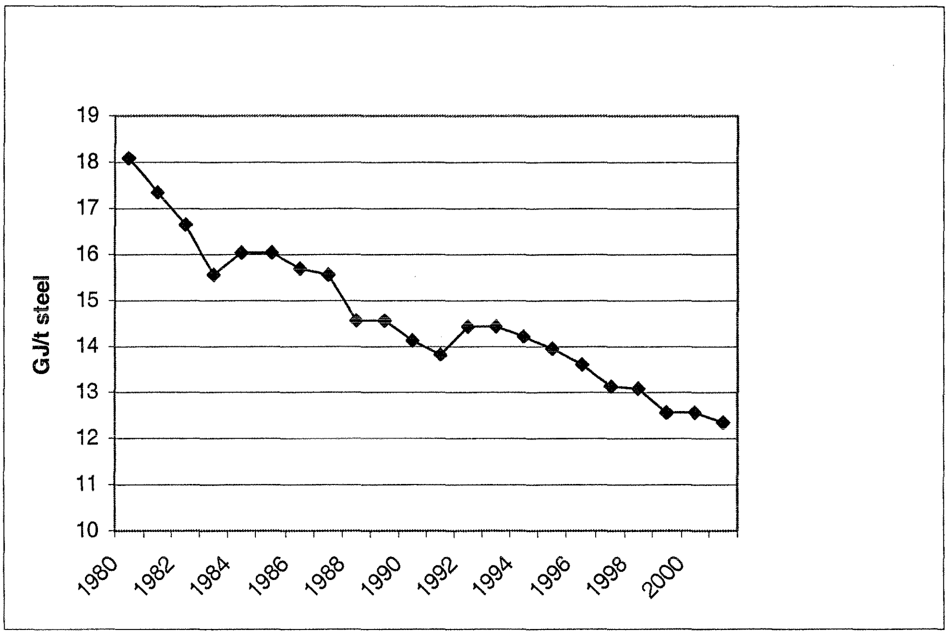


Source: WV Stahl and VDEH, different volumes

In general, the demand for steel is highly cyclical and follows closely the development of gross domestic product. Deviations from growth trends are however, more pronounced than for GDP in general. Since about one third of the steel market supply goes into vehicle construction and into mechanical engineering, steel production in Germany also depends on the world economy via the high export-share of the automobile and mechanical engineering sectors. Whereas the production of BOF steel has fluctuated around 30 million metric tons per year (M t/a) over the last twenty years, the production of EAF steel has increased continuously from around 6.5 M t/a in 1980 to over 13 M t/a in 2000. Germany is the largest producer of crude steel in the European Union, and the sixth largest producer world wide. Globalisation has also lead to takeovers and increased concentration in the German steel market. After the merger of Thyssen and Krupp in 1999, the newly created TKS is – with a production share of about one third - by far the largest producer in Germany. Similarly, the technical development in the steel industry was characterised in the past by the concentration on a few larger capacity production plants. The 104 blast furnaces operating in the Federal Republic in 1970 fell to 80 in 1980 and to 42 in 1990. In 2000, there were 22 blast furnaces left in Germany, of which only 16 were actually being operated. The number of oxygen steel converters fell from 47 to 26 between 1980 and 2000, that of electric arc furnaces from 71 to 29 (WV Stahl and VDEH, 2002).

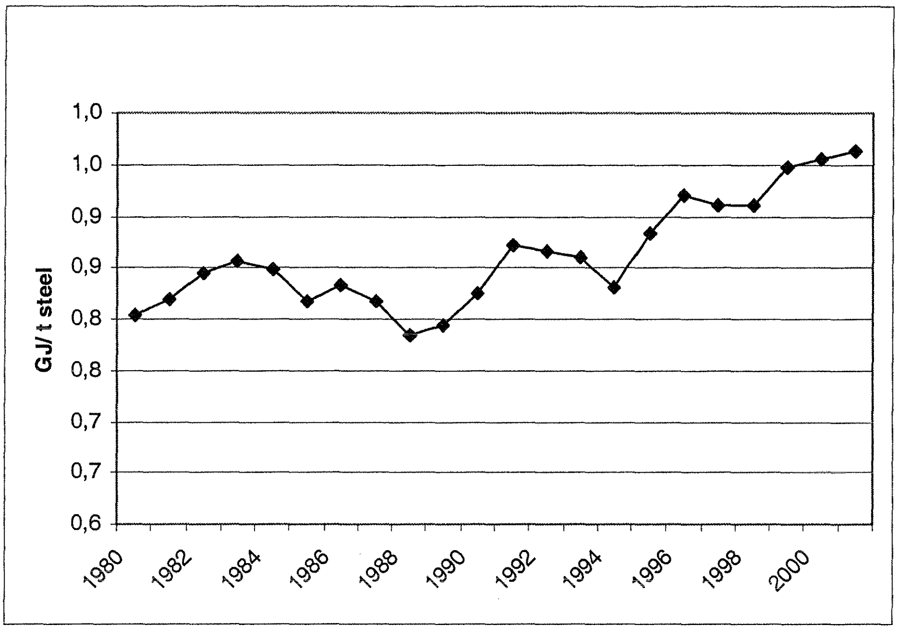
Figure 3-2 and Figure 3-3 show the development of average specific fuel use and electricity use in German steel production from 1980 to 2001. The curves reflect both, the substitution of coke-intensive BOF steel by electricity-intensive EAF steel, as well as the diffusion of more energy-efficient best-practice BOF and EAF technologies over these two decades.

Figure 3-2: Average specific fuel consumption in German steel production



Source: WV Stahl and VDEH, different volumes, own calculations

Figure 3-3: Average specific electricity consumption in German steel production



Source: WV Stahl and VDEH, different volumes, own calculations

In the historical period under review, technical measures to improve energy efficiency which are reflected in the chronological changes of the energy input structures include, among others, decreasing the consumption of the reducing agent in iron making - e. g. by partly substituting injected pit coal, fuel oil or scrap plastics for coke - measures in integrated ironworks, in coking plants and in sintering plants as well as control technology measures and the optimisation of the energy supply in electric arc furnace steel works (see Aichinger et al. 2001 or Köhle 1999).

3.1.2 Implementation of the new modelling approach

In the conventional form of PANTA RHEI, the steel industry is one of 59 industries described. To enlarge the model and explicitly describe the two paradigms of steel production, BOF and EAF, these are modelled in technical and economic detail and linked to the driving parameters of PANTA RHEI in a consistent way. At the same time parameters of PANTA RHEI such as energy input coefficients of the iron and steel industry depend explicitly on the weighted energy input structures of BOF and EAF. The same approach is applied to investment and prices. As pointed out earlier, in the conventional form of the model assuming a homogenous good for every product group including iron and steel, specific technology information cannot be used. OLS-estimation results for the diffusion of EAF steel for investment in EAF and in BOF and for energy intensity in the best-practice technologies appear in Table 3-2 and are explained in more detail below.[16]

Table 3-2: Regression results (t-statistics in parentheses)

Regressors	Lags	Dependent variable: Share of EAF steel production	Gross investment in EAF	Gross investment in BOF	Best practice electricity input in EAF	Best practice fossil fuel input in BOF
Constant		4.241 (14.19)			7.548 (1508.99)	11.148 (39.47)
Capacity EAF/Capacity BOF		0.823 (13.36)				
Price ratio scrap/iron ore		-0.160 (-3.701)				
Price ratio electricity/coke and hard coal		-0.052 (-1.11)	-1.911 (-4.71)			
Real interest rate			-0.212 (-2.73)			
Production/capital stock EAF			2.018 (5.07)			
Gross investment EAF	t-1		0.448 (3.33)			
Price ratio steel/mechanical engineering	t-2			3.495 (7.01)		
Production/capital stock BOF	t-2			0.749 (29.46)		
Price ratio electricity/steel	t-1				-0.333 (-7.364)	
R&D expenditures of mechanical engineering-mechanical engineering-mechanical engineerin g in constant prices						-0.327 (-4.91)
Price ratio coke/steel	t-1					-0.175 (-4.31)
Adjusted R^2		0.974	0.667	0.817	0.856	0.813
Durbin-Watson		1.79	2.22	2.10	1.60	2.07
Degrees of Freedom		12	16	15	17	16

16 All estimated regression equations can be found in Annex B.

Steel production

Firstly, the production of EAF and BOF has to be determined from the original PANTA RHEI model where steel production was included as part of the metal industry. So crude steel production is econometrically estimated from the gross output of the metal industry which is explained by the demand of the 59 industries. The share of EAF in total steel production can then be estimated as a function of the relation of the price of electricity to coke and coal, the price of scrap versus the price of iron ore as well as the relative capacity share of both process lines. The price ratios are included to reflect relative differences in unit costs. The ratio of EAF capacity to BOF capacity is included to reflect actual output potentials.

Estimation results in Table 3-2 show that all parameter estimates exhibit the expected signs and are highly statistically significant for the ratio of EAF capacity to BOF capacity and for scrap/iron price ratio. The price ratio of scrap to iron ore which is considered to be an important determinant for the diffusion of EAF exhibits the expected sign but – most likely due to the relatively small number of observations – turns out not to be statistically significant at the 10 % level. This conjecture is supported, for example, by results obtained by Schleich (2001) for the West German steel industry and for a different time horizon. The amounts of electric arc furnace steel and oxygen steel produced are then given by definition from the total production of crude steel.

Capital Investment

The actual choice of technology takes place via new investments in both process lines of crude steel production. The real gross investments of EAF steel technology can be estimated as a function of the ratio of electricity price to coal price (reflecting relative profitability of the two production lines), the ratio of actual production of EAF to the installed capacity for EAF (reflecting the pressure to expand), the real interest rate (reflecting real capital cost), and the investment of the last period (reflecting the fact that investments are typically spread out over several years). All parameter estimates exhibit the expected signs and are statistically significant at least at the 1 % level. The real gross investments of BOF are determined in the model by the ratio of the demand for oxygen steel to production capacity and the price relation of steel output and the most important demand sector, the mechanical engineering sector (reflecting expected profitability of the investment). Input price relations such as the price ratio between electricity and coal were not statistically significant for gross investments in BOF steel even at a low confidence level and were dropped from the regression equation. However, since the input price ratios affect production shares and thus capacity utilisation, they indirectly affect investment in BOF. Again, parameter estimates exhibit the expected signs and are statistically significant at least at the 1 % level.

This modelling step makes it possible to describe the changes in production structure and thus the changes in input use of crude steel production which result from a change in the technology choices. The next step describes the development of technological change which is modelled as a change in specific input use.

Technological change

Starting from the best-practice trajectories of the two technological paradigms, it is possible to endogenise technical progress in the model. To do so, the relations between the development over time of the best-practice energy consumption of electric or oxygen steel production, respectively, and a set of price variables are estimated econometrically as well as the R&D expenditure of the steel industry and the mechanical and electrical engineering sectors. Expenditure for R&D in the mechanical and electrical engineering sectors was included to test the hypothesis that the producers of investment goods, when targeting their research efforts, take into account the production costs in the demand sectors (cost-pressure hypothesis). In the concrete implementation of the model, the best-practice EAF technology can be estimated by the lagged ratio of electricity price to steel output price. The best-practice technology with regard to the consumption of fossil fuels in BOF steel production is determined by the R&D spending of the mechanical engineering sector and the lagged price relation of coke, the most important energy input, to steel output.

For both process lines, a cost pressure hypothesis has proven useful to explain technical change. In addition, the results support the hypothesis that the R&D expenditure of the mechanical engineering sector raises the energy productivity of BOF steel production. The R&D spending of the steel industry, however, proved to be statistically insignificant. This may be due to the fact that the branch-internal R&D expenditure primarily targets processes downstream or product innovations, which are excluded from the model. Another reason could be that R&D expenditure is a function of the electricity prices and that collinearity occurs in the "explanatory variables". Thus, the individual influence of R&D spending might show statistical significance over a longer observation period. However, the results are consistent with the hypothesis that the companies are to be regarded as "supplier-dominated firms" with regard to the characterisation of technical change (Pavitt 1984). The innovation process mainly consists of the diffusion of best-practice capital goods and takes place primarily through the technology choice of the investment decision (Dosi 1988).

The extrapolation of the input structures is explained using the example of the fossil fuel consumption of BOF steel production. For modelling the investment decision regarding a putty-clay technology, it is reasonable to assume that companies invest in the best-practice technology (Silverberg 1988). In this case, the average specific fossil fuel consumption taken over all the investment vintages is determined as a weighted average of the coefficients of the preceding year (OSF[1]) and the best-practice coefficients (OBF), with the capital stock of the previous year (OKK[1]) and the current gross investments (OIB) of the BOF technology as weights.[17] The new average fuel consumption is transferred to the energy module of PANTA RHEI via energy input coefficients of fossil fuels (see equation 115 in Annex A), that are scaled to the new fuel energy consumption of the BOF and EAF process.

3.2 Modelling the paper industry

First a brief overview of the most relevant technological and energy-related aspects of pulp and paper manufacturing in Germany will be given. Then the actual implementation of the paper industry into PANTA RHEI will be presented.

3.2.1 Pulp and paper manufacturing

Paper is usually manufactured in a two-step process. In a first step the main resource inputs, wood and waste paper, are mechanically or chemically processed into three different kinds of pulp. Mechanical and chemical pulps are processed from wood, whereas recycled pulp is processed from waste paper. According to the desired paper characteristics, a specific mixture of the different kinds of pulp, added by other mainly mineral substances (e.g. fillers and coatings), is further processed in a second step to paper. Energy consumption is highly process specific (Table 3-3). The manufacturing processes need electricity and steam which are either generated on-site or – especially in the case of electricity – purchased (from outside). In the German paper industry a significant share of heat and electricity is delivered by co-generation.

17 See Annex A.

Table 3-3: Average specific energy consumption of pulp and paper manufacturing processes in Germany (estimates for 2000)

Process	Electricity	Process heat
	(GJ/t output)	(GJ/t output)
Mechanical pulp	6.7	-0.7*
Chemical pulp	1.8	11.0
Processing of imported chemical pulp	1.0	0
Waste paper processing	0.9 **	0.4 **
Paper	1.8	4.6

* Heat recovery from electricity use results in a negative sign.[18]
** per t waste paper input

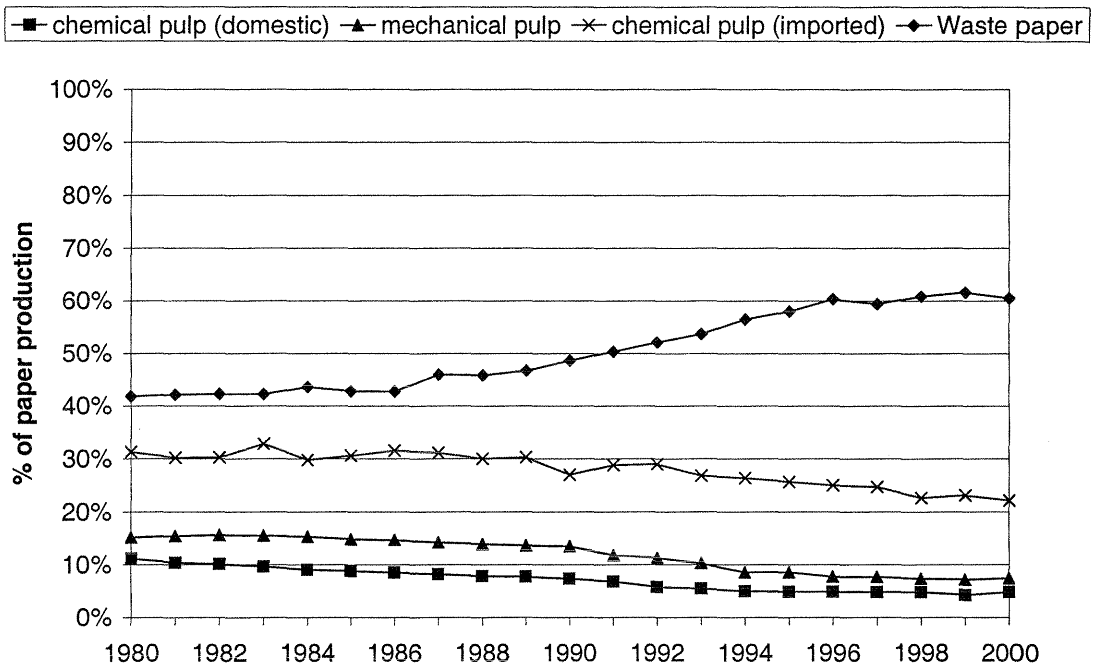
Source: Own calculations based on data sources mentioned in chapter 3.2.2

In the last twenty years paper production in Germany has increased considerably, from 7.6 million tons in 1980 to over 18 million tons in 2000 (VdP 2002). In the same period the mix of material inputs for paper manufacturing has significantly shifted (Figure 3-4), with the share of wastepaper increasing at the expense of wood-based pulp. Regarding chemical pulp the German paper industry largely depends on imports. Furthermore the use of ancillary materials has increased because of a changing mix of paper grades.

Due to a significant improvement in energy efficiency, the energy consumption of the German paper industry has increased much slower than production. Progress has been markedly higher for fuels than for electricity. Between 1980 and 2000 specific demand for fuels has fallen by 50 % compared to only 20 % for electricity (Figure 3-5). The temporary increase in 1991 is due to German unification and significantly less energy efficient paper mills in East Germany. Energy efficiency improvements in the East German pulp and paper industry can to a large extent be traced back to the modernisation and closure of plants (Buttermann and Hillebrand 2000, p. 18).

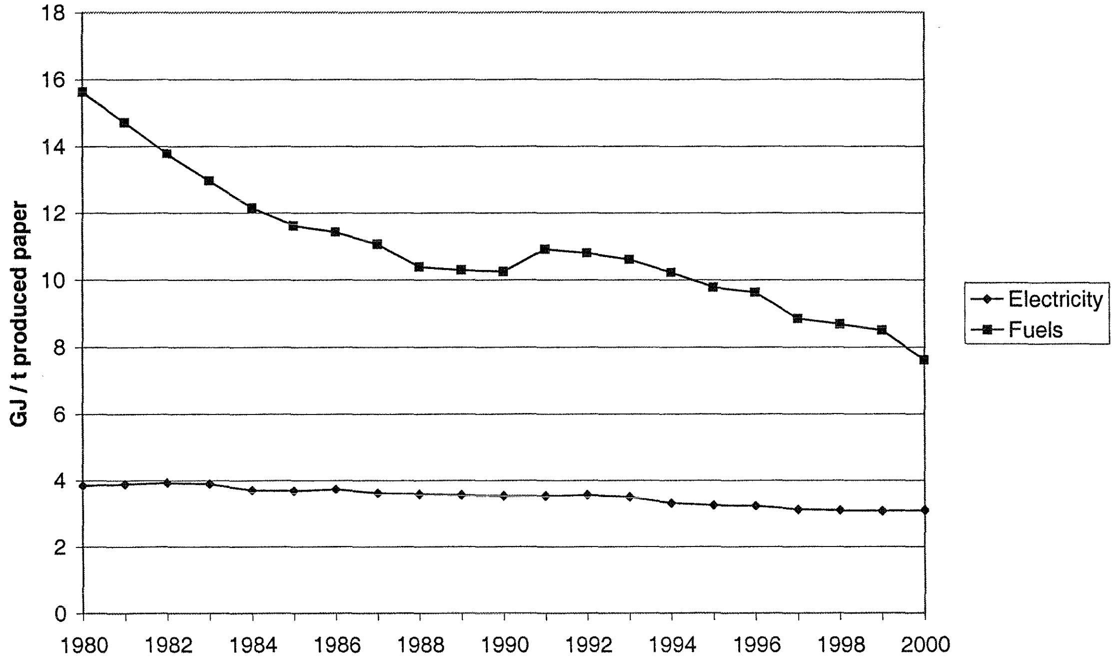
18 For example, in the TMP process – a mechanical pulping process - up to 60 % of electricity input can be recovered as steam.

Figure 3-4: Production/import of pulp and waste paper use as percentage of paper production



Source: Own calculations, VdP (1980-2002)

Figure 3-5: Specific energy demand of the German paper industry in GJ/t produced paper between 1980 and 2000



Source: Own calculations, VdP (1980-2002)

The reasons for this impressive energy efficiency increase in the paper industry are manifold. We can distinguish between intra-sectoral structural effects and purely technological factors.

The intra-sectoral structural effects comprise:

- substitution of recycled pulp for more energy-intensive wood-based pulp;
- increasing shares of ancillary materials in paper production at the expense of domestically produced pulp;
- a shift from electricity produced in co-generation in the paper industry to electricity purchased from the national grid in response to a declining electricity vs. natural gas price relationship. This has reduced fuel consumption in the paper industry.

Technological factors include:

- improved efficiencies of energy conversion technologies;
- technical progress leading to less electricity and heat demand of best-practice technology processes and diffusion of best-practice technologies into the capital stock, resulting in a modernisation of the paper industry's capital stock;
- continuous optimisation of existing plants / improved energy management.

Examples for specific energy saving technologies are (Blazejczak and Edler 1998, Götz 1999, Buttermann and Hillebrand 2000):

- improved paper drying hoods, reducing heat demand,
- shoe presses in the press section reducing heat demand in the paper drying section (this technology has become commercially available in the early 1980s),
- improved heat recovery and
- the use of gas and steam cogeneration plants.

3.2.2 Implementation of the new modelling approach

In the sectoral classification of PANTA RHEI, the paper industry is a part of the sector "Manufacture of Paper and Paper products". The other subsector, the paper converting industry, is not included in this detailed analysis since its energy intensity is significantly lower than that of the paper industry. In the new modelling approach the paper industry is portrayed with more technological detail, especially with regard to its energy demand. The level of detail is determined by the sector characteristics and by data availability.

In a technical sense the three basic pulping technologies mechanical pulping, chemical pulping and waste paper processing can be regarded as alternative paradigms, which can substitute each other within certain limits.[19] On the other hand paper manufacturing as the second production step is a rather homogenous process and largely independent of the input (pulp) mix. An ideal modelling approach would therefore mirror the two-step process setup. Yet, such an approach could not be realised because data was not available at the necessary level of disaggregation. Instead we chose a "composite technology" approach, distinguishing between two alternative process lines, (i) paper based on primary fibres (PFP) and (ii) paper based on secondary or recycled fibres (RCP). These process lines include the respective pulping and paper manufacturing processes and with regard to energy demand also an average energy supply technology. Given the lack of data availability, this approach allows to capture the important recycling effect appropriately.

The main data sources used for setting up the necessary time series were

- statistics from the Federal Statistical Office (Statistisches Bundesamt) and the German Pulp and Paper Association (Verband deutscher Papierfabriken) regarding process output and capacities, input and output prices, investment and energy demand of the pulp and paper industry in total;
- technical literature as well as information from process databases and expert interviews for allocating average energy demand and investment to the considered process lines and for determining the development of best practice technology inputs, since pure statistical data was not available (e.g. Süttinger 1979, Schmidt 1979a, Schmidt 1979b, Brugger 1979, Wolter 1979, Schiel 1975, Schädler 1979, Maier and Angerer 1986, Bölle 1994, Schneider et al. 2000a, Schneider et al. 2000b, Drasdo and Starrmann 2000, European Commission 2001, FIZ IKARUS database).

The two process lines (or paradigms) are modelled in technical and economic detail and linked to the driving parameters of PANTA RHEI in a consistent way. At the same time parameters of PANTA RHEI such as energy input coefficients of the paper industry depend explicitly on the weighted energy input structures of PFP and RCP. The same approach is applied to investment and prices. The specification of the main model parameters is explained in more detail below (see Table 3-4 for the OLS-estimation results) and also compared to the case of the iron and steel industry.[20]

19 For the U.S. pulp and wastepaper industry, Lee and Ma (2001) find that the substitution elasticity is positive but not statistically significant.

20 All estimated regression equations for the paper industry are presented in Annex B.

Paper production

Firstly, the production of PFP and RCP has to be determined from the original PANTA RHEI model where paper production is included as part of the paper and paper products industry. So paper production is econometrically estimated from the gross output of the paper and paper products industry which in turn is explained by the 59 sectors' intermediate demand and final demand. The share of RCP in total paper production is assumed to be mainly driven by waste policy, which determines waste paper supply, and is therefore set exogenously. Other influences, such as relative prices of waste paper vs. wood or imported chemical pulp were not found to be significant. From a statistical perspective, highly fluctuating prices for waste paper may have prevented the price variable to become significant, in particular since the time series available is relatively short. Yet, this is also consistent with the literature. For example, Baumgärtner and Winkler (2003) argue that as a result of waste paper regulation in Germany, the supply of waste paper is mostly independent of its price and its demand. Under certain conditions, waste paper prices may – as actually observed – even become negative.[21]

Given the share of RCP, the output of PFP and RCP are then calculated from the total paper output.

Capital Investment

Technology choice is modelled via new investments in both process lines of paper production. The real gross investments of PFP and RCP technology can be estimated as a function of the ratio of actual production to the installed capacity (reflecting the pressure to expand). Unlike for the steel industry, relative input prices were not found to be statistically significant for the choice of technology in the paper industry. To some extent, this supports the earlier claim, that investment in RCP was primarily driven by waste paper regulation.

This modelling step makes it possible to describe the changes in production structure and thus the changes in input use of paper production which result from a change in the technology choices. The next step describes the development of technological change which is modelled as a change in specific input use.

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21 According to Baumgärtner and Winkler (2003) these conditions are: collection and utilisation quota by law, costly disposal and limited disposal alternatives to recycling, limited short term substitutability of paper produced from secondary inputs for paper produced from primary inputs.

Technological change

Energy saving technological change is modelled as a process of best practice technologies continuously entering the capital stock according to reinvestment patterns. Thus, technological change is embodied in the new capital vintage and the evolution of best practice technologies is endogenous to the model.

When preparing the time series for the econometric estimation of influencing factors for best practice technology evolution, in the case of PFP it was necessary to isolate pure technological change from a structural effect which results in reduced energy demand. In the past the share of ancillary materials, e.g. fillers and coatings, as an input to PFP production has increased significantly, mainly substituting domestically manufactured pulp. These ancillary materials are considerably less energy intensive than pulp and are furthermore purchased from suppliers outside the paper industry. Therefore, the increasing share of ancillary materials resulted in lower energy demand in the paper industry, especially in lower electricity demand. This effect is excluded from the estimation of PFP best practice technology inputs but added to the estimation of average specific energy consumption of PFP (described below). With the adjusted time series several potential influencing factors on best practice technology development could be tested.

As in the steel industry, the development of the best practice fuel inputs in both paper paradigms can be explained by the price relation of fuel inputs to the output price of the industry, although compared to the production of steel, the production of pulp and paper is less energy intensive: the gross product share of energy costs is around 11.2 % in the steel industry and about 6 % in the pulp and paper industry (Statistisches Bundesamt 2003). For years with strong energy price decreases such as 1986, dummy variables are added to catch the fact, that energy saving technological progress is not revoked by lower energy prices. Obviously, reducing energy demand has been an important objective of paper technology development.[22] To a certain extent energy efficiency seems to have been a side effect of general technology development, (e.g. in the case of the shoe press, primarily designed for increasing productivity).

Regarding best practice electricity demand for both paper technology lines, R&D expenditures of the mechanical engineering sector – of which manufacturing of printing and paper machines is the leading sector in terms of exports and the third largest in

22 Voith, which is one of the dominant suppliers for the paper industry, states that one of the most important objectives of the firm was to satisfy the increasing demand for energy-efficient technologies by its customers (Müller 2003).

terms of production (VDMA 2003) - were found to be significant. R&D expenditures of the paper industry did not have an influence. This result supports the hypothesis that technical progress in the paper industry is mainly supplier dominated (Pavitt 1984).[23] As a result the innovation process mainly consists of the diffusion of best-practice capital goods and takes place primarily through the technology choice of the investment decision (Dosi 1988).

Furthermore increasing concentration of the industry, as measured by the Herfindahl-Hirschmann index, turns out to have a slightly negative, but statistically significant, impact on best practice electricity demand. From a theoretical point of view, the impact of firm size or industry concentration on adoption of new technologies is ambiguous.[24] On the one hand, large dominant firms are able to spread the costs of adoption over more production units. On the other hand, large dominant firms may not feel the pressure to cut costs, though this will also depend upon the characteristics of the specific product markets (price vs. quality driven markets) and the extent of international competition[25].

The extrapolation of the average energy input structures without the above mentioned structural effect is carried out as follows. For modelling the investment decision regarding a putty-clay technology, it is reasonable to assume that companies invest in the best-practice technology (Silverberg 1988). In this case, the average specific input coefficient taken over all the investment vintages is determined as a weighted average of the coefficients of the preceding year and the best-practice coefficients, using the capital stock of the previous year and the current investments as weights. For PFP the outcome is then adjusted by a factor reflecting the structural effect related to the increasing share of ancillary materials.

Fuel mix and CO_2-emissions

After having estimated fuel demand for the two technologies, in a second step the fuel mix for meeting this demand is determined. The shares of the main fossil fuels coal and

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23 Analysing the innovation process for the shoe press technology Fischer (2004) also finds that the paper industry is supplier dominated. See also Luiten (2001).

24 See Hall (2004) for a recent overview on the determinants of innovation and diffusion.

25 Similarly, the degree of concentration of providers of new technologies may also have an impact on innovation and diffusion. Highly concentrated providers tend to charge higher prices, they may slow diffusion, but they may also be in a better position to determine a standard, increasing the benefits of adoption (Hall 2004, p. 21). While the concentration of the supply industry was not examined specifically, there is some evidence, that the degree of concentration in the technology supply for pulp and paper manufacturers is fairly high: in 2000 there were only two companies in the production of shoe presses left worldwide (Luiten 2001, Fischer 2004).

natural gas as well as of CO_2-neutral biomass fuels depend upon relative fuel prices and a time trend. The maximum use of biomass fuels partly depends on PFP output, especially on production of chemical pulp and is therefore restricted. CO_2-emissions are then calculated according to the fuel mix via standard emission factors.

Table 3-4: Selected regression results for the paper industry (t-statistics in parentheses)

Regressors	Lags	Dependent variable: Gross investment in PFP	Gross investment in RCP	Best practice fossil fuel input in PFP	Best practice fossil fuel input in RCP	Best practice electricity input in RCP
Constant		7.966 (19.704)	6.870 (22.687)	2.173 (65.127)	1.882 (52.298)	1.208 (33.354)
Production/capital stock PFP	t-1	9.773 (2.200)				
Production/capital stock RCP			7.066 (2.385)			
Price ratio weighted fuel inputs/paper				-0.187 (-3.737)	-0.200 (-3.708)	
Herfindahl-Hirschmann Index						-0.033 (-11.625)
R&D expenditures of mechanical engineering in constant prices						-0.085 (-11.348)
Adjusted R^2		0.608	0.856	0.945	0.944	0.980
Durbin-Watson		1.38	1.54	2.24	2.22	1.34
Degrees of Freedom		14	16	16	16	17

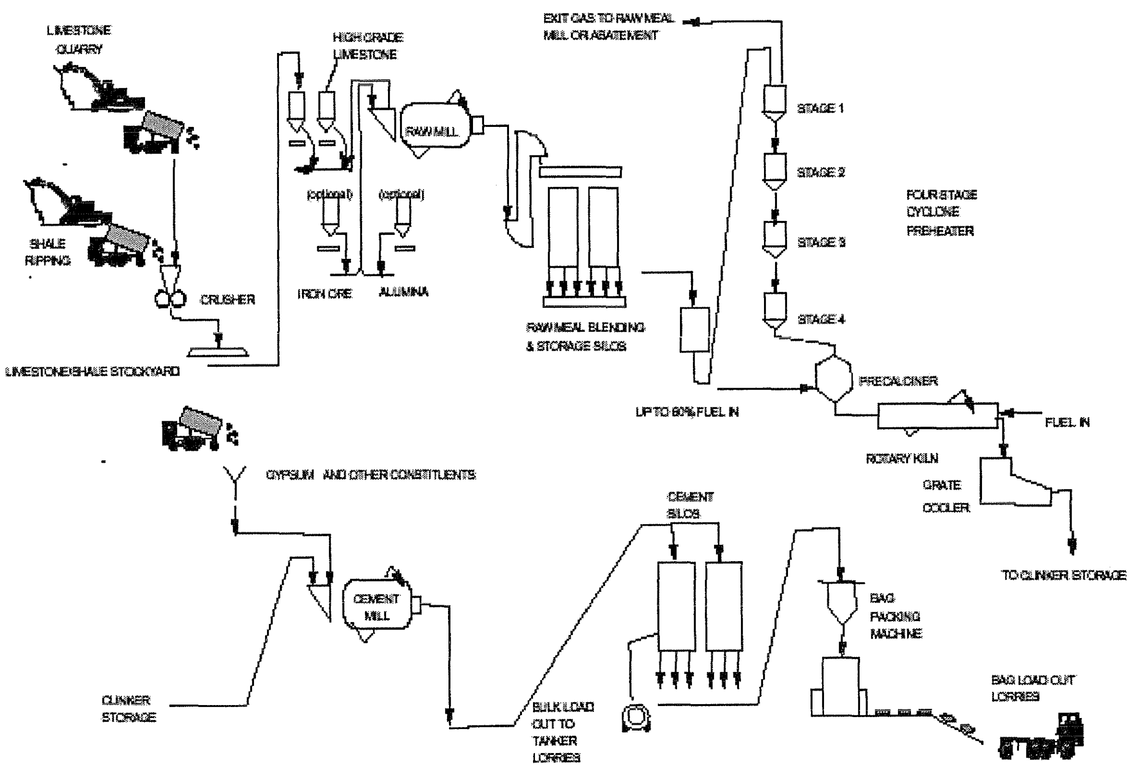
3.3 Modelling the cement industry

After a short overview of the most relevant technological and energy-related aspects of cement manufacturing in Germany we will present the modelling approach and the implementation into PANTA RHEI.

3.3.1 Cement manufacturing

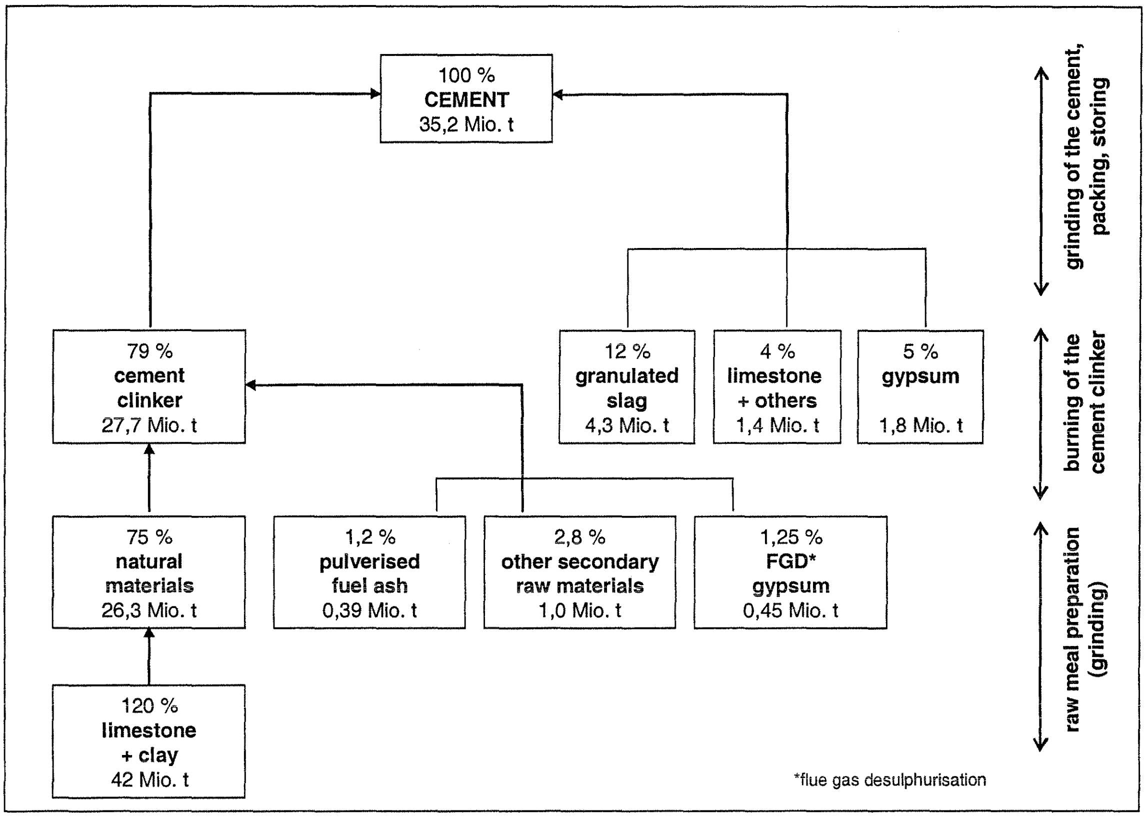
The production of cement can be divided into three stages (Figure 3-6). The first stage consists of preparing the naturally occurring mix of the raw minerals limestone and clay or marl by breaking, grinding and mixing these to a fine powder, or raw meal. The grinding of the raw meal is very electricity-intensive. In the second production stage, the raw meal passes through a multistage cyclone pre-heater (calcinator), in which the decisive chemical reaction of de-acidification (removal of the carbon dioxide from the limestone) takes place. Subsequently, the raw meal enters the rotary kiln. There it is burnt at temperatures of 1400 to 1450 °C and cement clinker is formed. This second production stage accounts for almost the entire fuel consumption in cement production. Finally, in the last stage, the clinker is ground down to very fine cement together with certain additives.Figure 3-7 gives an overview of the material flow in the production of cement. The cement grinding, necessary to develop the desired hydraulic characteristics, is the most electricity-intensive production stage. The shares of the individual production steps in total electricity production are as follows: raw meal preparation: 35 %, burning of the cement clinker: 22 %, grinding of cement: 38 %, others: 5 % (Sozialpolitische Arbeitsgemeinschaft der Deutschen Zementindustrie 2002).

Figure 3-6: Overview of cement production



Source: BREF (2000)

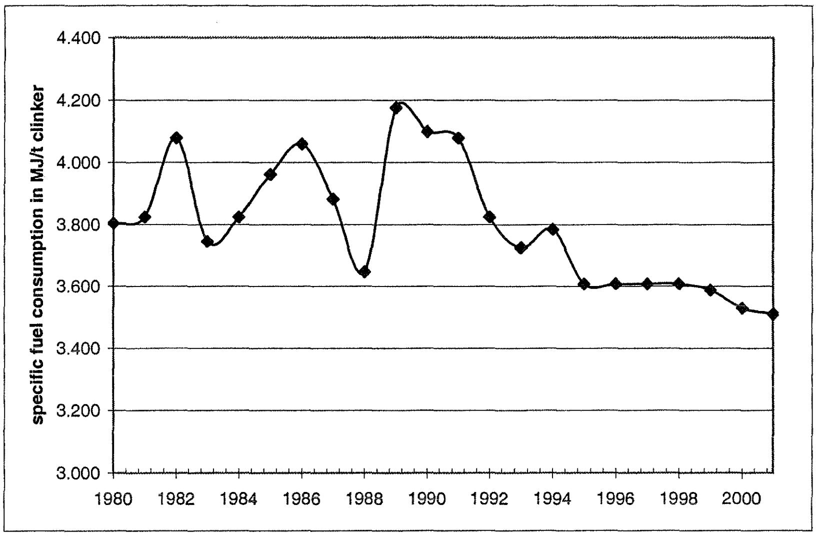
Figure 3-7: Overview of material flow in the production of cement



Source: Own calculations

On average, the specific fuel consumption for the production of clinker decreased by about 0.5 % between 1980 and 2000 (Figure 3-8). Today, average specific fuel use amounts to around 3,500 MJ/t clinker (including secondary fuels). The sharp increase in specific fuel use in 1989 resulted from the plants in the former East Germany, which were smaller and older than those in West Germany. In the years following reunification, those older plants were either modernized or decommissioned. Even the cement industry itself does not appear to be able to offer a clear explanation for the strong fluctuations in specific fuel consumption prior to 1989. There appears to be no correlation between specific fuel use and capacity use for the entire period (1980 to 2000). For 1991 to 2000, a U-shaped relation could be found which is consistent with the hypothesis that low capacity use is associated with a higher specific fuel use. Once capacity use approaches the upper limit, older, less energy-efficient plants from the reserve have to be re-activated.

Figure 3-8: Specific fuel consumption of the German cement industry in MG/t produced clinker

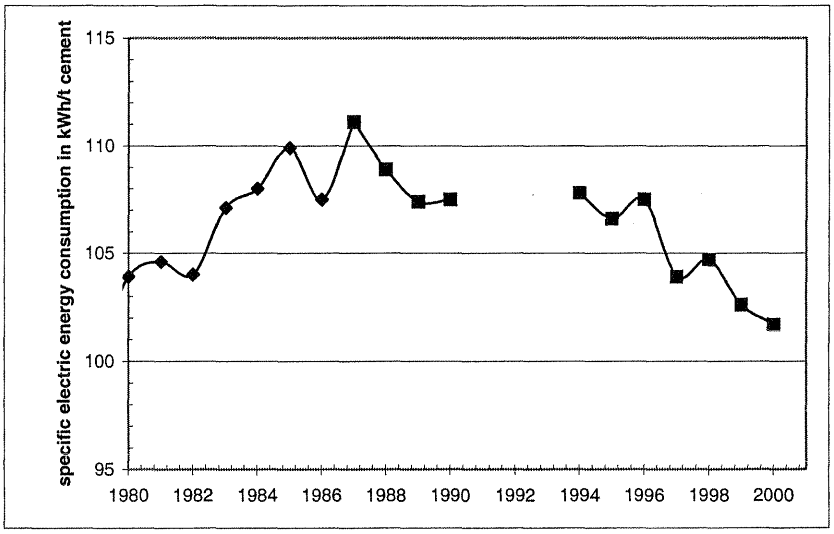


Source: Sozialpolitische Arbeitsgemeinschaft der Deutschen Zementindustrie (2002)

As can be seen in Figure 3-9, specific electricity use in the German cement industry increased between 1980 und 1987. The main reason for this is an increase in the production shares of high quality cement. Whereas the quality of the final product does not affect the specific fuel use for clinker (intermediate product), it does affect the electricity consumption in the grinding mill: the higher the quality of cement, the more electricity is consumed. Since 1988, specific electricity use has been decreasing and average values now lie around 102 kWh per t cement.

To meet higher environmental standards as mandated by German imission control law and subsequent ordinances cement manufacturers had to install electronic filters. As can be seen in Figure 3-9 this resulted in higher electricity use. Since this effect is rather small, it will be neglected in the modelling approach.

Figure 3-9: Specific electricity use in the German cement industry

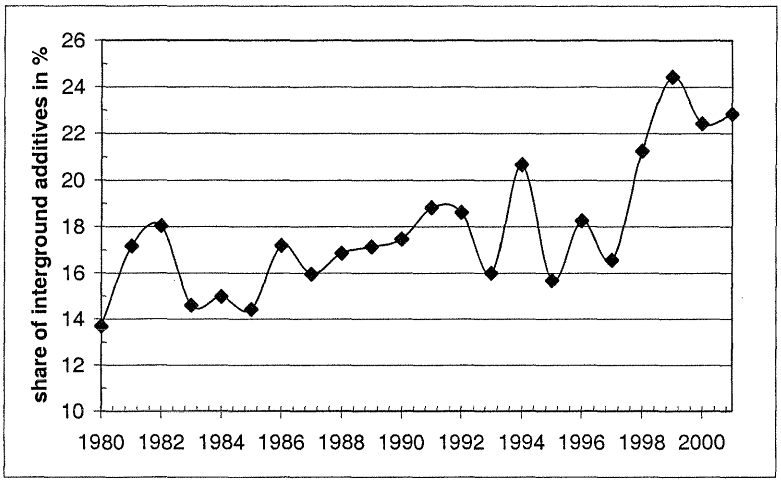


Source: Sozialpolitische Arbeitsgemeinschaft der Deutschen Zementindustrie (2002)

Between 1980 and 2000, the German cement industry substantially increased the share of secondary raw materials and energy carriers (waste processing) in order to lower production costs. The share of interground additives (gypsum, granulated slag, limestone) increased from 13.7 % in 1980 to 22.4 % in 2000 (see Figure 3-10) and substituted (costly) cement clinker. According to industry experts, the technical upper limit for the share of these additives in cement production is about 50 %.

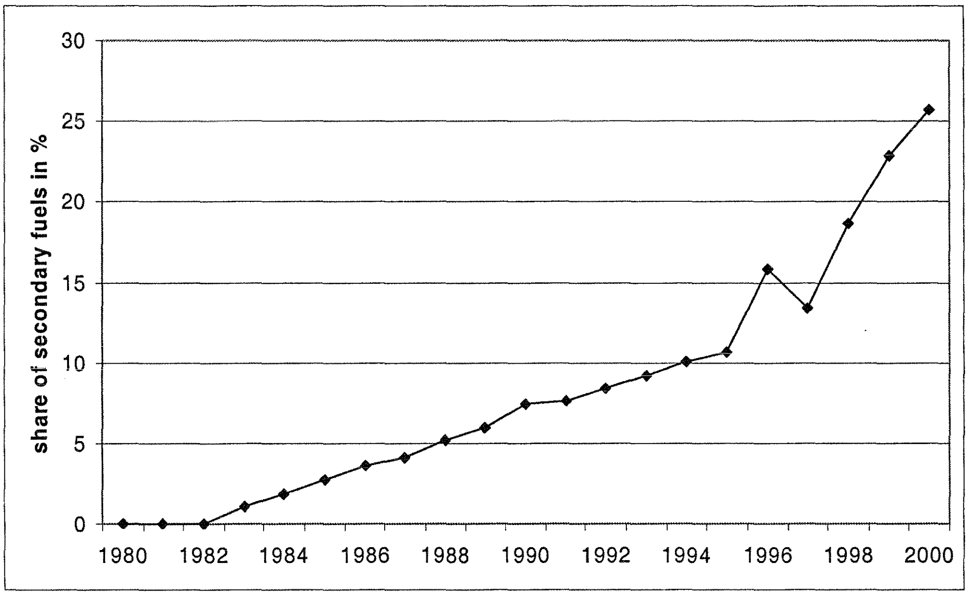
At the beginning of the 1980s, secondary fuels such as tyres, rubber, industrial waste or solvents were hardly used. By 2000, however, they accounted for about a quarter of the entire thermal fuel use in the cement industry (see Figure 3-11). According to industry experts, the technical-economic limit for the use of secondary fuels is around 60 %. Although additional investments would be necessary to reach this level in Germany, increasing the share of secondary fuels still remains a profitable measure. Burning secondary fuels does lead to a reduction in the efficiency of the rotary kilns, but since this effect is only small, it will be neglected in the subsequent steps.

Figure 3-10: Share of interground additives in the German cement industry



Source: Bundesverband der Deutschen Zementindustrie Verbandsstatistik

Figure 3-11: Share of secondary fuels in thermal energy use in the German cement industry



Source: Sozialpolitische Arbeitsgemeinschaft der Deutschen Zementindustrie (2002)

The improvement in energy efficiency since 1987 can be traced back to two major developments: technological progress in the process technology and modifications in the resource basis. In addition, (smaller) scale effects were able to be realized for rotary kilns.

Pre-calcination is the most important new process technology to be introduced. Pre-calcination allows shorter rotary kilns which are still able to achieve the same throughput but at lower costs and with fewer heat radiation losses. Similarly, larger ovens can achieve higher throughputs. In Germany, the first plant with pre-calcination was commissioned in 1981. In 2000 there were 11 plants using the pre-calcination technology, accounting for 26 % of total capacity.[26] The specific fuel saving is estimated at 15 % including optimisation of heat recovery at the clinker cooler which is then used to preheat the hot clinker. Plants with this technology show a specific fuel consumption today of 3000 MJ/t clinker. The technology has no appreciable effect on electricity demand.

Developments in information and communication technology have made it possible to improve the measurement and control technology as well as the electronic process control. As a result, the energy efficiency should have improved by 4 % between 1981 1990 and by another 4 % between 1991 and 2001.

The reduction of the specific electricity consumption after 1987 is mainly due to more efficient grinding systems. Ball mills or roller pressers are traditionally used to grind cement. These have poor energy efficiency, but manage to achieve the optimum grit size for cement. More recent developments with better electricity efficiency include the roll crushing mills to pre-grind the cement and roller mills to grind the raw meal. The first production plant to combine a roll crushing mill and a ball mill for grinding cement started operating in 1986 (Schneider et al. 1989), a second followed in 1987 (Rosemann et al. 1989). The specific total electricity demand of the sector is estimated to have been reduced by 11 % due to the more energy-efficient mills. The introduction of the new milling system coincides quite well with the observed decline in specific electricity consumption since 1987. It does not influence fuel consumption. It has already been pointed out how strong the influence of grit size is on the electricity demand for grinding. The electricity demand is also influenced by quality fluctuations in the raw meal and clinker so that there are significant uncertainties involved in recording the specific electricity demand. Against this background it was not possible to detect any

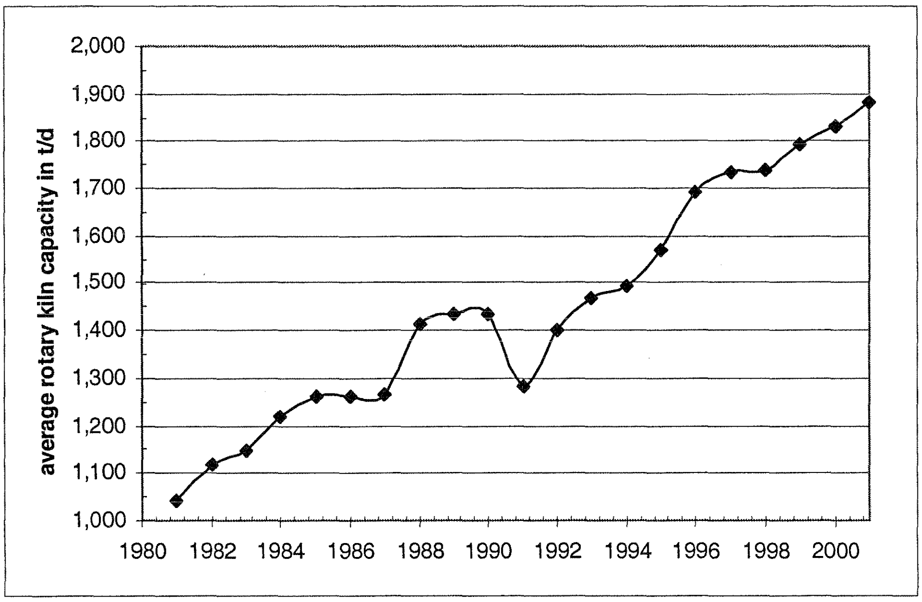
26 Verein Deutscher Zementwerke and Forschungsinstitut der Zementindustrie (2002).

technical optimisations of the mills which have resulted in a significant percentage improvement of the electricity efficiency. For this reason it is not possible to provide data on changes in the specific electricity demand of combined milling due to technical progress.

The modification of the resource base (increased use of interground additives) has resulted in considerable fuel savings since interground additives are not burnt in the rotary kiln. However, the electricity saved in the burning stage is compensated by the greater effort necessary for grinding compared to clinker. Their use does therefore not have any influence on the total electricity consumption (Buttermann 1997).

The number of kilns in Germany today has been more than halved in the period 1980 to 2000. In 2001 there were only 70 kilns left. At the same time, the average kiln capacity has continuously increased from around 1000 to 1900 tonnes per day (Figure 3-12). This could have impacts on the specific fuel demand, but influences on electricity demand are not presumed.[27]

Figure 3-12: Development of average kiln capacity



Source: Bundesverband der Deutschen Zementindustrie Verbandsstatistik

27 The sector expects an annual availability of the kilns of 320 d/a (Verein Deutscher Zementwerke 1997).

3.3.2 Implementation of the new modelling approach

The production of cement can be divided into three stages according to Figure 3-6. The second production stage, calcination or clinker production, is by far the most energy-intensive part of cement production. Therefore analysis is concentrated on this second stage. Pre-calcination is a new process technology on this stage, having been introduced since the beginning of the 1980s. According to the concept of best practice technologies being used for new investment, pre-calcination is used in all new rotary kilns for clinker production. Consequently, only one production process, is explicitly modelled for the simulation period up to 2020.

In contrast to the steel and the paper industry, shifts between different production processes cannot be analysed. But in relation to the conventional modelling approach, cement production is described based on the explicit capital stock and the technical process entering and diffusing via new investments.

Cement production

Firstly, the production of cement has to be determined from the original PANTA RHEI model where cement production is as part of the industry glass and ceramics. Cement production is econometrically estimated from the gross output of the glass and ceramics industry which in turn is explained by the 59 sectors' intermediate and final demand. The price ratio of cement to the sector glass and ceramics is also statistically significant. Demanders may choose the share of cement, glass or other ceramics according to the relative prices. The price index of cement can be explained by the major cost components of cement production: costs of raw material, labour, capital and energy. The Herfindahl-Hirschmann-Index also plays a certain role. The amount of clinker production is closely related to cement production.

Capital investment

Technology choice is modelled via new investments in the process line of cement production. The real gross investments of the cement industry can be estimated as a function of the ratio of actual production to the installed capacity (reflecting the pressure to expand).

Diffusion of best practice technology

The best practice energy consumption of clinker production is explained by the cumulated R&D expenditures of the cement industry. The specific (average) fuel input of the clinker production depends on the development of the best practice technology and on the price ratio of weighted fuel input into cement production and the output price of the sector glass and ceramics. The overall energy input of cement production depends on the energy input in the clinker production. The econometric estimation takes into account, that part of the energy input is not used for clinker production.

Fuel mix

According to Buttermann (1997, p.19) “the fuel mix in the cement industry is in the long run not limited by technical or product-specific restrictions.“ A drastic shift in the fuel mix of the cement industry – almost completely from oil and gas to coal – has been taken place from 1976 to 1982. Since 1982 the mix of fossil fuels has been stable, except due to German unification, the share of brown coal increased in the 1990es. But the share of secondary fuels has increased, which is difficult to describe in econometric estimations due to lacking data.

In the model, the fossil fuel shares depend on the price ratio of the energy carriers – explicitly modelled in PANTA RHEI – to the weighted energy input price index. The growing share of secondary fuels is set exogenously.

4 Simulations for single sectors

In this chapter results of seven so-called policy scenarios are compared to the base simulation (see Table 4-1). Five of those policy scenarios are policy simulations which evaluate the impact of certain policy measures. A change of scrap prices is due to world market changes. Windows of opportunity are related to investment cycles of industry.

Table 4-1: Overview of policy simulations

Industry	Scenario	Trigger
Steel	CO_2-tax	Climate policy
Steel	Higher scrap price	World market
Steel	Windows of opportunity	Investment cycles
Paper	CO_2-tax	Climate policy
Paper	Higher share of RCP	Waste policy
Cement	CO_2-tax	Climate policy
Cement	Higher R&D expenditures	Research policy

The quantitative analysis is based on the scenario technique: A reference or base scenario, which describes economic variables, energy use and emission levels, is compared to different policy scenarios. The policy scenarios differ only in one or few explicitly stated variables from the base scenario. A CO_2-tax scenario differs from the base scenario only in the CO_2-tax rate. Differences in model variables between the policy and the base scenario can then be traced back to the introduction of the CO_2-tax.

4.1 Simulations for the steel industry

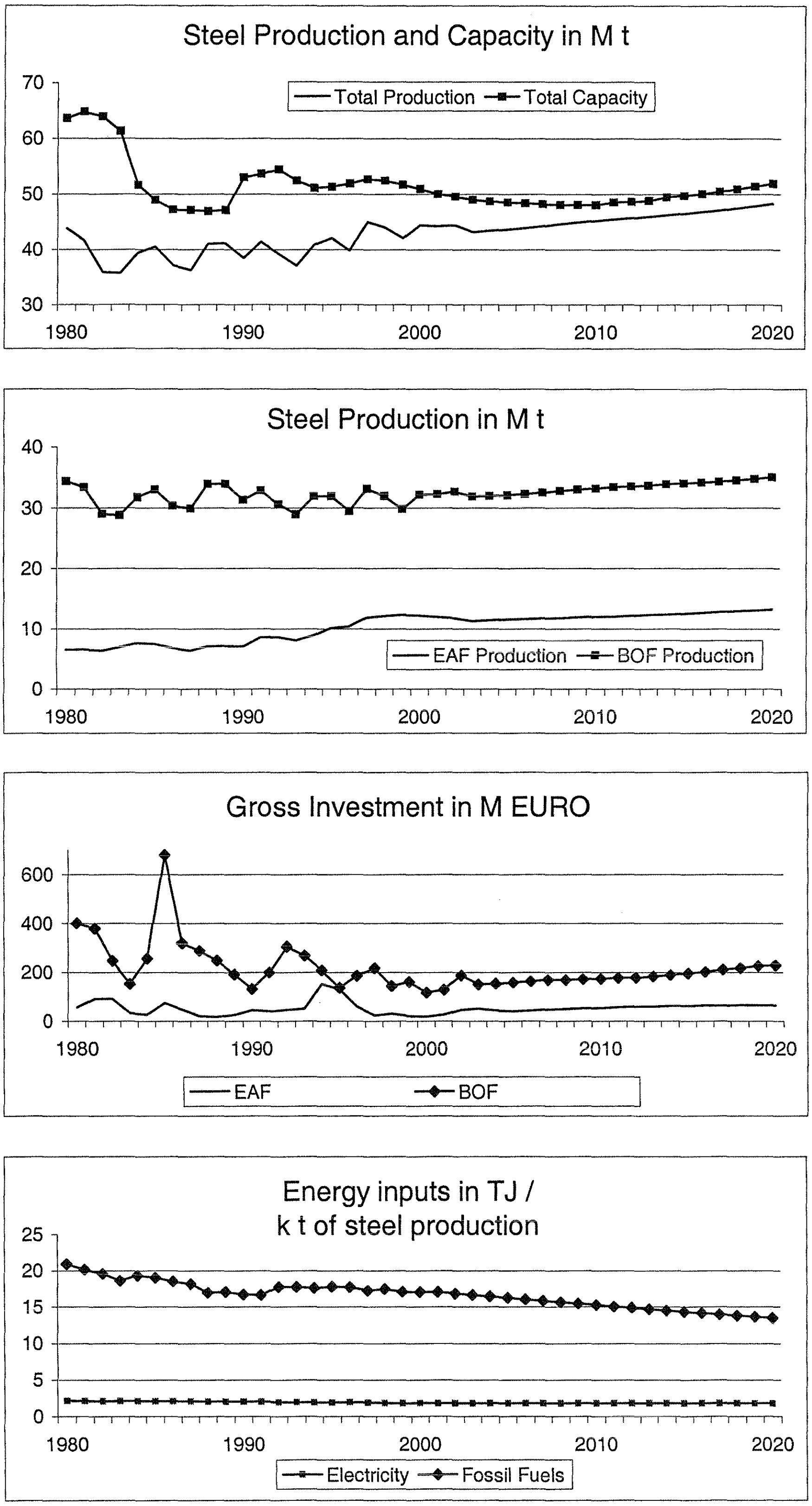
In addition to the base simulation two simulations for the steel industry have been conducted, a tax policy scenario and a higher scrap price scenario. In the tax policy scenario, a CO_2-tax is introduced in progressive stages starting in 2005. As for the environmental impact, this tax can be interpreted as the national implementation of a global CO_2-trading system where emission targets are gradually tightened over time. At the end of the section, the important drivers of the CO_2-effect of the tax are presented and discussed. In the second simulation, the exogenously given price for scrap, that is an important input for electric steel production, is increased compared to the base simulation. The modelling approach has also been used to explore possible windows of opportunity for a new technological paradigm in the German steel industry. An overview of this modelling experiment is given at the end of this chapter.

4.1.1 Base scenario

In the base scenario of PANTA RHEI, German GDP is growing at an annual average rate of about 1.7 % between 2000 and 2020. The model forecasts that the German economy - after a phase of weak growth in the first half of this decade - will recover and return to its previous long-term growth rates. International energy prices are supposed to reach the level of the mid 1990s again up to 2005 and grow slowly afterwards, in line with world inflation. We assume that there will be no further increase in energy taxes in the future. Therefore, price relations between energy carriers relevant for the steel industry will not change significantly in the future. For price relations between scrap and iron ore, we assume no changes to the current level.

The growth rate of raw steel production in Germany will be below the growth rate of GDP. But in contrast to the assumptions for the US steel industry made by Ruth and Amato (2002), production figures in tons will be about 10 % higher in 2020 than in 2000. Capacity utilisation will be very high as the shares of both technologies are stable and it is possible to increase production using existing capacities. The main reason for increasing production will be higher world steel demand due to fast growing markets in Asia. Market shares between electric arc furnaces (EAF) and basic oxygen furnaces (BOF) will remain almost constant. Neither capacity relations nor important input price relations between the two technologies are assumed to change significantly in the base scenario. Because energy prices are stable in real terms, energy use in TJ per k t decreases only slightly for EAF steel. The energy efficiency improvement for BOF is higher with about 1 % per year. Total energy use and CO_2-emissions of the steel industry remain at their present level. In 2020, CO_2-emissions which are either directly or indirectly (via electricity production) related to the steel industry will account for about 7.5 % of German total emissions.

Figure 4-1: The base scenario



4.1.2 Effects of a CO_2-tax

In the second simulation, a CO_2-tax is introduced in 2005, which increases linearly from 5 € to 20 € per ton CO_2 in 2010, i.e. by 3 € per year. After 2010 the tax remains at the level of 20€ per t. Thus, the CO_2 tax lies in the range of recent model estimates for CO_2-market prices (Springer and Varilek 2004). This is equivalent to a price per ton of carbon of more than 73 Euro in 2010 which is close to the price of 75 US $ per ton of carbon assumed by Ruth and Amato (2002) in a study concerning the US steel industry. From 2011 on, the tax rate is kept constant at that level. The CO_2-tax is levied on all fossil energy carriers according to their carbon content, so that the use of coal is more heavily taxed than oil or gas. As the tax burden is at least partly passed on, electricity will also become more expensive as a result. Since the tax burden on electricity is already heavier than that on coal because of existing electricity taxes and since some electricity production is carbon free, coal prices are affected to a greater extent by the additional CO_2-tax than are electricity prices.

The macroeconomic effects of the CO_2-tax are almost negligible: the effect on GDP is below 0.1 % in 2020. As we assume the tax forms part of global CO_2-trade, similar price increases in competing countries can be expected. The German steel industry will suffer almost no trade losses. Raw steel production will be 0.4 % lower compared to the base scenario in 2020. Of course, this minor effect is the result of the global tax design. Thus, under a Kyoto-type regime, where major steel producers like China and South Korea have not committed to emission limitations, the effects on the German steel industry may be more severe, since some major competitors are not levied with additional costs. However, since almost 90 % of the German iron and steel imports stem from the EU or other European OECD countries (OECD 2003), the magnitude of these effects is difficult to foresee. If the CO_2-tax were only levied in Germany, or alternatively, if there were only an EU-wide emission trading system, the negative impacts of the tax on steel production in Germany would be more severe.

Figure 4-2 to 4-4 show the economic and environmental impacts of this tax on the steel industry as absolute deviations from the base scenario. Hence, the CO_2-tax induces a significant shift in production from BOF steel to the less carbon intensive EAF steel. EAF production share will almost double by 2020 and will reach 46 %. Implicitly, this analysis assumes that there are no significant second-order effects following a potential increase in the price of scrap from the increased demand for EAF. However, recent bottom-up estimations for the future supply of scrap in Germany suggest, that there would be excess supply of scrap even for the high EAF market shares estimated above (Schön and Ball 2003). In particular, due to the age structure of buildings increasing amounts of scrap will become available until 2020. Thus, second-order effects are likely to be small.

The shift towards EAF is also accompanied by a clear increase in investments in the EAF process so that capacities also shift towards more EAF steel production. At the same time, investment in the BOF process is reduced compared to the base scenario. Interesting developments can be observed for specific energy inputs in the two processes. Surprisingly, specific electricity input for EAF steel rises in the first years of the tax scenario. But best practice can only react with a time lag and less efficient capacities have to be used when EAF production starts to increase in relation to the base scenario. Only after 2008 does the technological effect increasingly exceed the capacity effect.

For oxygen steel, we observe that the carbon tax immediately initiates an increase in technical progress. Specific energy inputs react until 2020, when BOF production is increasingly substituted by EAF production and capacity utilisation of BOF production is reduced. When comparing CO_2-emissions which are to be allocated to steel production either directly (BOF) or indirectly via electricity generation (EAF), it was assumed for the calculations that the electricity generation for EAF steel has the same CO_2-intensity as the average electricity generation in Germany - in both simulations, we see the shift from BOF steel production to EAF production. In 2020, overall CO_2-reduction will be around 5.1 M t, which will be more than 0.5 % of German total CO_2-emissions or 8.5 % of German steel industry total emissions. In 2010, when the tax reaches its maximum, CO_2-reduction is still only 1.65 M t. So the biggest reduction takes place in the years after the tax increase.

Figure 4-2: Effects of the CO_2-tax on production - deviations from the base scenario

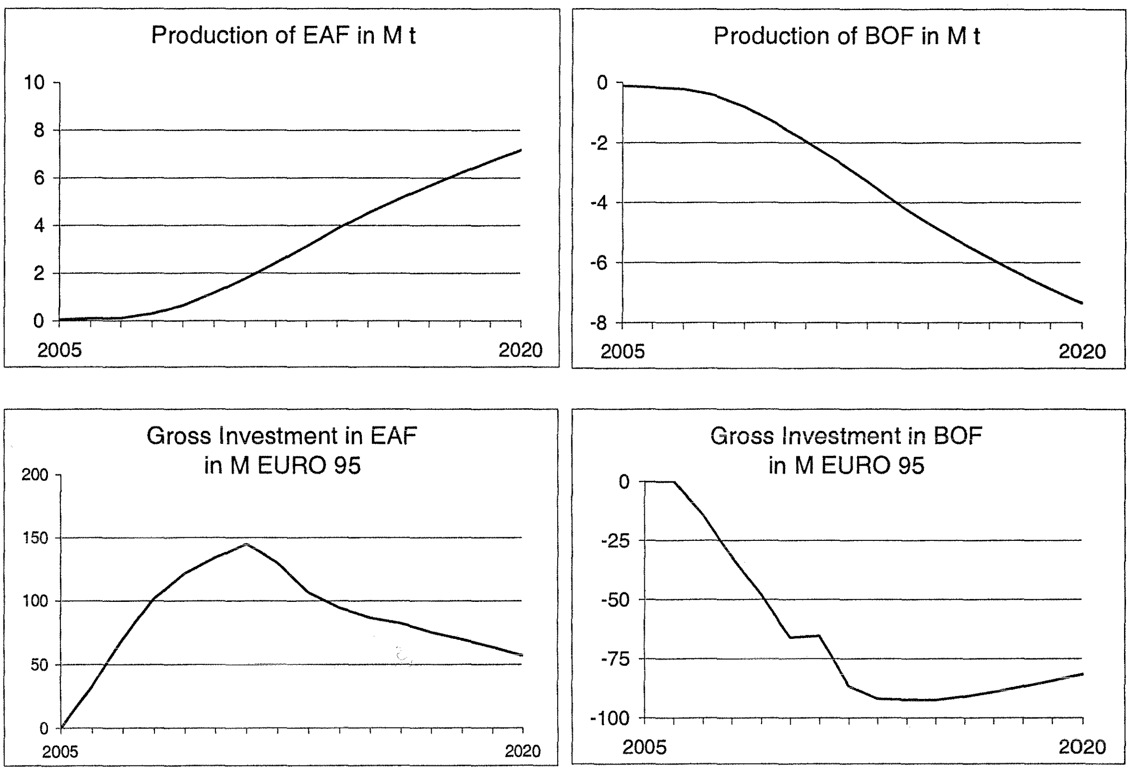


Figure 4-3: Effects of the CO_2-tax on energy and emissions - deviations from the base scenario

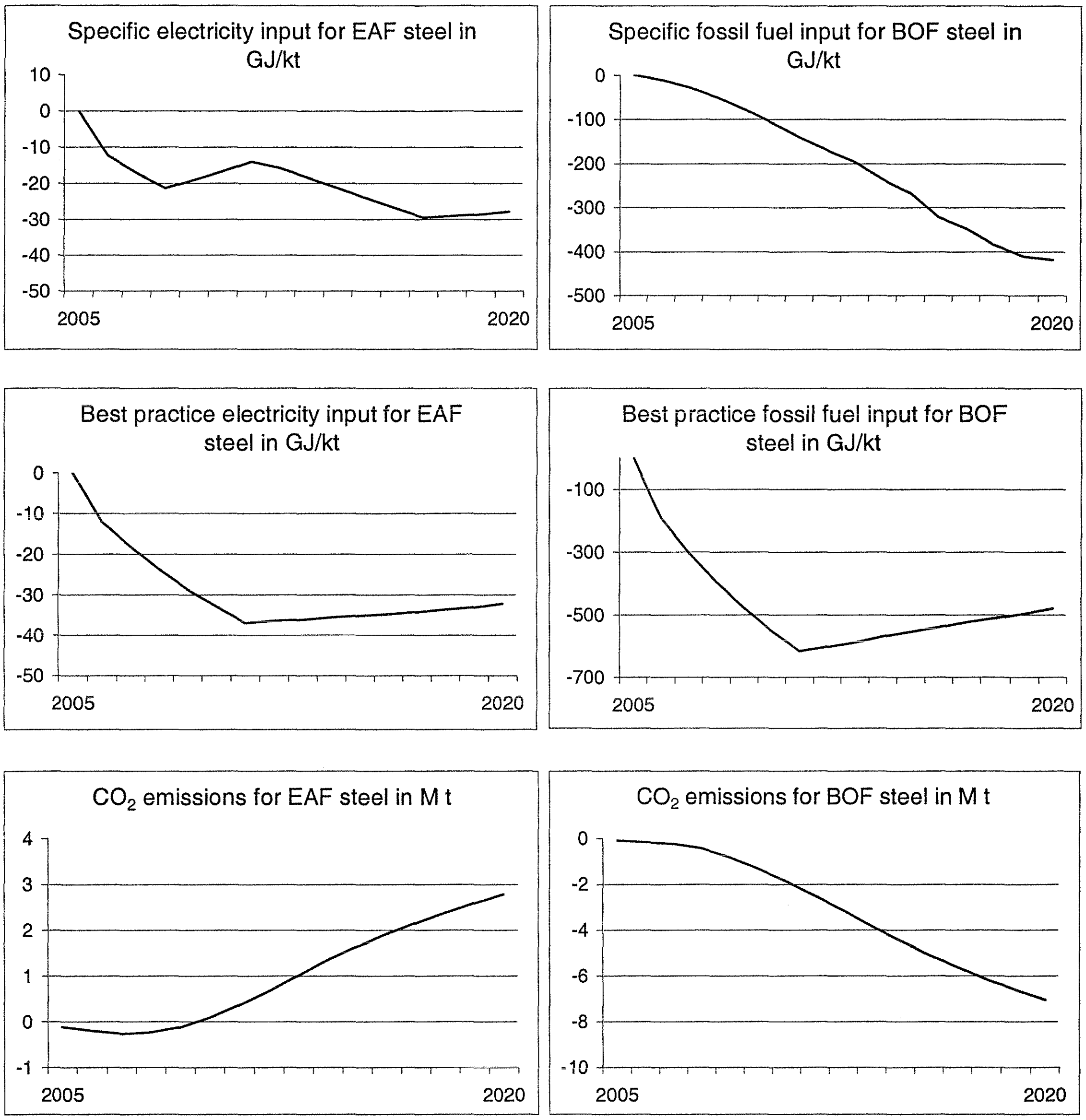
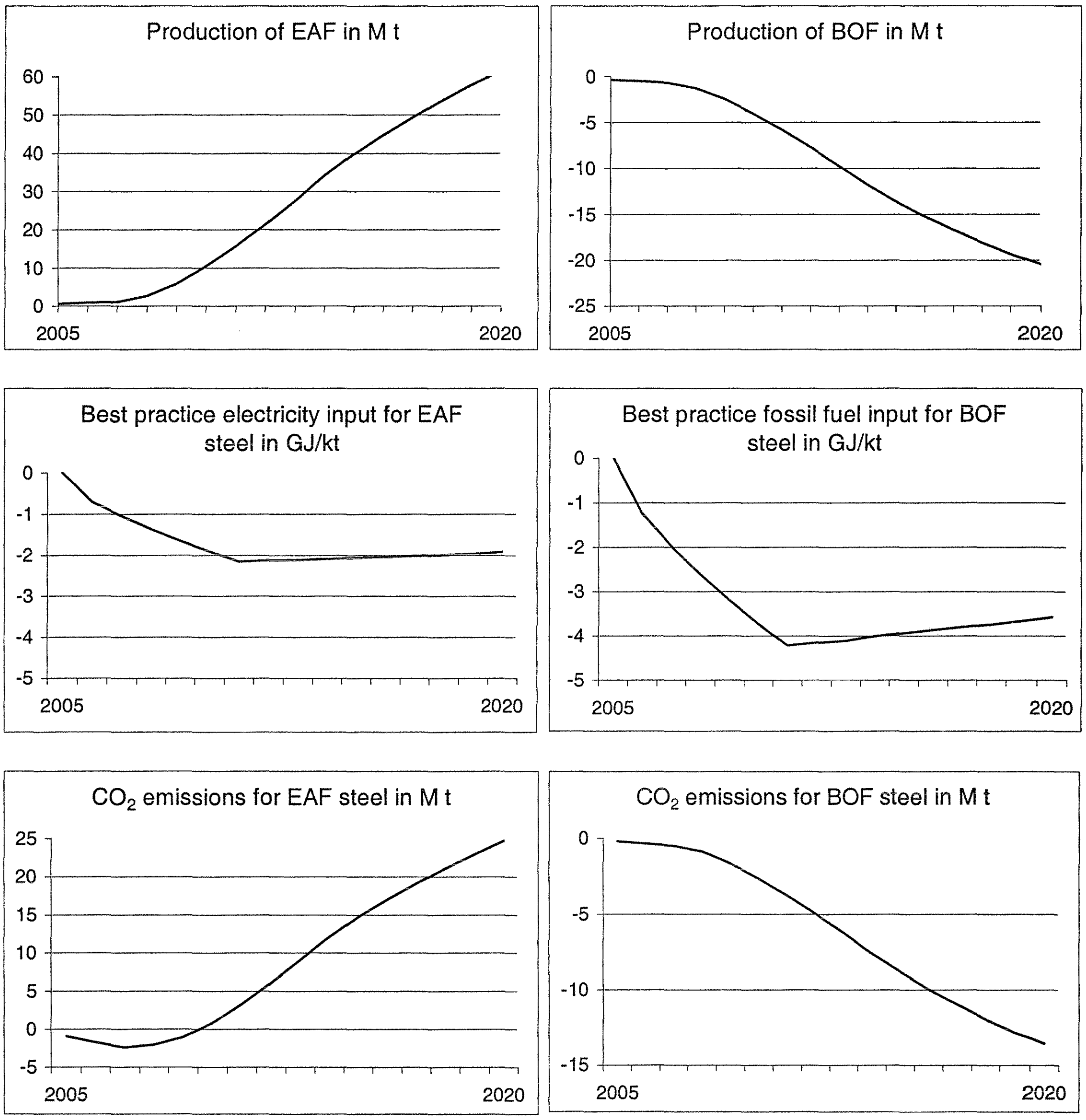


Figure 4-4: Effects of the CO_2-tax – percentage deviations from the base scenario

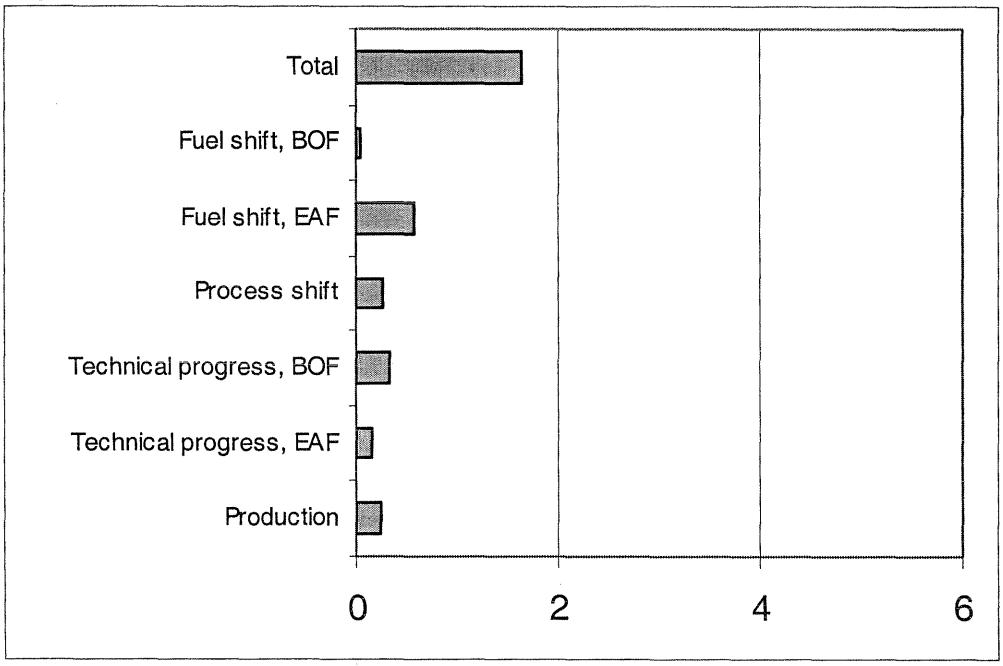


Overall, the reduction in CO_2-emissions can be decomposed in five effects: i) a reduction in steel production, ii) energy saving technical progress via more energy-efficient best-practice technologies, iii) faster implementation of best practice technologies via greater investment, iv) a long-term shift from more carbon-intensive BOF production to EAF production, and v) a change in fuel mix either in BOF production -from coke and coal to less carbon-intensive fuels like heavy fuel oil - or in electricity generation for EAF production - from carbon-intensive coal to gas or carbon-free renewable energy carriers.

The shares of these CO_2-reduction factors are shown in Figures 4-5 and 4-6 for the years 2010 and 2020. In 2010, when the CO_2-tax rate reaches its maximum, the fuel shift in electricity production is the most important source of CO_2-reduction. Technological progress, a process shift to EAF and steel production decrease are the other major sources of emission reduction. Total reduction is 1.65 M t or about 2.7 % of steel industry-related total emissions. Technological progress accounts for 0.49 M t of CO_2-reduction.

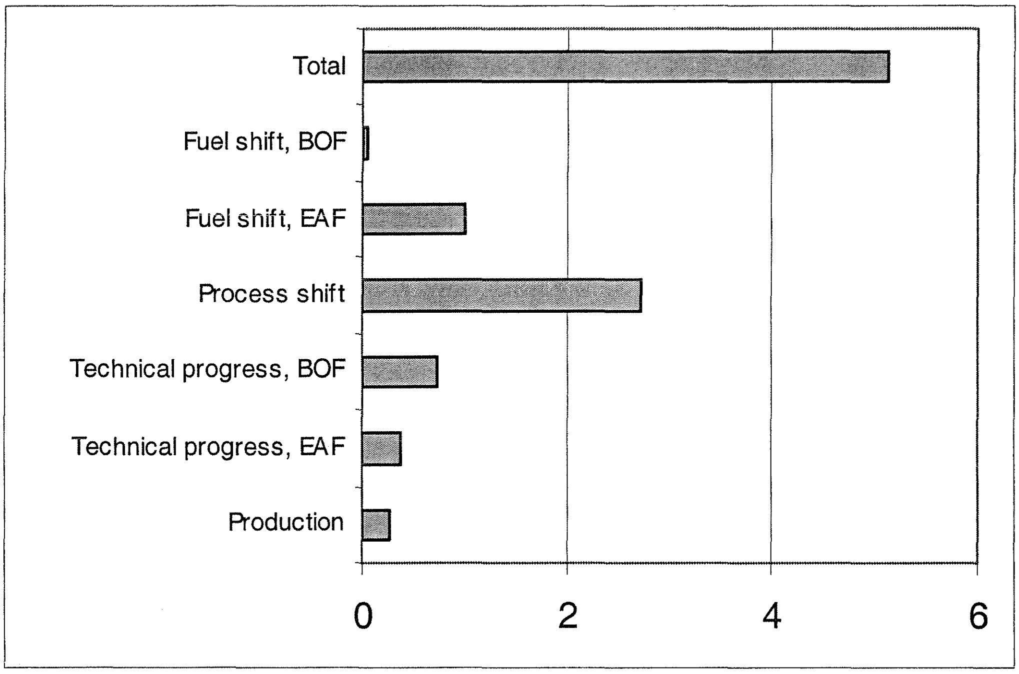
The most significant long-term development is the process shift from EAF to BOF production which accounts for 2.73 M t emission reduction in 2020. The lower steel production is only responsible for 0.26 M t. But it is important to emphasise that, with any other kind of international carbon trade, production losses would be higher due to carbon leakage. Fuel mix changes in the EAF process explain another 0.99 M t of CO_2-reduction; for BOF, this effect is very small with only 0.05 M t due to low investment. The effect is substantial for capital-embodied technological progress in BOF with 0.74 M t, and smaller again (0.37 M t) for EAF production. This can also be explained by a cost pressure hypothesis and the vintage structure of capital. Higher price increases for BOF induce more rapid technological change. At the same time older plants can be closed down earlier due to the process shift to EAF and therefore lower capacity utilisation. On the other hand, even older EAF plants remain competitive against older BOF ones.

Figure 4-5: CO_2-reduction factors in million metric tons in 2010



Comparing the effects for 2010 and 2020 shows some very interesting results: most of the CO_2-reduction takes place after the CO_2-tax has reached its maximum of 20 € per ton of CO_2 in 2010. Production reacts immediately to price signals, but investment-based process shifts and technology effects tend to develop more slowly over time. In past conventional simulations using the model PANTA RHEI (e. g. Bach et al. 2002) - as well as in almost all price-driven top-down models - this long-term effect could not be observed or only roughly modelled using long-term elasticities, that are not process-related. These findings demonstrate that integrating technologies explicitly can help to explain part of the gap between the high costs of CO_2-reduction estimated in top-down models and the low costs estimated in bottom-up models.

Figure 4-6: CO_2-reduction factors in million metric tons in 2020



4.1.3 Effects of a higher scrap price

In the last two years international raw material prices have been increased drastically. In the following simulation it is supposed, that the price for scrap is 50% higher than in the base simulation from 2004 onwards. Other prices for important inputs of the steel industry such as iron ore or coke remain unchanged compared to the base simulation. The aim of this simulation is to show possible influences of an important input price and not to model impacts of the actual price increase of many raw materials.

Figure 4-7: Share of EAF on total steel production in %

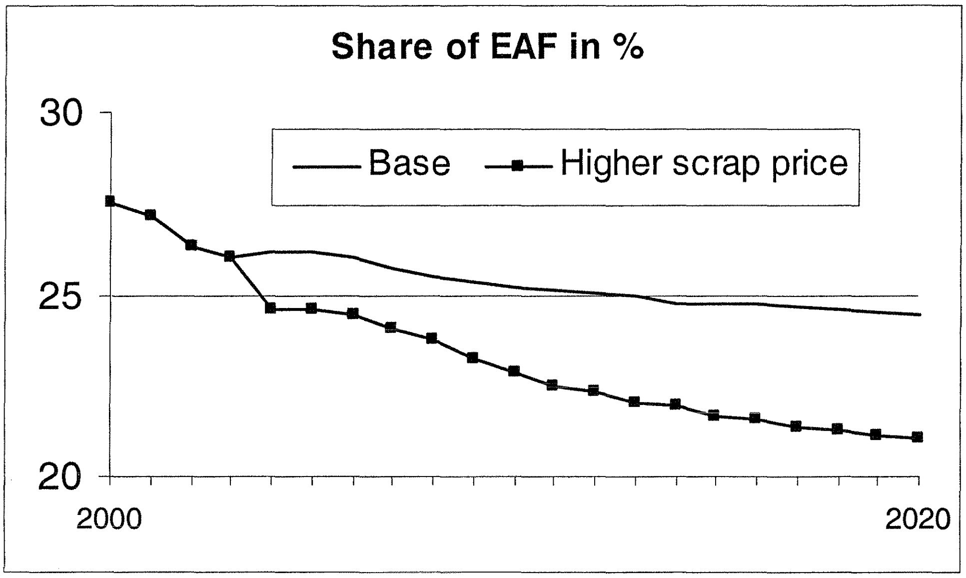


Figure 4-7 shows the dependency of electric steel production, that is based on scrap, on the price of scrap. Due to the higher scrap price, EAF share will be only about 21% instead of about 24.5% in the year 2020. As electric steel production is less carbon intensive than oxygen steel production, CO_2-emissions of the steel industry will be about 0.4 M t higher compared to the base simulation. The CO_2-effect is completely driven by the process shift from EAF to BOF. Best practice technologies remain unchanged, as they are only influenced by relative energy prices.

4.1.4 Windows of opportunity for radical technological change[28]

As pointed out earlier, steel production is one of the most important industrial energy consumers. A new technology for iron making – the smelting reduction technology SRT – is competing with the older two stage coke oven/blast furnace technology, which delivers iron for about 70% of German steel production. The question arises of whether the SRT technology may replace existing dominant technologies, i.e. BOF and EAF.

In general, technologies which exhibit increasing returns to adoption because of scale effects, learning effects or network effects, may not be easily substituted for by other, possibly more environmentally friendly technologies. According to Zundel et al. (2003, 2004) stable phases of competition where a certain technology or a set of technologies

28 This section is a brief summary of Lutz et al. (2005b).

which is characterised by increasing returns to scales is s dominating allow only for incremental technological change. Only instable phases of technological competition may create a techno-economic "window of opportunity" for competing radical innovations. Nill (2003) argues that such conditions may be found in the production of iron and steel. Under certain conditions SRT is less energy and carbon intensive than the BOF route because SRT basically replaces the traditional first stage of the steel production process, i.e. the coke-oven blast furnace route of BOF steelmaking, and produces prig iron directly from normal coal based on the principle of gasifying coal in a molten bath and or in a new type of oven, thus avoiding the coke oven operations entirely. [29]

For Japan and the Netherlands such a window of opportunity was expected to exist for the SRT. [30] For Germany, however, the current age of the capital stock for steel making suggests, that investment cycles do not allow for such a window of opportunity for SRT.

In 2003 about one third of German capacity of the old technology has been renewed, though in the 1990s, when the investment decision has been made, the SRT technology had been an alternative. We have tried to answer the question, whether the existence of a CO_2-tax at the end of the 1990s might have opened a window of opportunity for the new technology.

For Germany we have not found such a window of opportunity due to different technological parameters and different boundary conditions in the energy markets. Simulations with the econometric model PANTA RHEI for the introduction of a CO_2-tax in Germany show instead a long-term shift towards more electric arc steel production and improved competitiveness of the old technology due to price-induced technical progress. Thus, in the future a possible window of opportunity for radical technical change in integrated steel mills will be closed.

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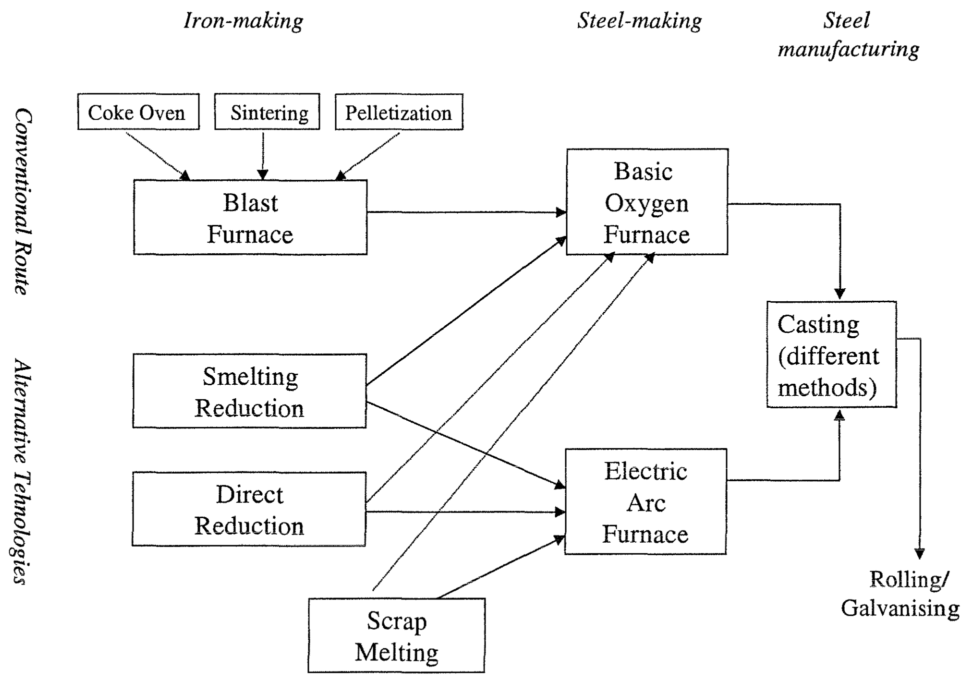
29 For sake of simplicity, the competition between scrap based EAF and SRT input based EAF is excluded for the thrust of the argument. We touch upon this question in our conclusion.

30 See Luiten (2001) for a thorough discussion of the Dutch case.

Figure 4-8: Schematic lay-out of the iron and steel industry



Source: Nill (2003, p. 4) based on Luiten (2001, p. 169)

The results generally highlight the importance of taking into-account the effects of policy-induced technological change on incumbent technologies when exploring windows of opportunities for new technologies which may be opened by policy interventions. Indeed, as already noticed by Nill (2003), windows of opportunity are a phenomenon of technological competition, and the progress of the incumbent technology has to be taken into account. It is sometimes even fuelled by revived competition, known in the literature as sailing ship effect. The progress of the conventional coke oven route in the 1990s was one reason that some conventional steel producers did stop investment into R&D on new technologies. For completeness the conclusions drawn by Lutz et al. (2005b) are reproduced: 1) the results generally highlight the importance of taking into-account the effects of policy-induced technological change on incumbent technologies when exploring windows of opportunities for new technologies which may be opened by policy interventions. Indeed, as already noticed by Nill (2003), windows of opportunity are a phenomenon of technological competition, and the progress of the incumbent technology has to be taken into account. It is sometimes even fuelled by revived competition, known in the literature as sailing ship effect. The progress of the conventional coke oven route in the 1990s was one reason that some conventional steel producers did stop investment into R&D on new technologies.

2) More specifically, the findings suggest that a CO_2-tax of the magnitude assumed might not be sufficient to render future investments in the SRT technology profitable compared to incumbent steel producing processes a) because differences in CO_2-emissions compared to BOF steel produced via the coke oven blast furnace route are not sufficiently large in the German case and even seem to become smaller because of induced improvements in energy efficiency in incumbent processes; and b) because the tax essentially favours EAF steel more than any variant of BOF steel in the long run. Hence, the window of opportunity for environmentally beneficial technological competition in BOF steelmaking in integrated steel mills may have vanished for quite a long time.

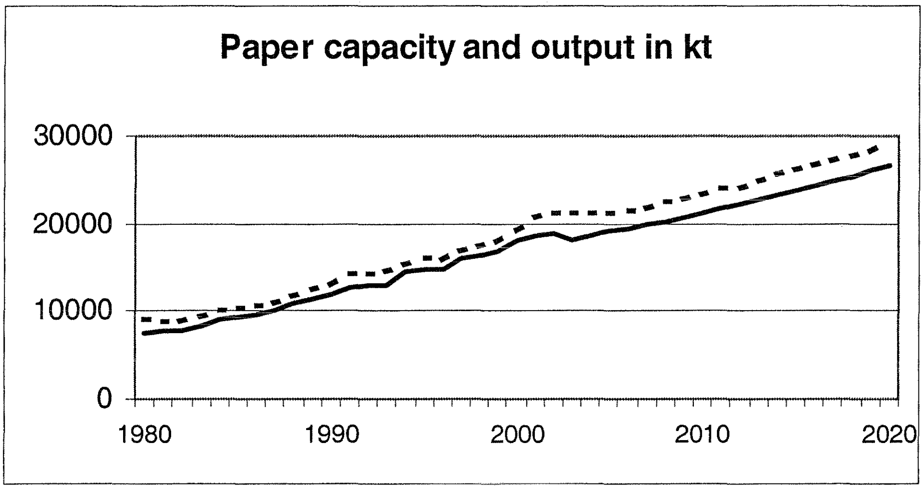
3) For the future the more interesting question is whether a CO_2-tax or emission trading enhance another kind of technological competition? Will such a tax induce the challenge of the conventional BOF route by an upgraded EAF technology with hot metal input, e.g. by SRT? To answer this question on solid grounds, a considerable modelling effort to integrate all environmental and economic aspects of this potential competition would be necessary which is beyond of the scope of this paper. Whether the EU CO_2-emissions trading system, which is scheduled to start in 2005 for most energy intensive companies, spurs such a competition is in principle an open question and also depends on the specifics of the national allocation plans. In countries where incumbent companies like existing BOF steel producers receive all allowances in the primary allocation for free (grandfathering) and new entrants, like new EAF/SRT steel producers have to buy their allowances on the market or through an auction such a competition would be difficult to arise (Nill 2003). However the emission trading system may also favour competition: in almost all EU Member States entrants receive allowances for free. In addition, in some Member States like Germany, plant operators may transfer allowances from closures to new installations, which is supposed to foster technological change.

4.2 Simulations for the paper industry

4.2.1 Base scenario

Paper production will continue to grow from 18 million tons in 2000 to more than 26 million tons in 2020 (Figure 4-9). Capacity will be about 10% higher during the simulation period and reach about 29 million tons in 2020. The share of recycled paper is set at constant 60% for the future reflecting two countervailing trends. Even though the share of recycled paper will grow for certain paper grades, this increase is likely to be compensated by faster growing grades with lower waste paper utilisation rates such as certain graphical papers. Specific energy demand will decrease by approx. 16% between 2005 and 2020 (Figures 4-10 and 4-11). Due to a fuel mix shift specific CO_2-emissions will be reduced by 22%. Because of the large increase in production, the absolute emission level in the pulp and paper industry still will increase by 16%.

Figure 4-9: Paper capacity and output in the base scenario



A significant part of energy consumption associated with paper production in Germany based on primary fibres occurs in foreign countries due to substantial pulp imports. If this additional foreign energy consumption is taken into account, specific fuel demand of PF paper more than doubles whereas electricity demand increases by approximately one third. In many pulp producing countries a considerable share of this energy demand is probably covered by biomass fuels, mostly production wastes, so that the CO_2-emissions associated with PF paper are not likely to increase as significantly as energy consumption when pulp imports are considered. Indirect domestic emissions of the paper industry due to the use of electricity are even higher than the direct emissions of the sector (see Figure 4-12).

Figure 4-10: Selected results for RCP paper in the base scenario

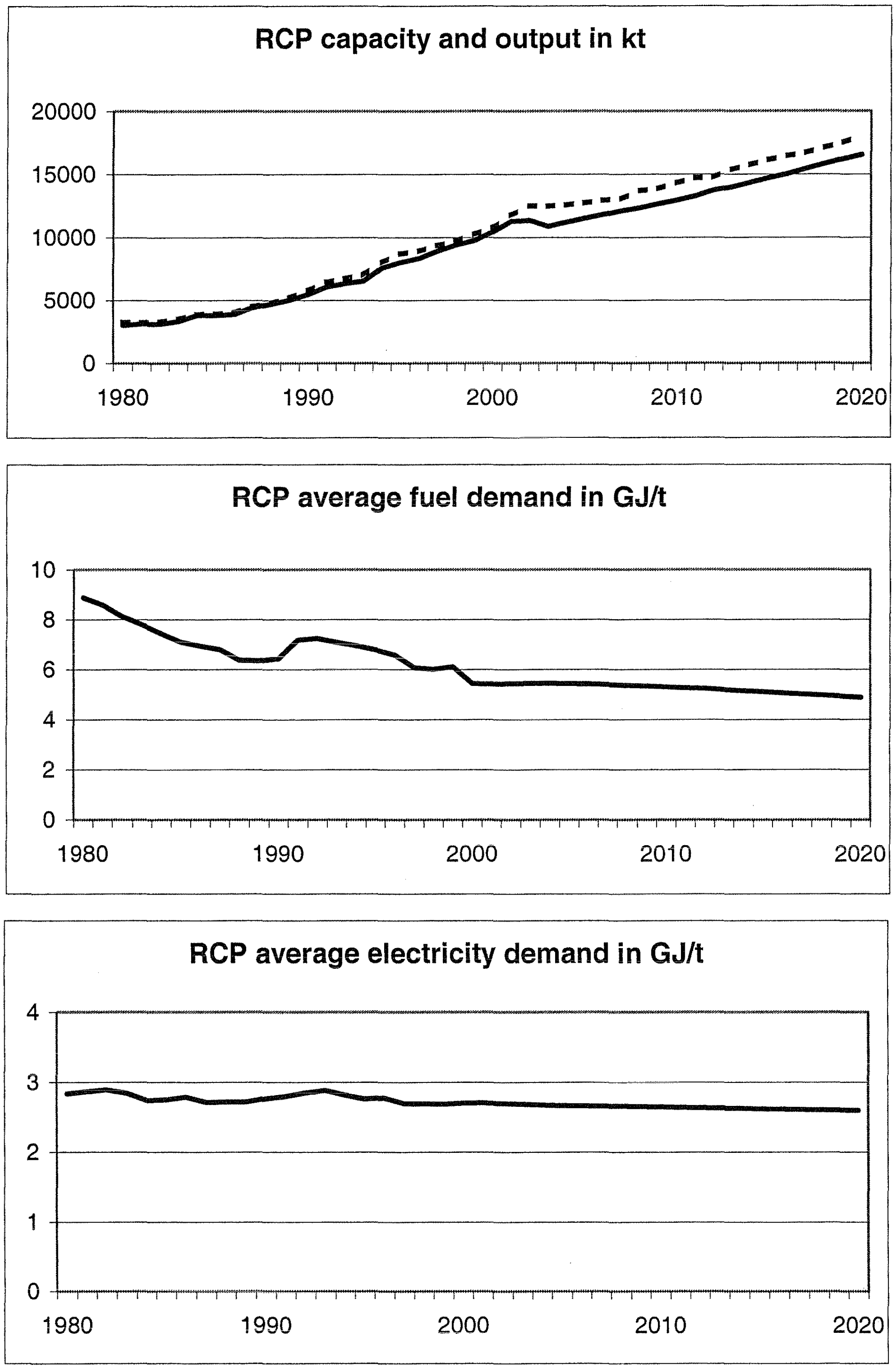
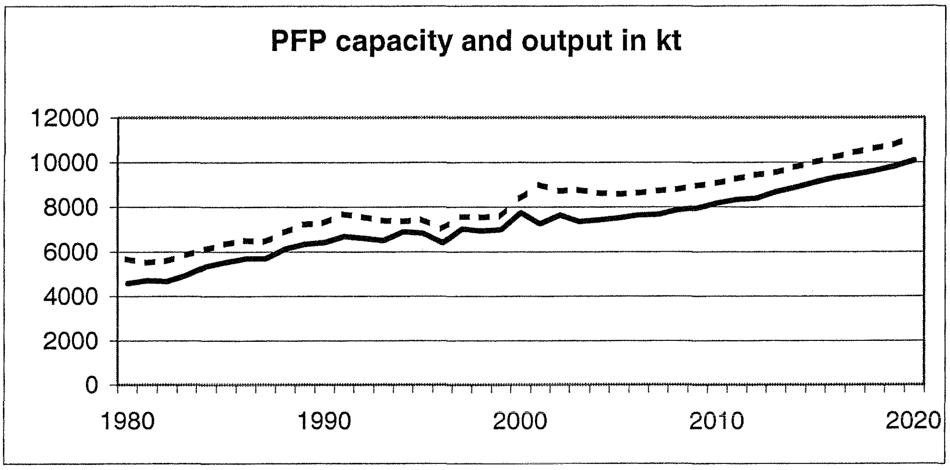
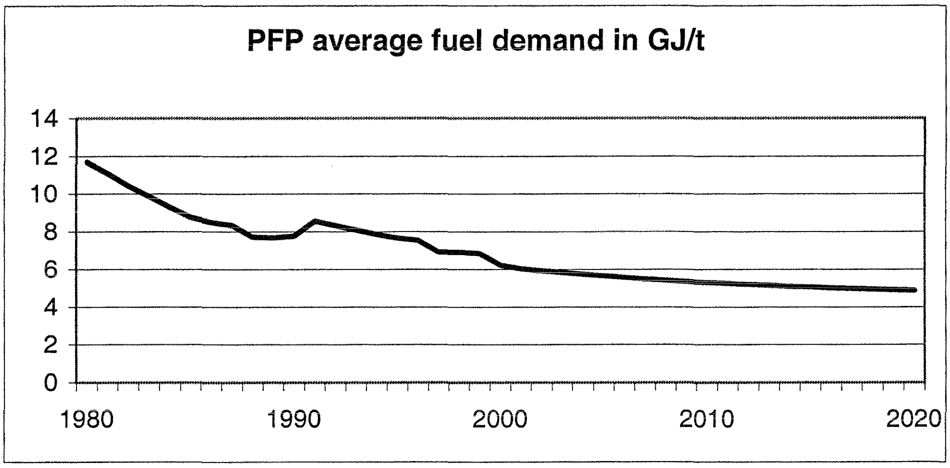


Figure 4-11: Selected results for RFP paper in the base scenario





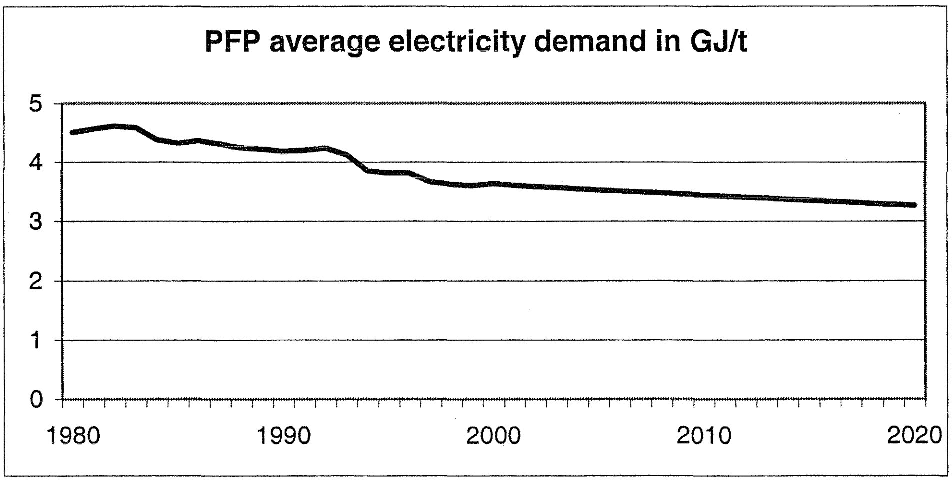
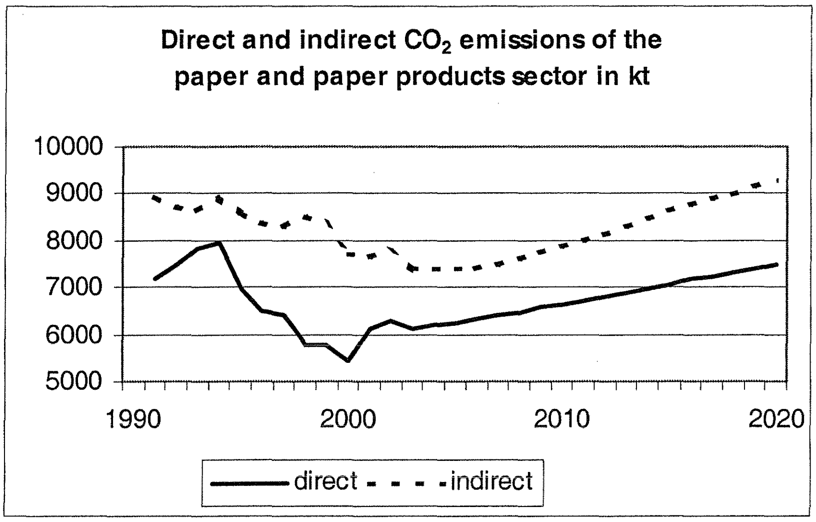


Figure 4-12: CO_2-emissions of the paper industry in the base scenario



4.2.2 Effects of a CO_2-tax

Suppose a CO_2-tax as described above is introduced in 2005, which increases from 5 € to 20 € per ton CO_2 in 2010. The weighted price of energy inputs of the paper industry increases up to 19% against the base simulation. The econometrically estimated price elasticity for the best practice fuel input is -0.20 for RCP and -0.19 for PFP. The output price for paper increase by about 0.6%. This causes a reduction of best practice fuel input for RCP of up to 3.5% in 2010 (Figure 4-13). The effect on average fuel demand is more gradual, as the more energy efficient technologies diffuse via investment into the capital stock over the years.

Fuel mix shift will be the other even more important source of CO_2-reduction in the paper industry. Compared to the base scenario the shares of low carbon natural gas and biomass fuels increase at the expense of coal and heavy fuel oil, thus leading to a CO_2-reduction of approximately 8 % in the year 2020 (Figure 4-14). Further remarkable CO_2-reduction via fuel mix shifts are not to be expected in the case of higher CO_2-prices, as the fuel share of gas and biomass will be more than 90 % in the CO_2-tax scenario in 2020.

Figure 4-13: Effects on best practice and average fuel input – relative deviations from the base scenario in %

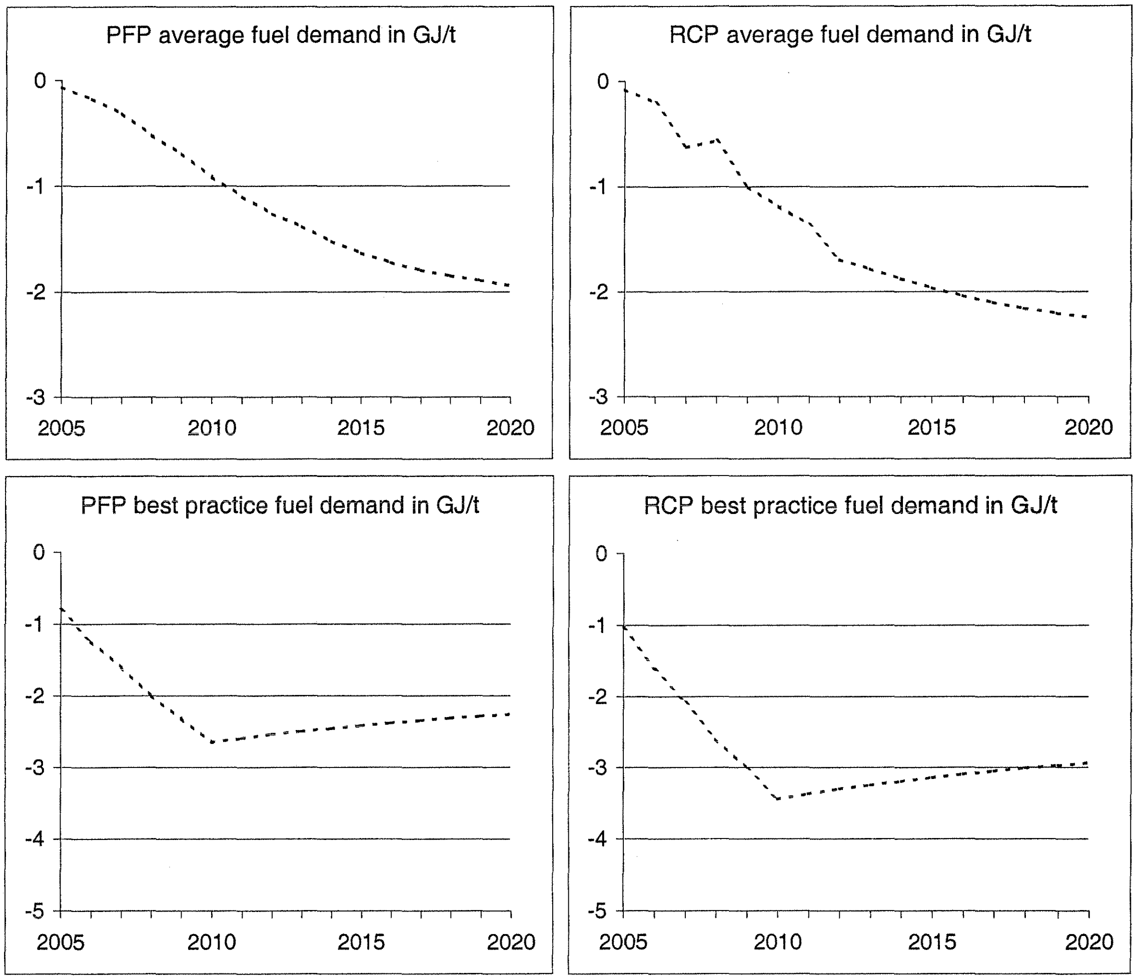
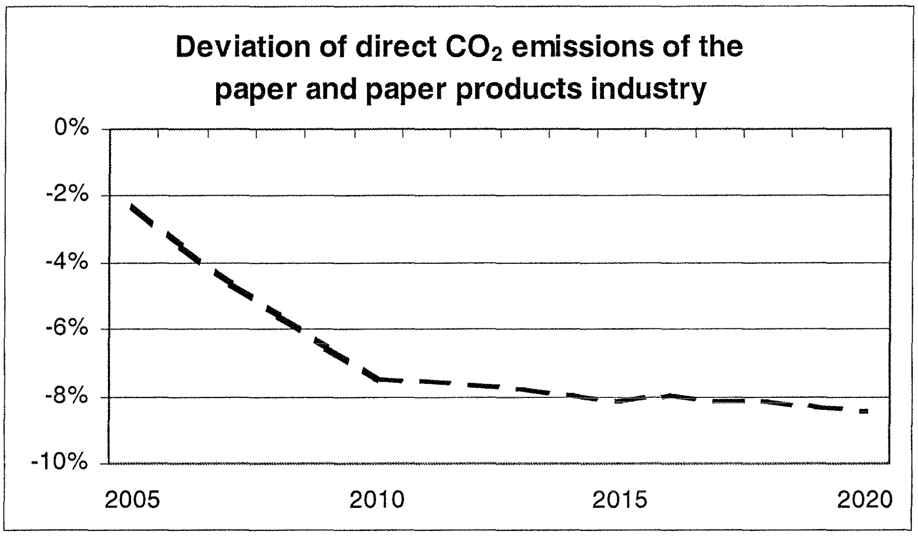


Figure 4-14: Effects of the CO_2-tax - deviations from the base scenario



The results presented are in line with Ruth et al. (2000), who – in a partial analysis framework – built a model based on econometrically estimated equations to explain the major determinants of energy use and CO_2-emissions of the American paper industry. Ruth et al. (2000) also predict a significant increase of energy efficiency in the base scenario as an autonomous trend, but only minor further improvements as a consequence of a similarly dimensioned CO_2-tax.

The work presented here has improved the accuracy of modelling energy consumption and emissions in the German paper industry in several aspects:

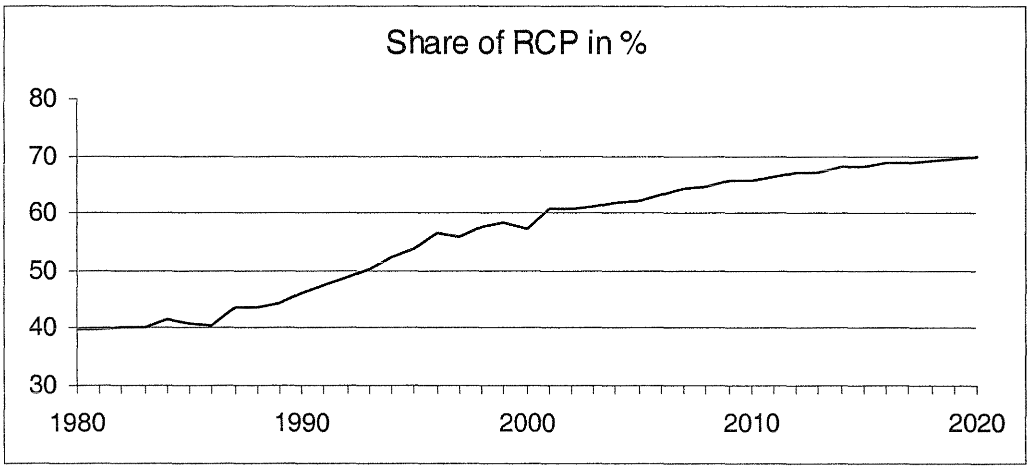
- calculation of energy demand and CO_2-emissions can be adapted to sector characteristics; in the case of the paper industry a two step approach is used, first calculating energy demand based on the evolution and diffusion of best practice technology and then fuel mix and CO_2-emissions;
- sector specific aspects such as the above mentioned structural effects (increase in waste paper recycling and ancillary materials input) or limits of biomass fuel use can be considered appropriately

A comparison of this analysis with the study of the iron and steel industry as described above (see also Lutz et al. 2005a) allows for the following conclusions. The econometric analysis of the iron and steel industry showed a higher correlation between best practice technology development and diffusion on one hand and energy and material costs on the other hand. Accordingly a CO_2-tax would have a stronger impact on the iron and steel industry and would induce several reactions including output effects, process shifts, enhanced energy efficiency and accelerating diffusion of best practice technology as well as fuel shifts. These stronger reactions seem plausible given the significantly higher share of energy and material costs in the iron and steel industry. A further, rather methodological reason might also rest in better data availability for the iron and steel industry. These findings also imply that the factors which appear to be responsible for the generation and diffusion of energy saving technologies differ among industries and that each industry has to be treated adequately in the proposed top-down/bottom up modelling framework.

4.2.3 Effects of a policy-induced higher share of RCP

A further increase of recycling paper (RCP) up to 70% of the overall paper production until 2020 is quite in line with the historic development since 1980 (see Figure 4-15). Paper made of primary fibres (PFP) is further substituted by RCP. There will be no additional effect on best practice technologies, which are only driven by energy prices. Development of the average fuel inputs of the two paradigms will change compared to the base simulation due to higher investment in RCP and lower investment in PFP. CO_2-emissions of the paper industry will be up to 1% lower than in the base scenario as RCP is less fuel intensive than PFP. C. p. lower production of PFP will also cause less energy inputs and emissions in foreign countries. As stated above, foreign and indirect emissions are even more important than direct emissions. But changes in these emissions or a production shift of PFP to these countries can not be modelled in PANTA RHEI. Therefore, this result for direct domestic emissions should be interpreted with care.

Figure 4-15: Share of RCP

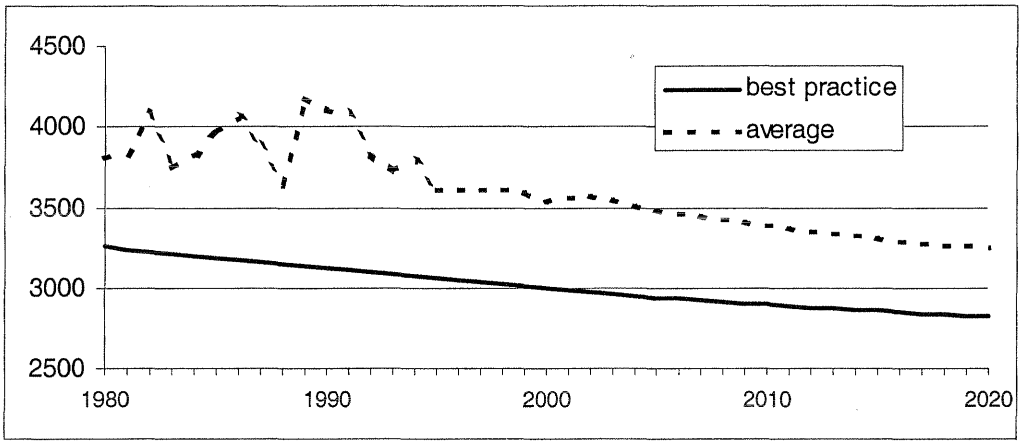


4.3 Simulations for the cement industry

4.3.1 Base scenario

The clinker production is by far the most energy-intensive part of the cement production. Best practice and average fuel input have been decreased since 1980. The development is supposed to continue up to 2020. Physical limits to further reduce the best practice fuel input might be reached after 2020.

Figure 4-16: Fuel input of clinker production in MJ/t



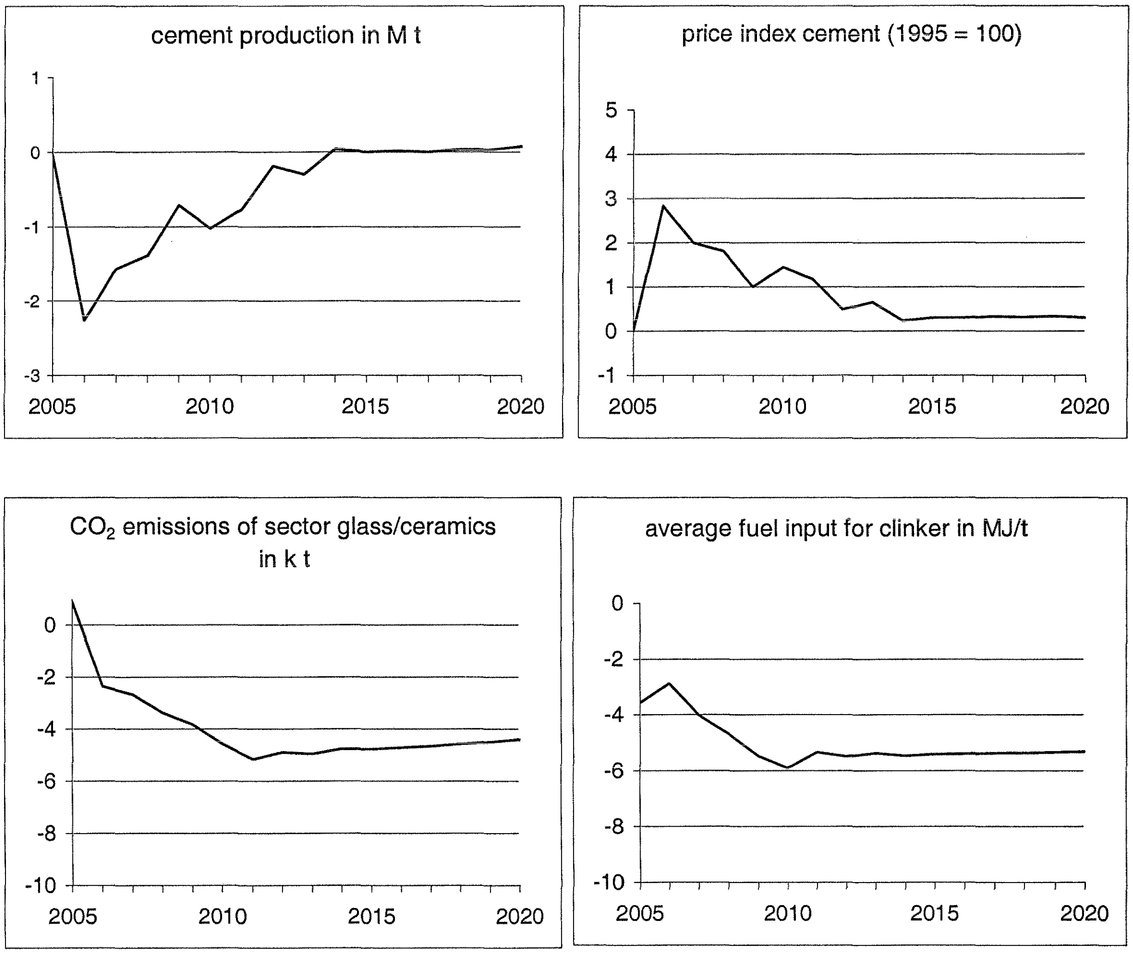
4.3.2 Effects of a CO_2-tax

For best practice fuel input of the cement industry no price influence could be found. It has only been driven by cumulated R&D spending of the cement industry. But the average fuel input depends among others on the price ratio of weighted fuel inputs and the output price of cement. Thus, improved energy efficiency will in case of the cement industry not only be introduced via new investment. Firms also have some possibilities to improve existing clinker production capacities. The average fuel input for clinker production is reduced up to 6% compared to the base simulation. Buttermann (1997) estimates this fuel-saving potential to about 8% of the overall fuel input.

CO_2-emissions of the sector glass and ceramics, that includes besides cement also some other processes, are about 5% lower in comparison to the base simulation. An additional driver for CO_2-reduction is fuel shift from soft coal to CO_2-neutral fuels. Waste-derived fuels such as automotive tires already hold a share in fuel input of the cement industry of almost 30% in 2000. This share will increase by another 16% due to the CO_2-tax.

The impact of the CO_2-tax on cement production is small. In 2000 energy costs accounted for about 20% of production costs of the cement industry. The weighted price for energy inputs, that already contains the shift from coal to waste-derived fuels is in 2010 about 40% higher than in the base simulation. Thus, production costs are about 8% higher compared to the base simulation. As production costs in competing countries are also rising – as assumed in the tax design – and price elasticities of domestic cement demand are low, cement production in tons will be only about 1% lower than in the base scenario.

Figure 4-17: Effects of the CO_2-tax - deviations from the base scenario



5 Simulation for all sectors

In the previous chapter the effects of policy interventions or changes in the economic frame conditions are analysed for single sectors. In this chapter, we explore the macroeconomic and environmental effects of a CO_2-tax/CO_2-emissions trading system on all sectors in the economy. In addition, we compare the results for the new modelling approach with the conventional modelling approach. Thus, a total of four simulations are carried out: simulations without the introduction of a CO_2-tax and simulations with a CO_2-tax for both the conventional and the new approach.

5.1 Effects of a CO_2-tax on the economy and on emissions

As for the single policy simulations in the previous chapter, the CO_2-tax is introduced in 2005 and increases from 5 € to 20 € per ton CO_2 in 2010. From 2011 on, the tax rate is kept constant at that level. The CO_2-tax is levied on all fossil energy carriers according to their carbon content, so that the use of coal is more heavily taxed than oil or gas. As the tax burden is at least partly passed on, electricity will also become more expensive as a result. Since in Germany the tax burden on electricity is already heavier than that on coal because of existing electricity taxes and since some electricity production is carbon free, coal prices are affected to a greater extent by the additional CO_2-tax than are electricity prices. The tax revenue is used to lower labour costs. Compared to the reference scenario the tax results in a reduction of CO2 emissions by 3.3 % in 2020.

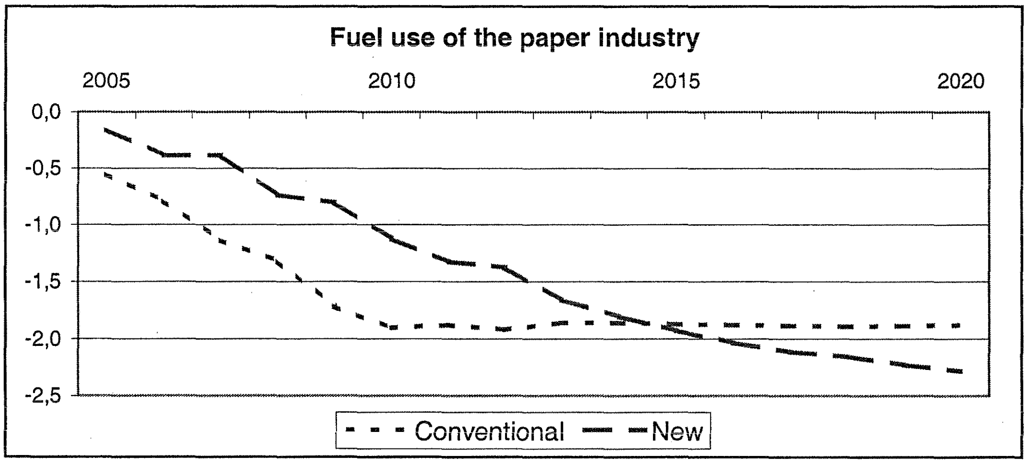
The macroeconomic effects of the CO_2-tax are almost negligible: the effect on GDP is below 0.2 % in 2020. The findings of small macroeconomic effects of climate policy are consistent with the thrust of the literature (IPCC 2001). As we assume the tax/CO_2-trading system forms part of a global CO_2 trading system, similar price increases in competing countries can be expected.

We first discuss the results for the German paper industry. The German paper and paper products industry will suffer almost no trade losses, but the CO_2 tax will primarily lead to a fuel mix shift in both approaches. Compared to the base scenario of the new modelling approach, the shares of low carbon natural gas and biomass fuels increase at the expense of coal and heavy fuel oil, thus leading to a CO_2-reduction of approximately 9 % in the year 2020. Further remarkable CO_2-reduction via fuel mix shifts are not to be expected in the case of higher CO_2-prices, as the fuel share of gas and biomass will be more than 90 % in the CO_2-tax scenario in 2020.

5.2 Comparison of a CO_2-tax for new and conventional modelling approach

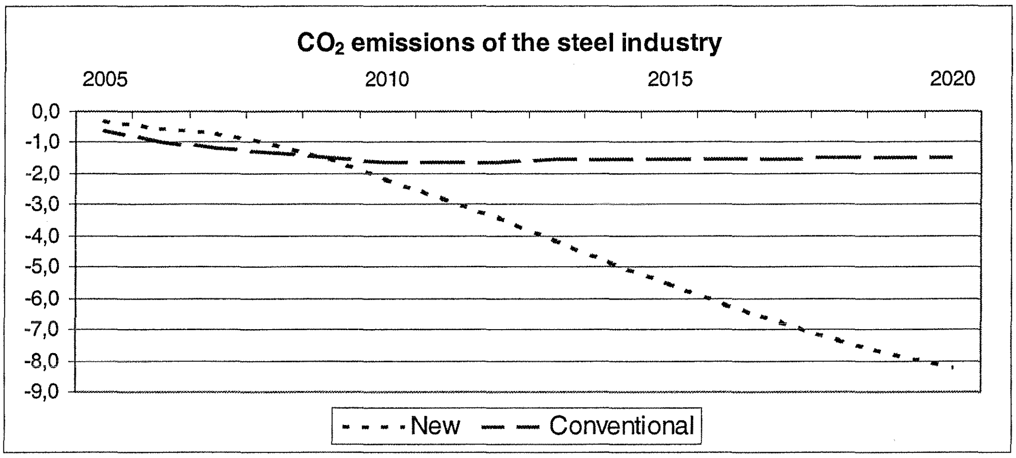
To highlight the differences between the new and the conventional approaches, we first look at the overall fuel use of the paper industry. In the conventional approach, it is driven by econometrically estimated low price elasticities. An increase of fuel prices via the CO_2-tax reduces the fuel inputs in the years 2005 to 2010, when the tax rate is steadily growing. Afterwards, this energy saving process comes to an end. In the new modelling approach, fuel use can only be changed via technical progress and its diffusion via new investment. So, in the first years of the CO_2-tax, the effect is smaller compared to the conventional approach, reflecting the time needed for adapting to the higher prices (see estimation results in Figure 5-1). But on the other hand, further energy savings result after 2010, better reflecting the influence of the higher energy price level after 2010 compared to the respective base scenario. In contrast to most macroeconomic top-down models the time needed for adaptation to changed price relations is depicted.

Figure 5-1: Effects of a CO_2-tax – percentage deviations from the base scenarios



The second example, refers to the steel industry which has more options to react to higher energy prices than the paper industry, as one of the technological paradigms is based on coal use (BOF) whereas the other is making use of electricity (EAF). As pointed out in the previous chapter, five factors of CO_2-reduction can be distinguished in the new modelling approach (see also Lutz et al. 2005a): i) a reduction of steel production, ii) energy saving technical progress via more energy-efficient best-practice technologies, iii) faster implementation of best practice technologies via greater investment, iv) a long-term shift from more carbon-intensive BOF production to EAF production, and v) a change in fuel mix either in BOF production - from coke and coal to less carbon-intensive fuels like heavy fuel oil - or in electricity generation for EAF production - from carbon-intensive coal to gas or carbon-free renewable energy carriers. The process shift between coal-based BOF production to electricity-based EAF production turned out to be the most important factor for CO_2-reduction. Fuel shift has been found to be only a minor option.

Figure 5-2: Effects of a CO_2-tax – percentage deviations from the base scenarios



In the conventional approach, this process shift is not explicitly modelled, but simply hidden – together with the process shift - in the substitution of the energy carriers used in the steel industry. Again the development over time is the most interesting difference. In the first years of the tax increase up to 2010, the conventional approach is more optimistic about the reduction potential of the steel industry. But in the long run, the process shift towards less carbon-intensive electric (EAF) steel production in the new approach offers much more CO_2-reduction. One of the major obstacles against price instruments to reduce carbon emissions in the long run can be observed. The steel industry itself is mainly concerned about the near future, where conventional macroeconomic modelling seems to be too optimistic about their reduction potential. Their argument, that they cannot react immediately to growing carbon prices is a serious one. But by arguing against higher carbon prices in the near future, the industry is at the same time preventing carbon-saving technical change and process shift in the long run.

To sum up, Figures 5-1 and 5-2 nicely illustrate how the conventional approach overestimates substitution possibilities between alternative production possibilities within the paper and the steel industry, thus underestimating the costs of climate policies in the early phase. For the later phase, however, the lack of accounting adequately for induced-technological change leads the conventional approach to overestimate the costs of climate policies compared to the new approach. This observation also highlights the importance of allowing for long adjustment periods and timeframes when analysing the environmental and economic effects of climate policies when technological change is endogenous.

Figure 5-3: Effects of a CO_2-tax – percentage deviations from the base scenarios

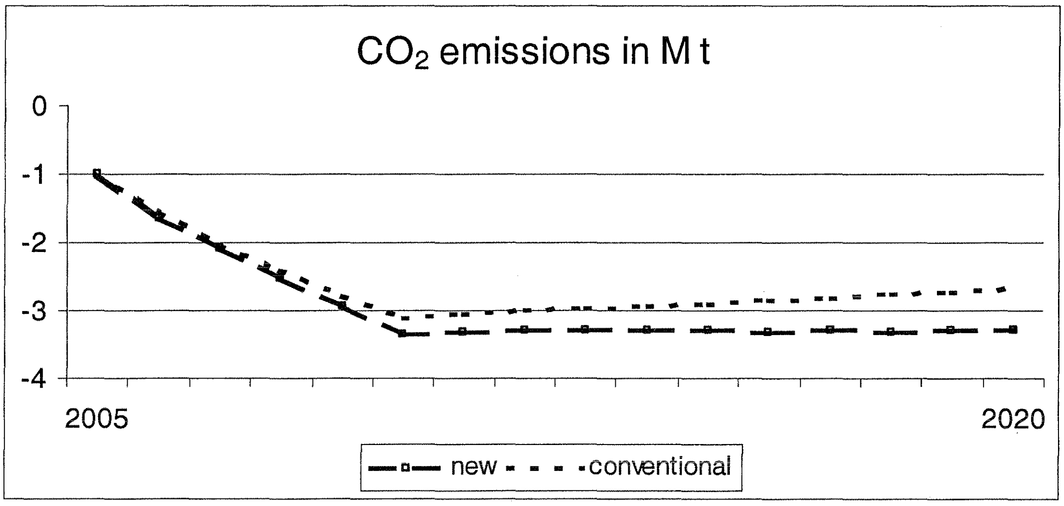


Figure 5-3 shows the impact of the CO_2-tax on total CO_2-emissions in the conventional and the new approach. The difference between the two approaches is very small at the beginning but growing significantly. In both approaches growing CO_2-tax rates from 2005 to 2010 induce additional emission reduction. Especially in the long run, emission reduction is higher in the new approach due to the process shift, substitution of energy carriers and induced technical change, although the modelling is now based on explicit technologies, which per se diminishes the reduction potential. The absolute difference of 0,6 percentage points in 2020 is also remarkable in relation to the small share of the sectors steel, paper and cement in overall emissions. As the effect on GDP is widely the same, it can be concluded that in the new approach economic costs for the same CO_2-reduction are lower than in the conventional approach.

6 Structural change and qualitative employment effects of CO_2-tax

In the previous section, the effects of a modest tax on CO_2-emissions were analysed. The results imply that the total impact on GDP is almost negligible. In this section, in addition to the economic and environmental effects, in the sense of a comprehensive sustainability concept, some dimension of the social impact of a CO_2-tax is also explored. In particular, the policy effects are analysed in a consistent modelling framework. Since the impacts of a CO_2-tax on qualitative employment depend on the effects of employment in the industry sectors, we first present the sectoral employment effects.

6.1 Impact of a CO_2-tax on sectoral employment

As in chapter 5, the CO_2-tax is introduced in 2005 and increases from 5 € to 20 € per ton CO_2 in 2010 and then remains at that level. The tax revenue is used to lower social security contributions as in other studies with former versions of PANTA RHEI, where the model was used to analyse the effects of an ecological tax reform: revenues from higher energy taxes are used to lower labour costs (Bach et al. 2002, Frohn et al. 2003). Lower labour costs compared to the reference scenario reduce the pressure to increase labour productivity and favours labour intensive sectors. In this sense, using tax revenues to lower relative labour costs may produce a double dividend: first CO_2-emissions will be reduced and second, employment (and possibly GDP) will increase in response to the CO_2-tax.[31]

The model calculations imply that the CO_2-tax results in an increase in total employment by about 313.000 jobs in 2010 and by 231.000 in 2020 compared to the reference scenario. Results of sectoral employment changes for the years 2010 and 2020 are displayed in Figure 6-1.

31 For additional literature on the double dividend hypothesis see, for examplle, Bovenberg and de Mooij (1994), Bovenberg and van der Ploeg (1994), Goulder (1995), Schöb (1995) or Parry et al. (1999).

Figure 6-1: Changes in sector employment for a CO_2-tax in 2010 and 2020 compared to the reference scenario in %

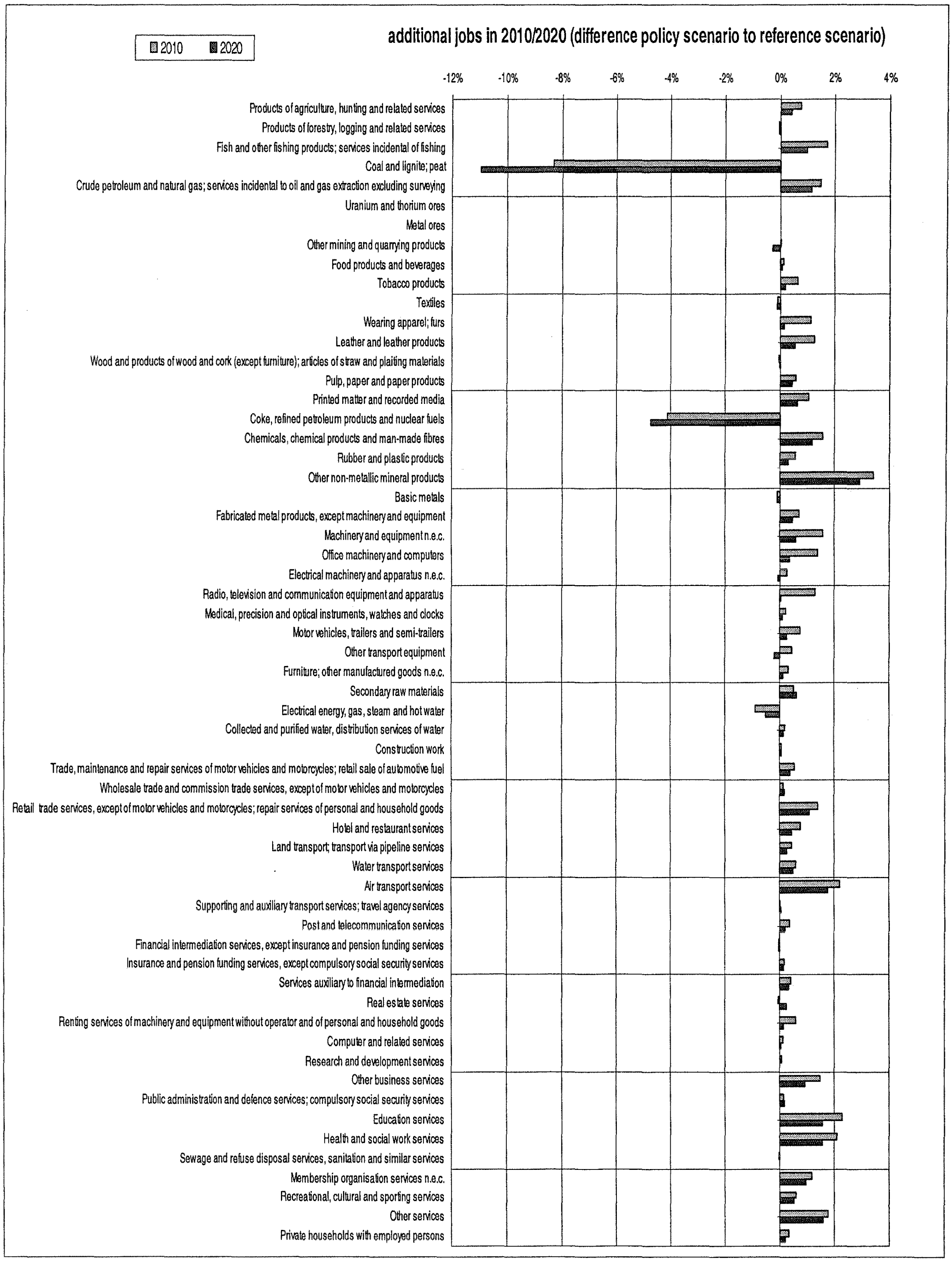


Figure 6-1 shows that in general, the effects of a modest CO_2-tax on employment are small for most sectors. The majority of sectors benefits from lower labour costs. Since the tax burden is relatively lower on natural gas than on other fossil fuels, the gas sector actually benefits slightly. Not surprisingly, the highest losses can be found in the production of coal and lignite, where losses range around 10 %. Other significant losses occur in the production of coke (mainly for BOF steel) and of refined products. The drop in the production of electricity, steam and hot water is around or below 1 % compared to the reference scenario. Even though the differences in absolute job numbers are small, the results for some sectors are not straightforward and will be explained in more detail. Employment increases in sectors "other non-metallic mineral products", which includes the cement industry, and "air transport services". Equation 95 in Annex B describes employment, which depends on gross production, the ratio of labour costs to the output price index of the specific sector and technical time trends. For both sectors the econometrically estimated elasticities for the ratio of labour costs to output price are high. Though gross production is slightly reduced due to the CO_2-tax the positive labour cost effect dominates the impact on employment.

6.2 Qualitative employment effects

The sectoral changes outlined in the previous section also imply different effects on the job characteristics and qualification requirements. To account for these structural adjustments, the sectoral employment changes were linked with data from the German microcensus on job characteristics and qualification requirements within each of the economic sectors. The data used in the microcensus relies on an anonymised 70 % sub-sample of the 1 % population census for private households in 1996 which in addition to basic socio-economic information also includes data on job qualification and working conditions. Since it is also known in which sector the interviewee is employed, information on working conditions and job qualifications could be complied for each industry sector. The sectoral employment effects calculated by PANTA RHEI were then linked with the sector data for job qualifications and working conditions from the microcensus data.[32] Thus, the differences between the reference scenario and the tax policy scenarios with regard to job characteristics and qualification requirements could be

32 Since the sector definitions of the microcensus differs from the input-output tables used in PANTA RHEI additional sector adjustments were carried out.

calculated in a consistent way.[33] More specifically, the following indicators were analysed:

- qualification requirements: master degree, bachelor degree, foreman/technician, apprenticeship, without education/training;
- job characteristics: percentage of full-time jobs and part-time jobs and jobs;
- job flexibility: percentage of jobs with an increased need for flexible working hours (weekend/holiday work; evening/night work; shift work).

In the analyses it was assumed that the emission tax policy does not change the pattern of distribution of the qualification requirements and working conditions within each sector.

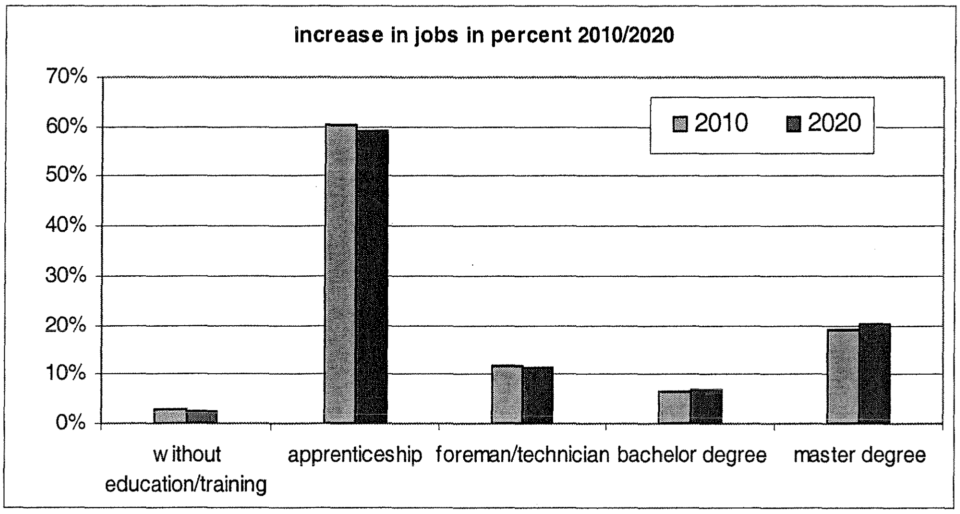
Absolute changes in job qualification and working conditions induced by the CO_2-tax are presented in Table 6-1. Figures 6-2 to 6-7 show the effects of the CO_2-tax for job qualifications and working conditions in 2010 and 2020 compared to the reference scenario in %.

33 Similar analyses on job characteristics and qualification requirements were conducted, for for example, by Walz et al. (2001), Nathani et al. (2001) or Walz and Schleich (forthcoming).

Table 6-1: Differences in job qualifications and working conditions between policy and reference scenario

		increase in jobs		decrease in jobs		total effect	
		2010	2020	2010	2020	2010	2020
education	without education/training	8.385	6.069	-254	-154	8.132	5.915
	apprenticeship	188.350	137.287	-5.437	-3.282	182.913	134.005
	foreman/technician	36.476	26.715	-911	-549	35.566	26.166
	bachelor degree	20.745	15.652	-472	-294	20.273	15.358
	master degree	59.335	47.101	-398	-247	58.937	46.855
	full-time	238.425	174.323	-7.221	-4.372	231.204	169.952
	part-time	74.867	58.501	-250	-154	74.617	58.347
saturdays	yes, permanently	34.445	26.077	-276	-158	34.170	25.918
	regularly	49.385	36.656	-856	-491	48.529	36.165
	occasionally	55.177	40.555	-1.716	-1.019	53.461	39.536
	no	174.285	129.537	-4.623	-2.858	169.662	126.679
sun- and holidays	yes, permanently	13.676	9.568	-70	-41	13.606	9.527
	regularly	31.475	22.599	-647	-364	30.828	22.235
	occasionally	40.462	30.339	-1.313	-756	39.149	29.583
	no	227.678	170.319	-5.440	-3.366	222.238	166.954
evenings	yes, permanently	21.769	15.657	-323	-194	21.446	15.463
	regularly	43.016	30.444	-1.163	-691	41.853	29.753
	occasionally	45.595	34.388	-1.172	-681	44.423	33.707
	no	202.912	152.336	-4.813	-2.960	198.099	149.376
night-shift	yes, permanently	6.327	4.259	-327	-191	5.999	4.068
	regularly	15.546	10.487	-1.001	-577	14.545	9.910
	occasionally	19.658	14.355	-742	-426	18.917	13.929
	no	271.760	203.724	-5.400	-3.332	266.360	200.392
shift-work	yes, permanently	20.365	13.251	-1.184	-699	19.181	12.552
	regularly	14.108	9.430	-634	-379	13.475	9.051
	occasionally	4.266	2.933	-274	-164	3.992	2.770
	no	274.552	207.210	-5.379	-3.284	269.173	203.926

Figure 6-2: Change in qualification requirements in %



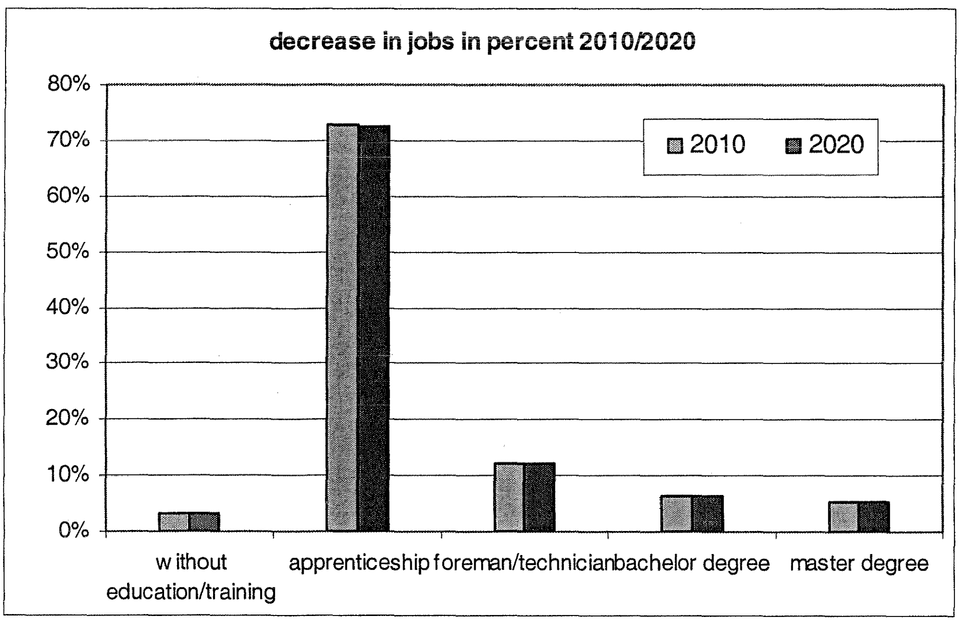
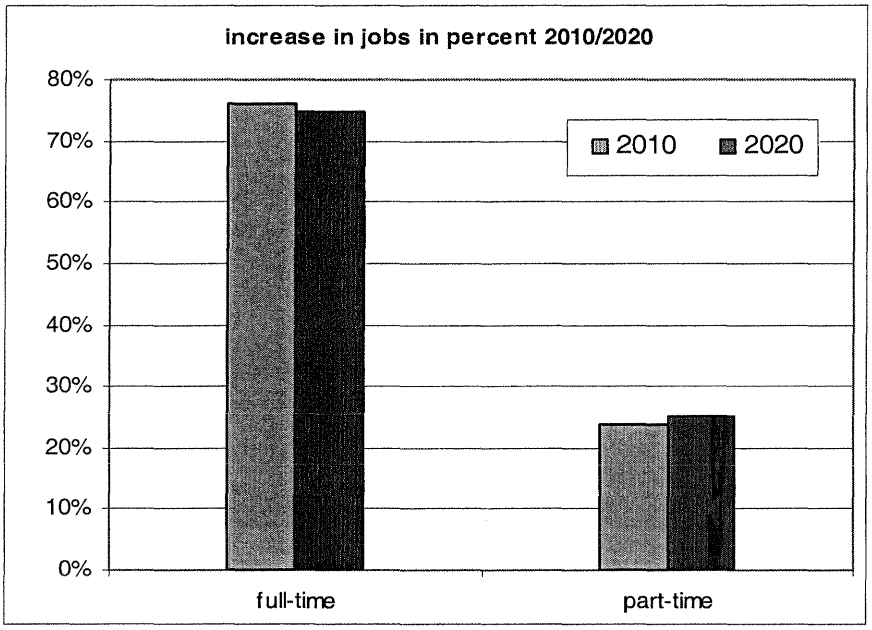


Figure 6-3: Change in job characteristics in %



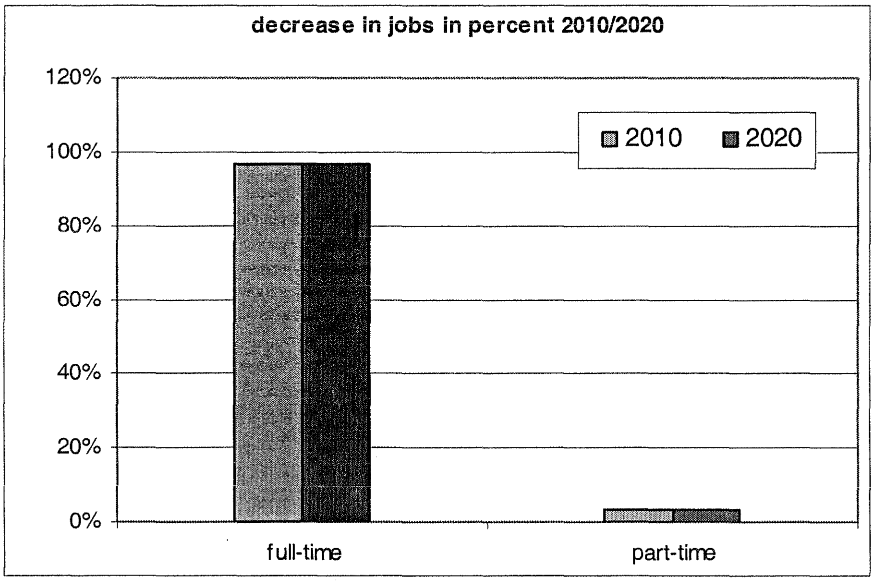
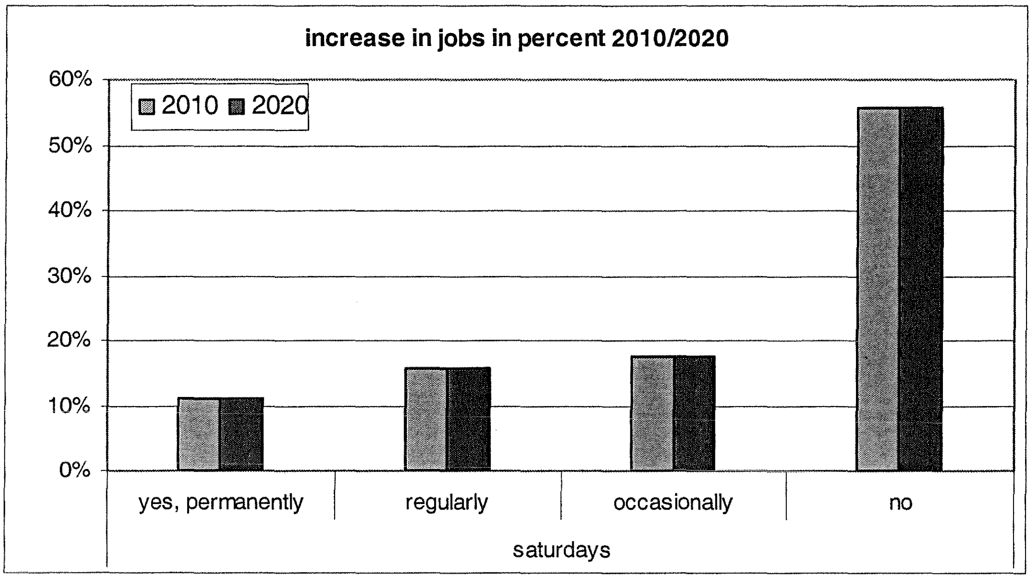


Figure 6-4: Change in job flexibility (work on saturdays) in %



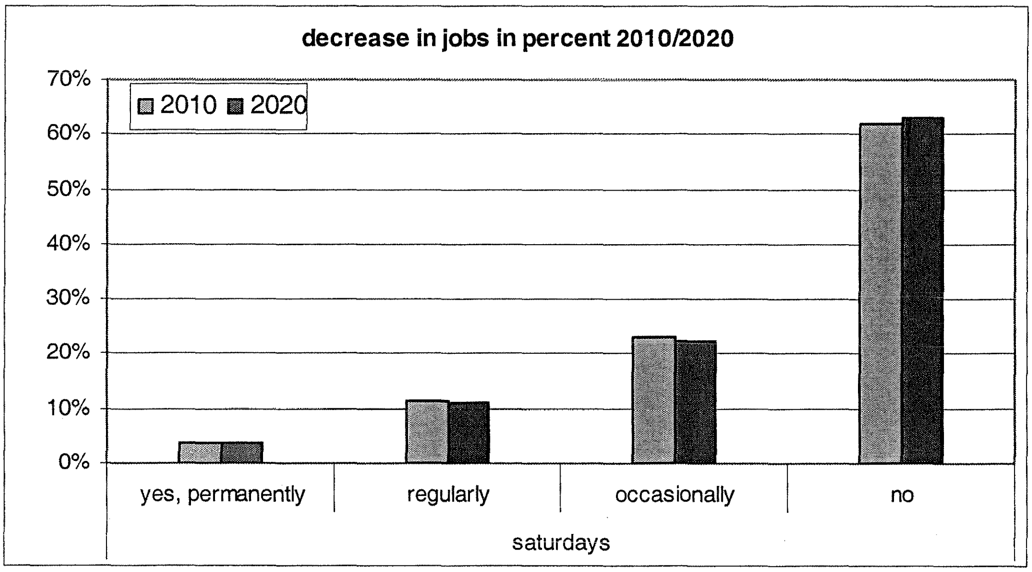
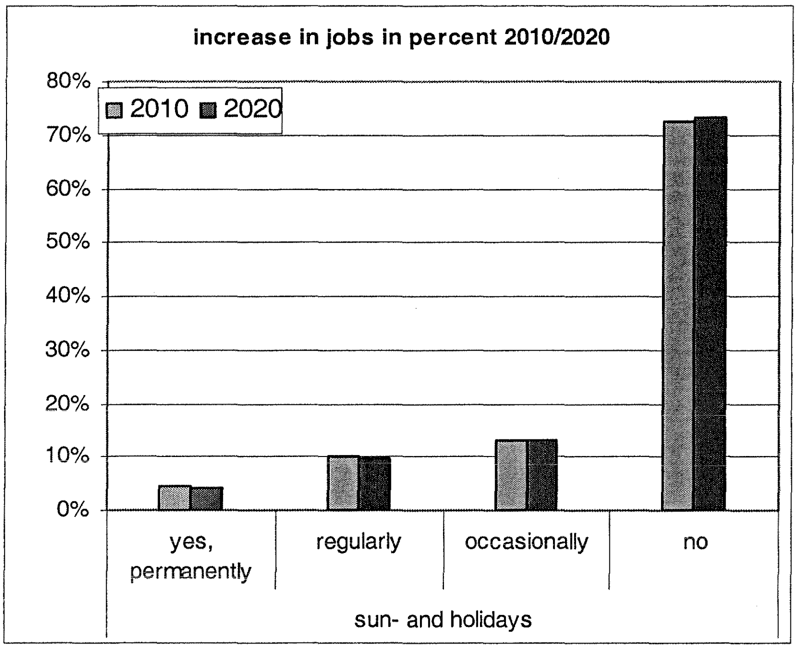


Figure 6-5: Change in job flexibility (work on sun- and holidays) in %



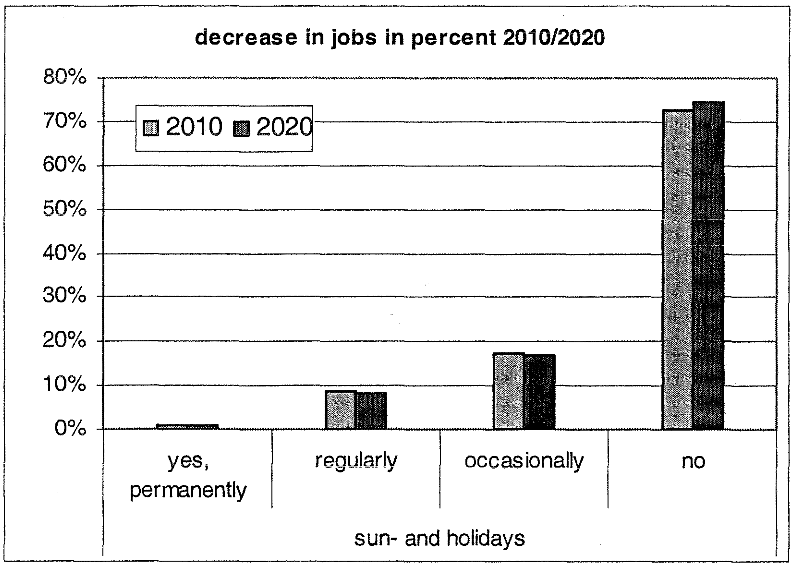
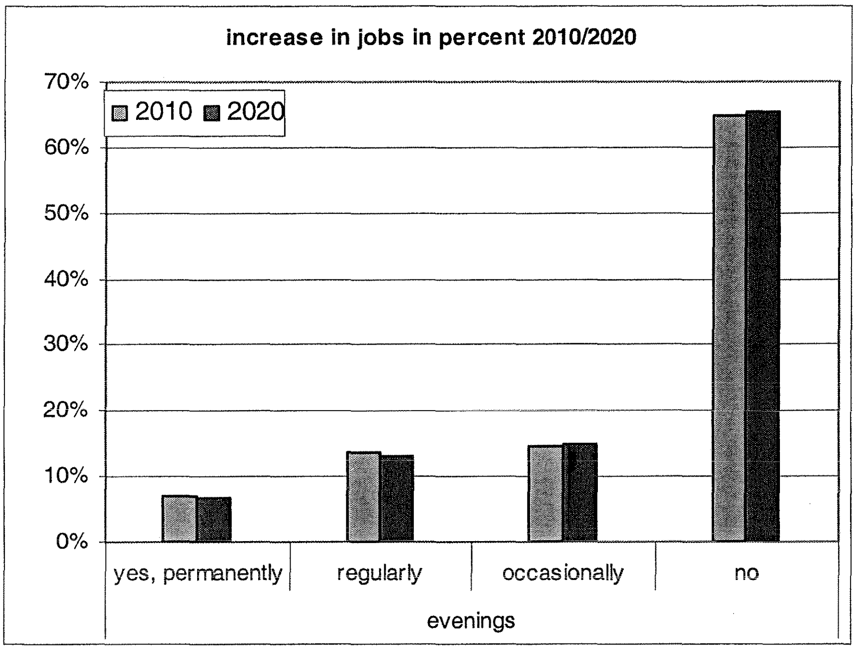


Figure 6-6: Change in job flexibility (evening work) in %



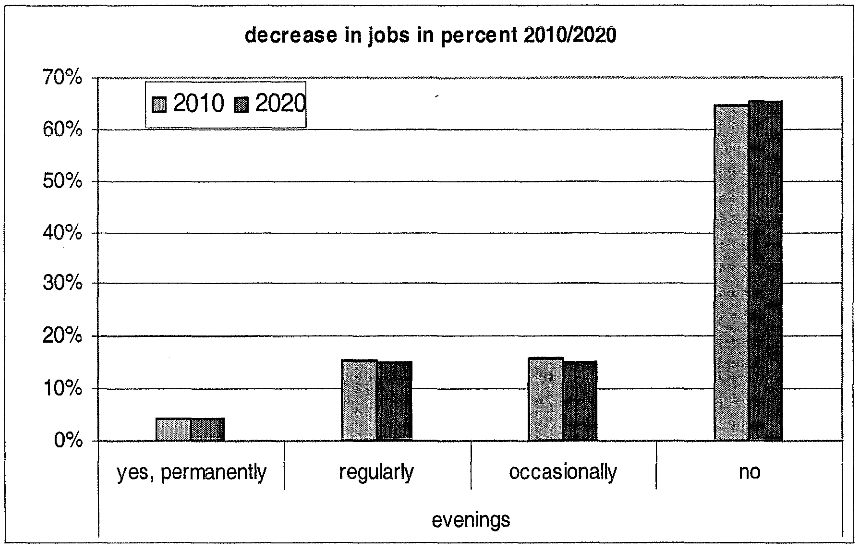
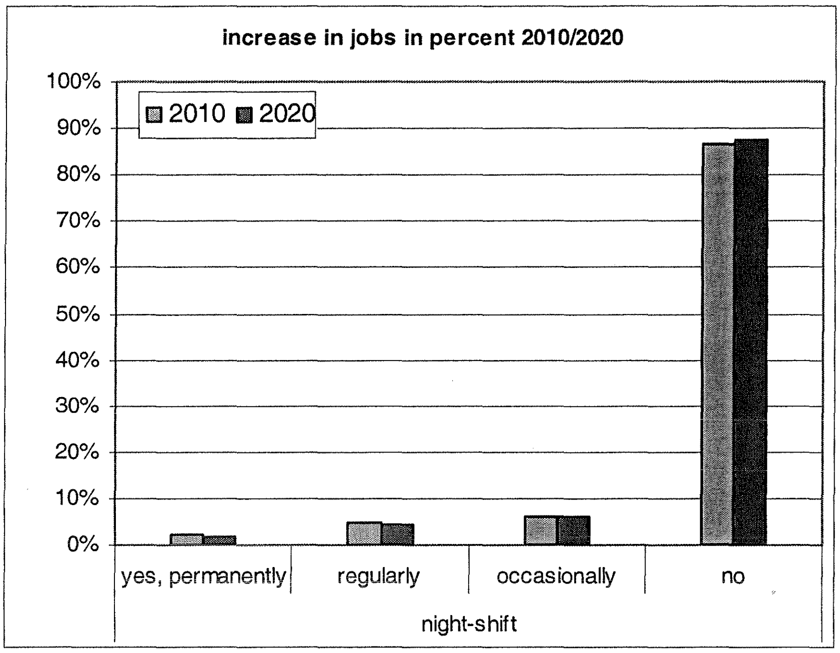
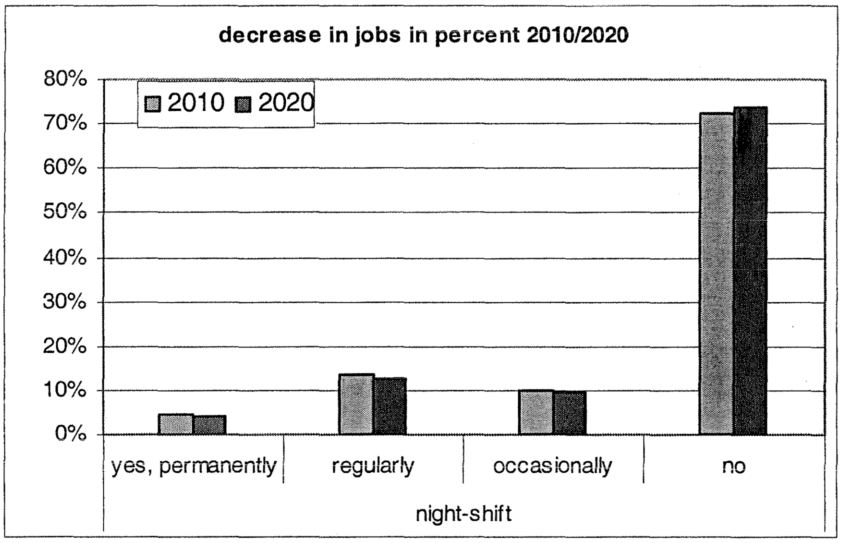


Figure 6-7: Change in job flexibility (night shifts) in %





The results in Table 6-1 show that the net effects of the emission tax on qualification requirements, job characteristics and job flexibility are generally small. Figures 6-2 to 6-7 nevertheless imply that for some characteristics, differences for winning and losing sectors are more profound. To highlight the effects, in Table 6-2, the percentage changes in qualification requirements and in job flexibility are displayed for sectors which – in terms of employment changes - benefit and lose above-average from the introduction of the CO_2-tax. Thus, the CO_2-tax leads to a clear shift towards higher (master) and a slight shift towards medium (bachelor and foremen/technician) education requirements. For the jobs with the lowest qualification requirement the CO_2-tax has no noticeable effect.

As for the split in part/full time work and for job flexiblity, the structural effects are less pronounced and almost negligible. The analysis for the winning and losing sectors in Table 6-2 implies that the CO_2-tax will only lead to very small structural shifts towards less flexible working conditions, i.e. less weekend and holiday work and less shift work.

Table 6-2: Change in qualification requirements and job flexibility in above-average winning and above-average losing sectors in %

		winner		loser	
		2010	**2020**	**2010**	**2020**
education	without education/training	2,50%	2,46%	3,51%	3,32%
	apprenticeship	57,08%	56,12%	73,99%	72,76%
	foreman/technician	11,78%	11,60%	10,86%	10,71%
	bachelor degree	6,90%	6,89%	5,22%	5,83%
	master degree	21,74%	22,93%	6,42%	7,38%
	full-time	74,05%	72,82%	83,65%	83,31%
	part-time	25,95%	27,18%	16,35%	16,69%
saturdays	yes, permanently	9,99%	10,62%	17,34%	15,33%
	regularly	16,34%	16,39%	13,40%	12,86%
	occasionally	17,27%	17,08%	18,57%	18,61%
	no	56,40%	55,91%	50,69%	53,20%
sun- and holidays	yes, permanently	3,00%	3,12%	11,99%	9,94%
	regularly	10,28%	9,97%	9,06%	8,48%
	occasionally	12,97%	13,00%	11,93%	12,73%
	no	73,75%	73,91%	67,02%	68,85%
evenings	yes, permanently	5,73%	5,88%	13,69%	11,65%
	regularly	13,47%	13,11%	14,81%	12,60%
	occasionally	14,79%	14,84%	13,13%	14,37%
	no	66,01%	66,17%	58,37%	61,39%
night-shift	yes, permanently	1,44%	1,39%	4,67%	3,92%
	regularly	4,63%	4,28%	5,40%	4,65%
	occasionally	5,99%	5,89%	7,20%	7,25%
	no	87,94%	88,43%	82,73%	84,18%
shift-work	yes, permanently	5,82%	5,30%	8,63%	6,56%
	regularly	4,28%	3,94%	5,08%	4,09%
	occasionally	1,28%	1,19%	1,43%	1,33%
	no	88,62%	89,56%	84,86%	88,02%

7 Summary and conclusions

The impacts of policy interventions on the economy and on the environment crucially depend – among other things – on how they affect technological change. Consequently, the way technological change is characterised in environmental-economic models affects the results of policy simulations. In most environmental-economic models, however, technological change is exogenous, that is, endogenous technological change such as induced innovations or learning effects are not captured by these models. From a policy perspective, models which portray technological progress as exogenous imply that policy interventions cannot affect the rate or direction of technological change. Further criticism regarding the portrayal of technological change in most top-down models arises from the postulated type of production functions which imply unlimited factor substitution possibilities. Since in reality, substitution possibilities are limited, the assumption of unlimited factor substitution results in an underestimation of the costs of climate policies. In contrast, most energy-intensive industrial production processes are better characterised by "putty-clay" type technologies where a choice can be made between different limitational processes, but the input structures of the existing plants are fixed. Technology-based bottom-up models, on the other hand, cannot account for macroeconomic effects and tend to underestimate the costs of climate change.

In this research project, a new modelling approach was developed which allows technological progress to be modelled as process-related and policy-induced. Also, the choice between limitational production technologies (technological paradigms) is explicitly modelled. This new approach has been applied and implemented in the macroeconometric model PANTA RHEI for three energy-intensive industries in Germany: the iron and steel industry, the pulp and paper industry, and the cement industry. For these three sectors, the existing top-down approach is replaced by a technology-based bottom-up approach taking into account capital vintage structure and process characteristics. At the same time, the interdependencies of the considered sectors and the overall economy are included in a consistent way.

The representation of the different energy-intensive industries is based on econometric time series analyses. For two steel production technologies, the coal-based blast furnace oxygen steel and electric arc furnace steel production lines (BOF and EAF-steel), the main parameters driving production and investment, the evolution and diffusion of best practice technologies, fuel mix and CO_2-emissions are estimated econometrically and consistently linked to the parameters of PANTA RHEI. A similar approach is applied to two paper technologies: paper manufacturing based on primary fibres (PFP) and recycled paper (RCP). In general, technology choice takes place via new investments in alternative process lines. For cement production, the modelling was somewhat easier. Since currently only one technological paradigm is used for the production of clinker, the rotary kiln, it was not necessary to model a choice of technology for the cement industry.

In terms of innovation, the steel, pulp and paper and the cement industries can all be best characterized as "supplier dominated" that is, these types of sectors contribute relatively little to innovation themselves. Thus, innovation is incorporated in capital goods and evolves through the adoption and diffusion of best-practice technologies. In the new modelling approach developed in this project, technological change is represented as the change in specific energy use of the best-practice technology (trajectories). To allow for endogenous technological change, the relations between the time path of the best-practice fuel and the electricity consumption of the technological paradigms are regressed on a set of determinants which are supposed to reflect factors affecting the costs and benefits of new technologies to the adopters as well as factors affecting the technical development of energy efficiency. These determinants generally include relative energy and material input prices and R&D expenditures by the industry sectors and by the mechanical engineering and electrical engineering sectors. In addition, indices were included to reflect the industry concentration in the production of steel, paper or cement in Germany.

As to the impact of energy prices on the energy efficiency of the best-practice technology, the empirical evidence is mixed. For the steel sector, fuel and electricity prices were significantly negatively correlated with fuel and electricity use in new BOF-steel and EAF-steel technologies, respectively. For the paper industry, higher fuel prices resulted in lower fuel use for the best-practice PFP and RCP technologies. By contrast, energy prices were not found to play a role in the electricity use for new RCP technologies in paper production or for best-practice fuel use in the cement industry. The greater impact of fuel prices on process shifts and on best-practice energy use in the steel industry compared to the paper industry may be explained by the higher energy cost share in the iron and steel industry. Our analyses provide empirical support for the hypothesis that the sectors considered are "supplier dominated" in terms of innovation. Usually, R&D expenditures by the sectors themselves were not found to play a role in terms of energy intensity. For the best-practice energy consumption of BOF-steel, R&D spending by the mechanical/electrical engineering sectors was found to be statistically significant. The only case in which industry concentration appeared to have a statistically significant impact was best-practice electricity use in the paper industry. Of course, the quality of the estimation results crucially depends on data availability, which was best in the steel sector. It should also be stressed that the relatively small numbers of degrees of freedom limited the evaluation of the estimated regression equations and that the results need to be interpreted carefully (especially for the cement sector). If longer time series data had been available, more variables might have turned out to be statistically significant, most notably the impact of fuel prices on best-practice fuel use in the cement industry.

This new integrated bottom-up/top-down modelling approach allows a paradigm-specific analysis of the impacts of policy measures and general framework conditions. The simulation of a tax on CO_2-emissions in the steel sector highlights the importance of analytically and empirically distinguishing between different production processes, in particular if they are affected asymmetrically by policy intervention or changed frame conditions. A CO_2-tax is introduced in 2005 in all policy scenarios, which increases from 5 € to 20 € per ton CO_2 in 2010 and then remains at that level. A higher tax on CO_2-emissions results in an overall emissions reduction which can be broken down into five factors for the example of the steel industry: i) a reduction in overall steel production, ii) energy-saving technical progress via more energy-efficient best practice technologies, iii) faster implementation of best practice technologies via increased investment, iv) a long-term shift from more carbon-intensive BOF production to EAF production, and v) a change in the fuel mix either in BOF production - from coke and coal to less carbon-intensive fuels like heavy fuel oil - or in electricity generation for EAF production - from carbon-intensive coal to gas or carbon-free renewable energy carriers. Empirically, the shift from coal-based BOF-steel production to electricity-based electric arc steel production is the major driving force for substantial emission cuts. But other driving forces such as (induced) technological change or a decrease in overall production also turn out to contribute significantly to lowering emissions. In terms of policy implications, these findings suggest that modifying the tax scheme under the German Ecological Tax Reform to provide stronger incentives to save energy in the manufacturing sector (which, under the current scheme, is largely exempted and pays very low marginal costs on energy consumption) would – at least for some industry sectors – further reduce energy consumption via a switch to less energy-intensive products and production processes within and across sub-sectors, and via the accelerated adoption and diffusion of more energy-efficient technologies. In principle, similar effects can be expected from the EU-wide emissions trading system, which is due to start in 2005 for most energy-intensive companies in the European Union.

Because of long investment cycles, energy-intensive industries typically need a long time to adapt to a new policy framework. The capital structure of industries is a very important feature when evaluating climate change policies. Since this structure differs between industries and countries, there is no general rule for the best climate change policy. Investment cycles may create a techno-economic "window of opportunity" for competing radical innovations under certain favourable conditions such as instable phases of competition. For a new iron making method - the smelting reduction technology (SRT), we addressed the question of whether a CO_2-tax at the end of the 1990s would have opened a window of opportunity for the new technology, as was argued for other countries like the Netherlands and Japan. For Germany, such a window of opportunity could not be found. Instead, the simulation results suggest a long-term shift towards more electric arc steel production and improved competitiveness of the old technology due to price-induced technical progress.

Based on simulations with an overall CO_2-tax, the new modelling approach is compared with the conventional approach in PANTA RHEI. The results show that, in the conventional approach, price changes mainly induce different input structures in the homogenous sectors. In the new modelling approach, three different effects can be observed: first, intra-sector substitution between different technological paradigms may take place. Second, this process shift is connected with changes in the fuel mix and therefore the carbon intensity. Third, efficiency progress within the technological paradigms depends in turn on frame conditions such as energy and other input prices. In terms of mitigation costs, the findings suggest that the tax policy leads to smaller changes in GDP and to higher emission reductions than the conventional approach. Thus, the estimated costs of climate policy are smaller under the new modelling approach. Since the new modelling approach was applied to only three industry sectors, the magnitude of these differences is small. These findings further suggest that the cost-reducing effects stemming from the modelling of induced technological change outweigh the cost-increasing effects from introducing limited intra-sectoral technological substitution compared to the conventional modelling approach.

Concerning the time needed to adapt to higher CO_2-prices, the simulations of a CO_2-tax scenario for the German pulp and paper and steel industries with and without the new modelling approach reveal interesting results. Obviously, in energy- and capital-intensive industries, the conventional top-down approach overestimates the short-term possibilities to adapt to higher CO_2 and energy prices in the first few years. In the new approach, substitution possibilities are limited in the first few years. In the longer run, higher energy prices induce process shifts and technological change, which will continue to reduce CO_2-emissions many years after the initial price impulse. The long-term reduction will be larger than expected in the conventional approach. Because of long investment cycles, energy-intensive industries such as the iron and steel industry need a long time to adapt to a new policy framework.

The simulation results also show that the effects on GDP of a modest CO_2-tax are almost negligible. Since the tax revenue is used to lower labour costs, the CO_2-tax results in a double dividend. First, emissions are reduced, and second, employment increases by about 313,000 jobs in 2010 and by 231,000 in 2020 compared to the reference scenario. For most sectors, the impact on employment of a modest CO_2-tax is small, but job losses in some energy sectors may amount to 10 % compared to the reference scenario. In sum, there is a slight shift towards jobs with higher (master degree) education and medium (bachelor degree and foremen/technicians) education requirements. The CO_2-tax has no noticeable effect on jobs with the lowest qualification requirements. Differences in the effects on job characteristics and working conditions are barely noticeable. Diverse extensions of the presented modelling approach are conceivable for future applications. The illustration of the technological conditions could be further improved by modelling the industries considered. For example, the assumption of perfect substitutability of both types of steel for the steel industry could be abandoned since electric arc furnace steel is mainly used for "long products", whereas the manufacturing of "flat products" (sheets) remains primarily a domain of oxygen steel.[34] A similar argument holds for paper production. Taking into account the actual limited substitutability of the technological paradigms for some applications makes it possible to analyse what effects on the choice of technology and technical progress result from demand-induced structural change. These changes in demand may be modelled exogenously or as policy induced, which is more challenging. In addition, the modelling approach presented could be tested for other energy-intensive sectors with production structures which can best be characterised by technological paradigms of a putty-clay nature. Possible candidates are electricity generation, the production of chlorine or other energy-intensive metals such as aluminium or copper. The discussion of substitutability of technologies, technological change and technology choice also suggests that a dynamic perspective may be appropriate. That is, (possibly induced) technological change may change the degree of substitutability of technological paradigms over time, thus increasing competition between existing technologies. Likewise, technological progress over time may produce superior technologies which then compete with existing technologies. In this case, investors' decisions do not concern the choice between two alternative technologies, but rather the timing of new investments. The approach applied in this project would have to be modified for radically new technologies, since there is no historic data available for these, on which econometric analyses could be based. Instead, expert opinions and technology foresight would have to be applied and translated into the modelling framework.

34 According to representatives of the sector, the size of the electric arc furnace steel share in total crude steel production depends mainly on the demand structure of the steel markets in conjunction with the availability of scrap and energy. See Ameling and Aichinger (2001).

In terms of innovation, it is often stated that, in most cases, several instruments from several policy areas affect innovation decisions simultaneously, and that regulation is only one of many (SRU 2002, Rennings et al. 2004). In principle, the new modelling approach applied allows several policy instruments to play a role (such as price policies or R&D). However, the set of policies that can be considered is restricted because of data limitations. In particular, only those determinants of innovation could be included which can be represented by variables or proxies. In addition, a sufficiently long time series of data would have to be available for the econometric analyses. Thus, incorporating "soft context" factors such as the regulatory context or communication patterns between actors remains a challenge for future research. Nevertheless, since the modelling approach presented explicitly includes technological paradigms, their trajectories, competition between existing technologies and barriers to diffusion, it does contain the most important elements of a system-oriented approach to addressing innovation processes.

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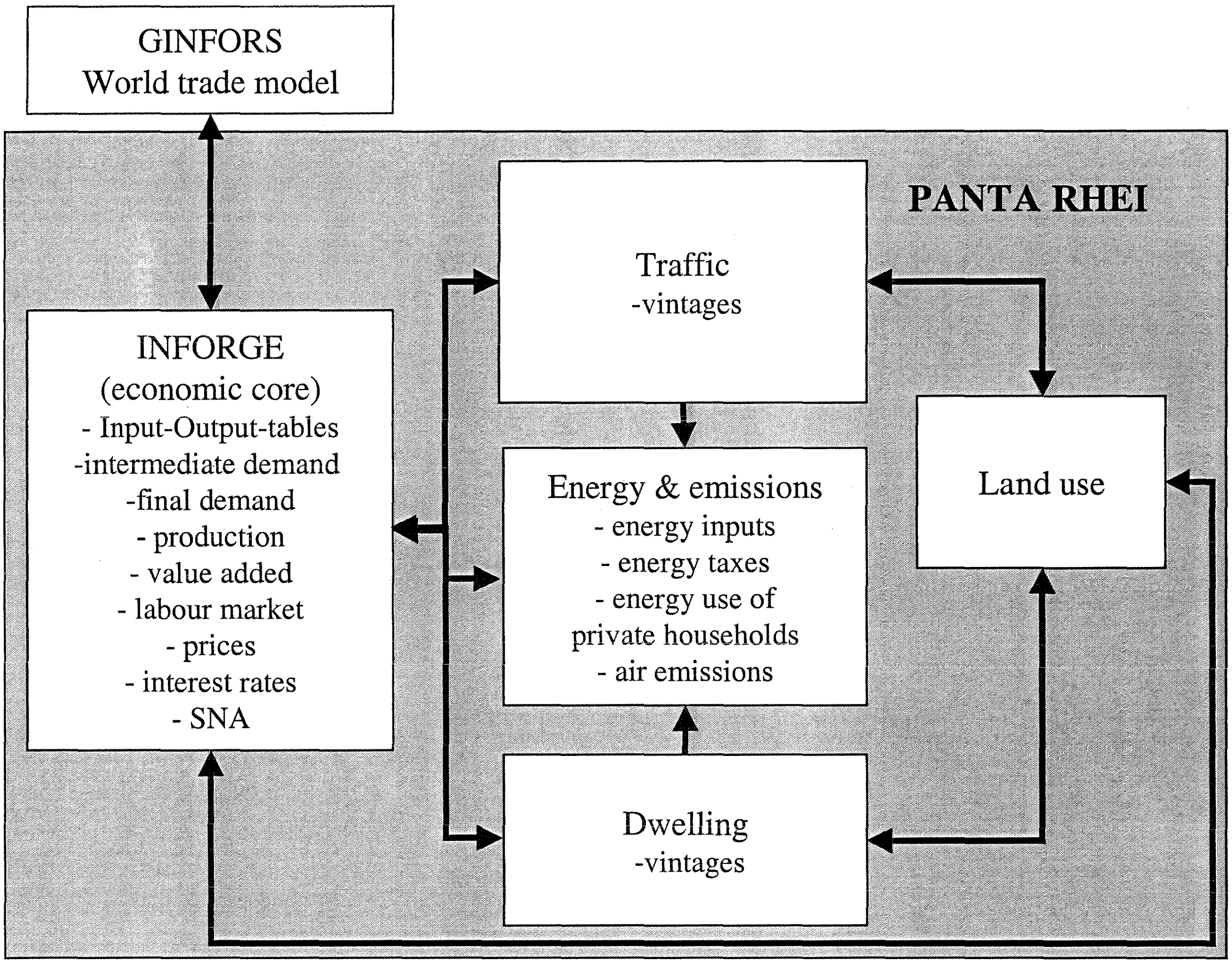
ANNEX A

A.1 The Model PANTA RHEI

PANTA RHEI - the name means "all things flow" and stems from the Greek philosopher Heraclitus - is a model for economy-energy-environment analysis in Germany. The national part is based on statistics of the German Federal Statistical Office. A1 gives an overview of the different modules. Besides the comprehensive modelling of the economy, energy and emissions, traffic, dwelling and land use are described in detail. All modules are consistently linked and solved simultaneously.

Figure A.1: Structure of PANTA RHEI



The model has been used for various studies including a study on the environmental tax reform in Germany (Bach et al. 2002), the development of technologies for reducing air emissions (Lutz 2000) and for different scenarios of a sustainable Germany (Coenen and Grundwald 2003, Keimel et al. 2004, Spangenberg et al. 2003). Different versions of the model have been developed since 1994. The version at hand is based on the „Statistical Classification of Economic Activities in the European Community" (NACE) of National Accounts. According to the classification of West (1995) it is an "econometric + input-output model", that belongs to the family of national interindustry models of the INFORUM family.

A.2 Philosophy

The performance of PANTA RHEI is founded on the INFORUM philosophy (Almon 1991), which means that econometric input-output models should be constructed in a bottom-up and fully integrated manner. Here "bottom-up" means that each sector of the economy has to be modelled in great detail and that the macroeconomic aggregates have to be calculated by explicit aggregation within the model. The construction principle "fully integrated" means that the model structure takes into account a variable input-output structure within the consistent System of National Accounts, which contains the complexity and simultaneity of income creation and distribution in the different sectors, its redistribution among the sectors and its use for the different goods and services which the sectors produce in the context of global markets.

The model shows a very high level of endogenisation and is highly interdependent. Basically, tax rates, labour supply and the global market variables of the international GINFORS system are determined exogenously, though it is technically possible to link both models (Meyer et al. 2003). It has to be stressed that the whole system is solved simultaneously. Apart from the regular interdependencies of the economic cycle, it monitors the volume-price interdependencies as well as the wage-price interdependencies.

The economic core of the model is an econometric input-output model, appropriately described as evolutionary. By means of behavioural equations, routines in decision-making processes are simulated which are not derived explicitly from optimisation activities performed by rational agents, but are based on bounded rationality on imperfect markets. Market prices result from mark-up calculation performed by companies. Time within this model is historic and irreversible. The adjustment of the capital stocks generates path dependency.

Usually, the input-output approach is considered to be a demand-oriented approach. This, however, does not account for PANTA RHEI. On the one hand demand determines production in the model. On the other hand, it needs to be emphasized that all variables concerning demand for commodities and factors depend on, among other things, relative prices with prices, in turn, being set with regard to the unit costs of companies by means of a price-setting hypothesis. The differences between macroeconometric models such as PANTA RHEI and the Computable General Equilibrium (CGE) models in which a competitive market is simulated, concerning this aspect, lies in the presumed market form, not in the emphasis on one side of the market or the other (West 1995, p. 216). It might as well be said this way: Companies, on the basis of their cost situation and the prices of competitive imported goods, set their sales prices. Potential customers react to that with their decision which in turn determines the rate of production. Therefore, elements of both supply and demand are equally present.

Innovations in economy and technology, that are caused by cost-push can basically be projected. This is monitored by the estimation of the dependence of the input coefficients on prices – input to output - and trends. Linear-limitational technologies form the assumed basis, which, in the course of time, may change due to cost-push induced technological progress. The system of factor demand functions, dependent on prices as well as trends, describes the technology with the correspondent vector of the coefficients of intermediate input and labour input for any given point in time. The change of the input coefficients reflects the technological change determined by the cost-push of the relative prices.

The dynamics of the model are caused by the adjustment of the assessed value of capital funds, the delayed adjustment of wages to the development of productivity and prices, the delayed adjustment of public consumption to the development of the government available income, and further lags in demand functions.

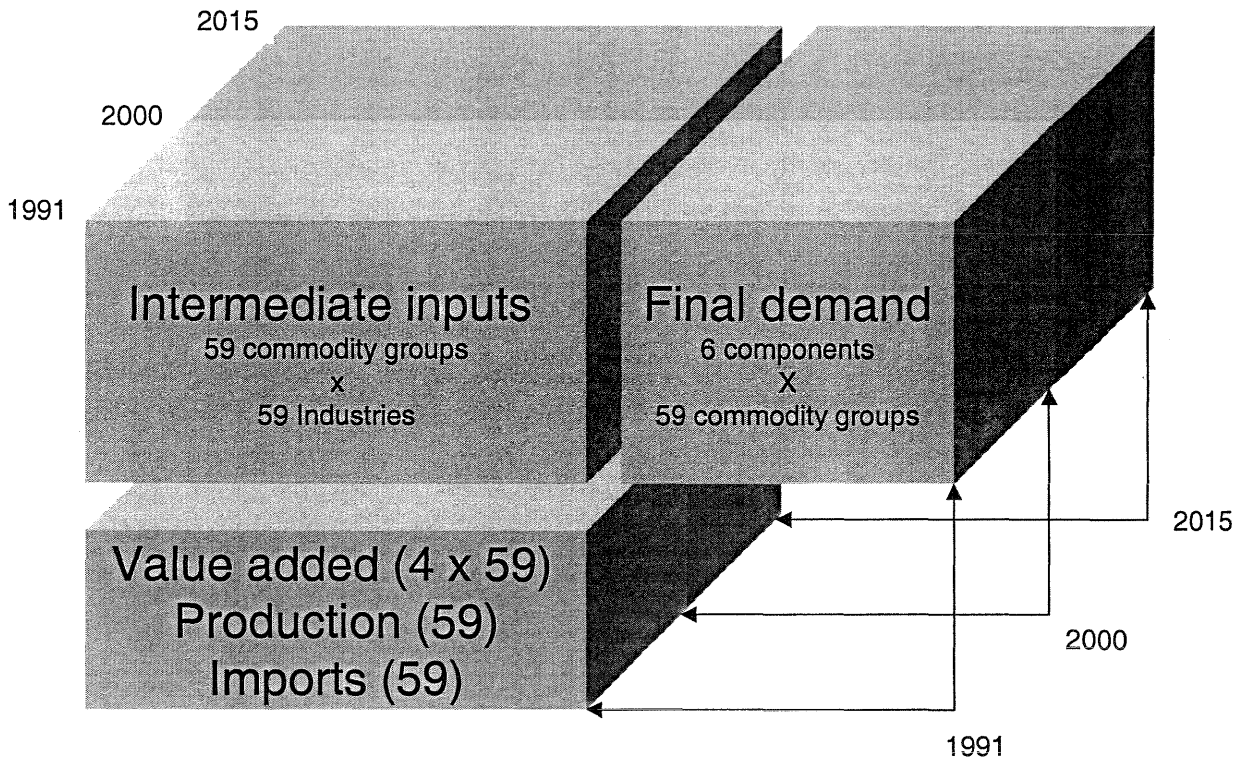
The parameters of the model equations have been econometrically estimated over the period from 1991 through 2000 using the OLS method. In choosing alternative approaches of estimation, first of all a priori information about sign and the order of magnitude of the coefficients to be estimated were utilized. In other words: Results of estimations that were economically nonsensical were dismissed. The remaining estimations were tested both for autocorrelation of residuals according to the Durbin-Watson statistics, and for the significance of the estimated parameters by means of the t-test. When, on that basis, a discrimination of competing approaches was not possible, the coefficient of determination of the estimation was referred to. With regard to the enormous volume of the model, the OLS method appears to be the appropriate, that is, the easiest estimation method.

A.3 Model structure

Figure A.3 describes the economic linkages within the model. The GINFORS global trade model provides the vector of global import demand and the vector of global market prices structured by composite commodities as well as the US interest rate. Along with the global market prices, the model is provided with a prognosis of global energy prices by the GINFORS system.

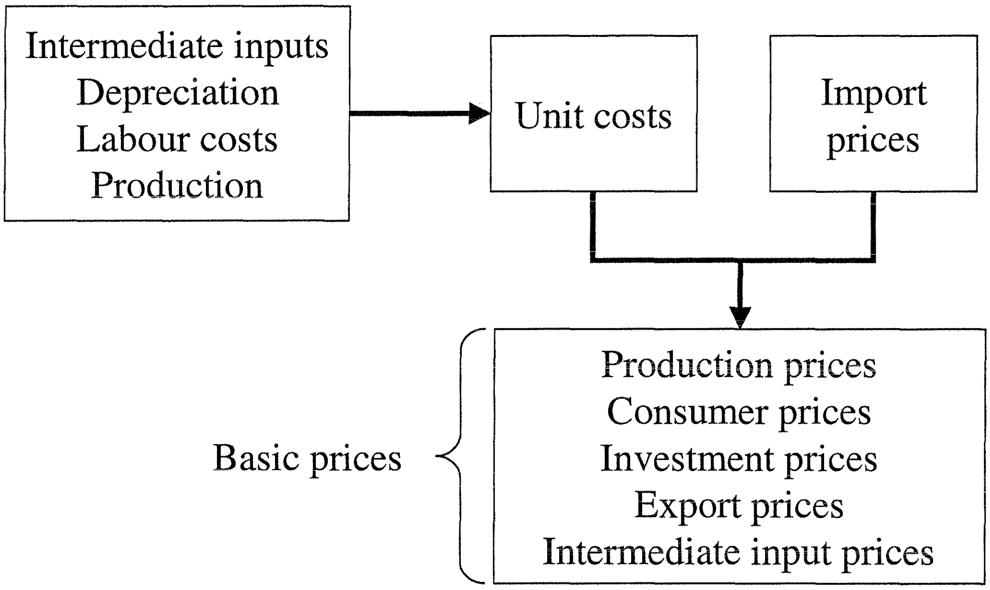
The model consistently describes the annual inter-industry flows between the 59 sectors (intermediate inputs), their contributions to 6 components of final demand: personal consumption, government, equipment investment, construction, inventory investment, exports as well as 4 components of value added: labour compensation, profits, indirect taxes minus subsidies and consumption of fixed capital as given in Figure A.5. Furthermore output, employment, productivity and imports are calculated for 59 industries. All variables are added up to come to the macroeconomic variables.

Figure A.2: The input-output module



The most significant determinants of labour demand are the production and the real wages of the respective sector. Wages, in turn, are determined by the development of productivity and prices. Earnings and unit costs result from definition. Along with the development of prices of similar imported commodities, the unit costs are the central determinants of prices within the basic price concept. These significant determinants of the development of prices are displayed in more detail in Figure A.4, while it needs to be stressed that the factors referred to are respectively modelled on the level of the 59 sectors.

Figure A.3: Explanation of prices



It is, however, not first and foremost basic prices which determines the development of demand (private consumption, government consumption, investment, export and intermediate input), but market prices. To describe this adequately, the model contains the complete transition from production to market prices for all components of demand including a differentiation between 59 composite commodities. This level of detail within the model is necessary in order to correctly monitor changes of the value-added tax or other taxes on products, such as the mineral oil tax, for the several production sectors. In correspondence with the respective production sector, the possibilities of the pass-along of indirect taxes differ.

Apart from the context of the input-output calculation for 59 industries the model includes the System of National Accounts with its institutional sectors – government, private households and non-profit institutions serving households (NPISHs), financial corporations, non-financial corporations and the rest of the world – as well as the functional accounts of production, generation of income, allocation of primary income, secondary distribution of income, use of disposable income, and capital in order to calculate the SNA of the Federal Republic of Germany. This system comprises the complete redistribution of income including social insurance and taxation between government, private households and corporations, thus allowing the calculation of disposable income which is once more a significant determinant of final demand. Moreover, the financing account balances are ascertained. Therefore, the model includes especially government budget constraints. As a result, the entire fiscal policy is endogenously integrated into this system.

Figure A.4: From basic to market prices

	Basic prices
+	Value added tax
+	Other taxes on products
+	Distribution and transport services
-	Subsidies on products
=	Market prices

In addition, PANTA RHEI contains a disaggregated energy and air pollution module which distinguishes 30 energy carriers and their inputs in 121 production sectors j and households as well as the related CO_2 and other air emissions. Energy demand is fully integrated into the intermediate demand of the firms and the consumption demand of households. Energetic input coefficients are generally explained by relative prices and trends.

The supply of nuclear energy and renewable energy for electricity production is modelled exogenously, since they primarily depend on policy decisions in Germany. As for the transport sector, the gasoline and diesel demand of households and firms is calculated using an extended road traffic module, which explains the stock of cars and trucks and their usage as well as technical progress in the new vehicle vintages.

A.4 The economic part of the model in detail

A.4.1 Final demand

A.4.1.1 Consumption of private households

The macroeconomic private consumption demand *CPVR* is explained with regard to the disposable income of households *YVANH* in constant prices and the interest rate *RKONT* for consumer credits. In the equation, *PCPV* stands for the index of consumer prices:

– $CPVR[t] = f\{YVANH[t] / PCPV[t], RKONT[t]\}$

The shares of the 43 utilization purposes $cpvrq_k$ of the consumption *CPVR* are explained with regard to the respective relative price, consisting of the price index of the utilization purpose $pcpv_k$ and the index of consumer prices *PCPV*, the 10 year treasury bond rate *RUML* and the time trend *ZEIT*.

– $cpvrq_k[t] = f\{pcpv_k[t]/PCPV[t], RUML[t], ZEIT[t]\}$

The expenditures in constant prices for the purposes of utilization *cpvr* result from the multiplication of the rates by the aggregate consumption of private households *CPVR*:

– $cpvrk[t] = cpvrqk[t] * CPVR[t]$

Equally by definition, the expenditures of the purposes of utilization in current prices are ascertained:

– $cpvn_k[t] = cpvr_k[t] * pcpv_k[t]$

The consumption demand for commodity groups in current prices is calculated by means of the *CPX* bridge matrix of the year 2000, which within the rows contains the shares of a commodity group *i* of the different consumption purposes *k*:

– $cpn_i[t] = \Sigma_k (CPX_{i,k}[t=2000] * cpvn_k[t])$

The trade and transport services included $htcpn_i$, the value-added taxes $mwtcpn_i$, the other taxes on products $sgutcpn_i$ and the subsidies $subcpn_i$ are ascertained using fixed rates which, however, are variable in model simulations.

– $htcpn_i[t] = qhtcp_i[2000] * cpn_i[t]$

– $sgutcpn_i[t] = qsgutcp_i[2000] * cpn_i[t]$

– $mwtcpn_i[t] = qmwtcp_i[2000] * cpn_i[t]$

– $subcpn_i[t] = qsubcp_i[2000] * cpn_i[t]$

By subtracting the trade and transport services as well as the other transitional factors from the consumption expenditures at market prices *cpn*, we get the consumption expenditures at basic prices *cpun*:

– $cpun_i[t] = cpn_i[t] - htcp_i[t] - sgutcpn_i[t] - mwtcpn_i[t] + subcpn_i[t]$

The basic prices of consumer products *pcpu* depend on the unit costs *uc* of the sector and the prices *pim* of the competing imported goods:

– $pcpu_i[t] = f\{(uc_i[t], pim_i[t]\}$

The market prices of consumer products *pcp* are explained with regard to the basic prices *pcpu* and the rate of the respective taxes on products levied on them:

– $pcp_i[t] = f\{(1+qmwtcp_i[t])*pcpu_i[t],(1+qmwtcp_i[t]) * (sgutcpn_i[t] - subcpn_i[t])/cpr_i[t]\}$

The prices of the 43 utilization purposes $pcpv_k$ are ascertained with regard to the market prices pcp_i of the consumer products included in them:

– $pcpv_k[t] = f\{pcp_1[t], pcp_2[t] ,..., pcp_n[t]\}$

The division of the nominal factors *cpn* or *cpun* respectively by the appertaining prices *pcp* or *pcpu* respectively leads to the actual factors *cpr* or *cpur* respectively in either price concept.

– $cpr_i[t] = 100 * cpn_i[t]/pcp_i[t]$

– $cpur_i[t] = 100 * cpun_i[t]/pcpu_i[t]$

The appertaining macroeconomic factors can be calculated by addition, the price indices by division of the nominal by the real factors with the price basis being 1995. The sum of trade and transport services paid over all commodities is zero.

The ascertaining of sums will not be explained any further in the course of this paper. Within the model, however, the macroeconomic variables for all sector variables are ascertained by aggregation.

A.4.1.2 Consumption expenditures of non-profit institutions serving households (NPISHs)

The consumption expenditures *cpour* in constant prices of NPISHs are determined by, among other things, the development of the gross domestic product (GDP) in real terms *BIPR* or the government consumption expenditures in the area of social security contributions *CSLR*:

– $cpour_i[t] = f\{BIPR[t], CSLR[t]\}$

The market prices of consumer products of NPISHs *pcpo* are identical to the basic prices *pcpou*, which depend on the unit costs of the respective sector:

– $pcpou_i[t] = f\{uc_i[t]\}$

The corresponding factors in current prices are the result of multiplication by the corresponding basic prices *pcpou*:

– $cpoun_i[t] = cpour_i[t] * pcpou_i[t]$

The macroeconomic parameters result from aggregation and division as explained above.

A.4.1.3 Consumption expenditures of general government

The consumption expenditures of general government is subdivided into for social security benefits and government consumption. Due to, among other things, the current political discussion, the simulation of overall government expenditures for social security benefits in current prices *CSLN* requires differentiation: Assuming that the demand among people from the age of 65 years upward (*ELDER*) for health benefits is about twice as high as among younger people (*CHILDREN*, *WORKING*), a level of cost per capita *CSLKN* can be calculated. Assuming that expenditures per capita in public health depend particularly on medical technological progress, the level of cost per capita is projected with a time trend (*ZEIT*).

– $CSLKN[t] = f\{ZEIT\}$

CSLN then results from the multiplication of the segments of the population by the level of cost:

– $CSLN[t] = CSLKN[t] * (CHILDREN[t] + WORKING[t]$
$+ 2 * ELDER[t])$

The social security benefits structured by commodity groups *csln* are ascertained by the relative price *pcsl* in proportion to the aggregated price *PCSL* and the aggregated expenditures *CSLN*:

– $csln_i[t] = f\{pcsl_i[t]/PCSL[t], CSLN[t]\}$

The trade and transport services as well as the value-added taxes included are recorded via constant rates *qhtcs* or *qmwtcs* respectively:

– $htcsn_i[t] = qhtcs_i[t=2000] * csln_i[t]$

– $mwtcsn_i[t] = qmwtcs_i[t=2000] * csln_i[t]$

When the trade and transport services as well as the value-added taxes are subtracted from the social security contributions at market prices *csln*, the result is the social security contributions at basic prices *cslun*:

– $cslun_i[t] = csln_i[t] - htcs_i[t] - mwtcsn_i[t]$

The division of the variables at current prices *csln* or *cslun* respectively by the corresponding price indices *pcsl* or *pcslu* respectively leads to the real variables *cslr* or *cslur* respectively in both price concepts.

– $cslr_i[t] = 100 * csln_i[t]/pcsl_i[t]$

– $cslur_i[t] = 100 * cslun_i[t]/pcslu_i[t]$

The prices *pcsl* and *pcslu* are projected with the growth rate of the price index of the consumption demand for the respective commodity group *pcg*, since an econometric explanation was not possible. The development of the price of health goods (commodity group 54) is exogenous to the model as it is dependent on policy decisions.

Government consumption in current prices as a whole *CSVN* is dependent on the development of the gross domestic product. The proportion of both factors *STVQ* is interpreted as the government consumption rate the development of which is predetermined. Thus it is presumed that the government consumption is a deliberate decision made by the government, according to government functions.

– $CSVN[t] = STVQ[t] * BIPN[t-1]$

The nominal government consumption structured by composite commodities *csvn* is explained with regard to the overall government expenditures:

– $csvn_i[t] = f\{CSVN[t]\}$

The market prices of the government consumption *pcsv* are identical to the basic prices *pcsvu*, which in turn depend on the price index of the respective commodity group or the macroeconomic price index of the gross domestic product.

– $pcsvu_i[t] = f\{pg_i[t], PBIP[t]\}$

The actual government consumption in prices of 1995 result from definition:

– $csvr_i[t] = 100 * csvn_i[t]/pcsvu_i[t]$

The overall government consumption demand (*csn*, *csr*) is ascertained by the addition of the consumption demand for social security contributions (*csln*, *cslr*) and government consumption (*csvn*, *csvr*).

A.4.1.4 Equipment investment

The starting point of the simulation of investments is the investing industries. The equipment expenditures of a industry *j* *iasr* depend on its gross production *xsr*, its capital stock *kasr* as well as the actual interest – treasury rate *RUML* minus inflation rate *INFL* – and further sector-specific variables. In order to record the expectations concerning the macroeconomic development, the CDAX share index in each sectoral function of investments is tested with a one-year advance (*CDAXL*). In case of obvious significance it is integrated into the function.

– $iasr_j[t] = f\{xsr_j[t], kasr_j[t], (RUML[t] - INFL[t]), CDAXL, ...\}$

The replacement from the capital stock of the industry *j* *aasr* depends on the development of the capital stock with allocated lags:

– $aasr_j[t] = f\{aasr_j[t\text{-}1], kasr_j[t\text{-}1]\}$

The development of the capital stock for equipment results from definition:

– $kasr_j[t] = kasr_j[t\text{-}1] + iasr_j[t] - aasr_j[t]$

The vector of the equipment expenditures structured by commodity groups at market prices in constant prices before the deduction of the purchases/sales of equipment and other assets *iarh* results from the multiplication of the *IAX* bridge matrix of the year 2000 by the vector of the equipment expenditures structured by industries. Within the rows the matrix includes the shares of the investments of the 59 industries which are made following the demand for equipment expenditures of the commodity group *i*.

– $iarh_i[t] = \Sigma_i\, (IAX_{ij}[2000] * iasr_j[t])$

The purchases/sales of equipment and other assets in constant prices (*invar*) are ascertained by means of constant rates (*qinvar*) of the year 2000 of equipment expenditures in constant prices before the deduction of the purchases/sales of equipment and other assets.

– $invar_i[t] = qinvar_i[2000] * iarh_i[t]$

The equipment expenditures with reference to commodity groups at market prices in constant prices (*iar*) result from definition:

– $iar_i[t] = iarh_i[t] - invar_i[t]$

Multiplication by the market prices *pia* results in the nominal equipment at market prices:

– $ian_i[t] = 0.01 * iar_i[t] * pia_i[t]$

The trade and transport services *htian* included as well as the value-added taxes *mwtian* and the taxes on products *sgutian* are ascertained via constant rates:

– $htian_i[t] = qhtia_i[2000] * ian_i[t]$

– $mwtian_i[t] = qmwtia_i[2000] * ian_i[t]$

– $sgutian_{51}[t] = qsgutia_{51}[2000] * ian_{51}[t]$

By the subtraction of the trade and transport services as well as the value-added taxes from the equipment at market prices *ian*, you get as the result the equipment at basic prices *iaun*. For line 51 (business-related services), additionally the taxes on products have to be taken into consideration.

– $iaun_i[t] = ian_i[t] - htian_i[t] - mwtian_i[t]$

The division of the parameters in current prices *iaun* by the appertaining prices *piau* leads to the factors in constant prices *iaur* within the concept of the basic prices:

– $iaur_i[t] = 100 * iaun_i[t]/piau_i[t]$

The basic prices of equipment *piau* depend on the appertaining unit costs *uc* and the prices of competing imported goods *pim*:

– $piau_i[t] = f\{uc_i[t], pim_i[t]\}$

The market prices of equipment *pia* again are determined by the respective basic prices and the rates of the taxes on products.

– $pia_i[t] = f\{(1+qmwtia_i[2000])* piau_i[t]\}$

The prices of equipment expenditures with reference to investing industries *pias* are determined by the prices of the composite commodities *n* included in them.

– $pias_i[t] = f\{pia_1[t], pia_2[t],..., pia_n[t]\}$

A.4.1.5 Construction expenditures

The simulation of construction expenditures *isbr* has been selected in analogy with the one concerning equipment. For the construction expenditures of industries the following approaches are estimated:

– $ibsr_j[t] = f\{xsr_j[t], kbsr_j[t], (RUML[t] - INFL[t]),...\}$

The function of construction expenditures of sector 47 (services of the real estate and housing sector) is subject to particular specification. For this sector, an estimation is dispensed with, presuming a development simulating a retrogression to the level of 1991. This simulation is based on the observation that an estimated function is by no means able to project the development of the years 2001 and 2002. Additionally, historical observation shows that, on the one hand, there has been economic cycles concerning construction, that on the other hand, however, a long-term rise in construction investment in constant prices is not in sight and that the development over the past years is exclusively due to German reunification or has been completely covered over by it.

A.4.1.6 Export demand

The export demand in constant prices of a commodity group exr_i is explained with regard to the respective German export $iexr_m$ of the international GINFORS system.

– $exr_i[t] = f\{iexr_m[t]\}$

Multiplication by the market prices *pex* produces the result of the export at current market prices:

– $exn_i[t] = 0.01 * exr_i[t] * pex_i[t])$

The trade and transport services included as well as the government subsidies are recorded by means of constant rates:

– $htexn_i[t] = qhtex_i[t=2000] * exn_i[t]$

– $subexn_i[t] = qsubex_i[t=2000] * exn_i[t]$

By subtracting the trade and transport services a well as the subsidies from the export at market prices *exn*, you get the export at basic prices *exun*:

– $exun_i[t] = exn_i[t] - htexn_i[t] + subexn_i[t]$

The division of the factors in current prices *exun* by the appertaining basic price *pexu* produces the result of the export in constant prices *exur*.

– $exur_i[t] = 100 * exun_i[t]/pexu_i[t]$

The export prices according to the basic price concept *pexu* of the commodity group *i* are explained with regard to the unit costs of the sector *uc* and the appertaining import price *pim*.

– $pexu_i[t] = f\{pim_i[t], uc_i[t]\}$

The export prices of the market price concept *pex* result from the export prices according to the basic price concept *pexu*. In the process, agriculture (commodity group 1) is the only sector for which government subsidies have to be taken into consideration.

– $pex_i[t] = f\{pexu_i[t]\}$

– $pex_1[t] = f\{pexu_1[t], subexn_1[t]/exr_1[t]\}$

A.4.1.7 Aggregated final demand

Up to this point, the simulation of the single component parts of final demand has been explained. Only the inventory stocks *ivur* or *ivun* respectively remain exogenous. For them, an exogenous development is presumed which, over a long-term period, will reduce them to zero. The combination of these aspects then results in the overall final demand at basic prices:

– $fgur[t] = cpur[t]+cpour[t]+cslur[t]+csvr[t]+iaur[t] +ibur[t]+ivur[t]+exur[t]$

– $fgun[t] = cpun[t]+cpoun[t]+cslun[t]+csvn[t]+iaun[t] +ibun[t]+ivun[t]+exun[t]$

– $pfgu[t] = 100 * fgun[t]/fgur[t]$

The final demand at market prices *fgr* or *fgn* respectively as well as the component parts of the net commodity taxes (*mwtfgn*, *sgutfgn*, *subfgn*) can be calculated accordingly. Eventually, the macroeconomic factors are determined by aggregation.

A.4.2 Intermediate demand and technology

The *XR* matrix describes the interlinking of intermediate inputs in constant basic prices of the year 1995, the *YN* matrix represents the interlinking of intermediate inputs in current basic prices. The input coefficient AR_{ij} is defined as the quotient of the intermediate inputs of the commodity *i* in the sector *j* and the gross production of the sector *j*. The input coefficients are variable and are explained by a relative price from the price index of the intermediate inputs pvg_i of the delivering sector and the price of the gross production pg_j of the receiving sector as well as a time trend *ZEIT*. The variability of the input coefficients is not considered the result of factor substitution, but the effect of cost-push induced technological progress which leads to improvements of limitational processes. The presumption of substitutional technologies is doubtful concerning the intermediate demand, since intermediate inputs are part of the product. Therefore, an alteration of the intermediate inputs redefines the product (Georgescu Roegen 1990).

– $AR_{ij}[t] = f\{pvg_i[t]/pg_j[t], ZEIT[t]\}$

The deliveries of intermediate inputs of the commodity group at constant basic prices then are the column sums of the matrix XR:

– $vgur_i[t] = \Sigma_j\,(AR_{ij}[t] * xgr_j[t]) = \Sigma_j\,(XR_{ij}[t])$

The appertaining price index *pvgu* is explained with regard to the unit costs *uc* of the domestic production of the commodity group and the corresponding import price, since import is included within deliveries of intermediate inputs as well. Subsequently, the intermediate inputs in current prices can be ascertained:

– $pvgu_i[t] = f\{uc_i[t], pim_i[t]\}$

– $vgun_i[t] = 0.01 * vgur_i[t] * pvgu_i[t]$

To summarize, in the conventional version of PANTA RHEI technical change is not directly modelled. Rather, the result of this process – changing input structures – is depicted in time series of input-output tables. This allows for a reduced-form type estimation of price dependent input coefficients, but there is no link to the underlying technologies.

A.4.3 Domestic production and import

The gross production is defined as the sum of demand for intermediate and final demand minus the import *imr*:

– $xgr_i[t] = vgur_i[t] + fgur_i[t] - imr_i[t]$

The substitution of the demand for intermediate inputs by the equation 59 and the solving of the equation towards the vector of gross production results in the vector terms:

– $xgr[t] = (E - AR[t])^{-1} * (fgur[t] - imr[t])$

In the equation, *E* is the unit matrix. In contrast to many input-out-based models such as CGE models, there is no explicit production function in PANTA RHEI.

The demand for import *imr* is ascertained with regard to the gross production of the commodity group and the proportion of the domestic price of the commodity group to the import price:

– $imr_i[t] = f\{xgr_i[t], pg_i[t]/pim_i[t]\}$

The import prices *pim* are explained with regard to the corresponding import prices of Germany within the international GINFORS system. The import in current prices *imn* then can be ascertained by definition:

- $pim_i[t] = f\{pim_m[t]\}$
- $imn_i[t] = 0.01 * imr_i\, [t] * pim_i[t]$

The gross production *ygn* is defined as the sum of the intermediate demand *vgun* and the final demand *fgun* at current prices minus the import in current prices *imn*:

- $ygn_i[t] = vgun_i[t] + fgun_i[t] - imn_i[t]$

The price index of the gross production *pg* then is determined by definition as:

- $pg_i[t] = 100 * ygn_i[t]/xgr_i[t]$

A.4.4 Gross value added of production sectors

The level of intermediate inputs of the sector *j* in constant basic prices can be ascertained by definition by the aggregation of the various single inputs of commodities utilized in the sector *j*:

- $vegur_j[t] = \Sigma_i\, (AR_{ij}[t] * xgr_j[t])$

The nominal intermediate inputs at basic prices of the sector *j* are the result of the multiplication of the intermediate inputs in real terms by the appertaining manufacturing price *pvgu* and their subsequent aggregation:

- $$vegun_j[t] = \Sigma_i\, (XR_{ij}[t] * pvgu_i[t]) = \Sigma_i\, (AR_{ij}[t] * xgr_j[t] * pvgu_i[t] * 0.01)$$

Subsequently, the net commodity taxes levied on the inputs of intermediate inputs sector *j* has to pay have to be ascertained. For this purpose, the corresponding tax or government subsidy vectors are transferred from composite commodities to sectors of production by means of subdivision matrices – *STX* for the value-added taxes and the other commodity taxes, *SUBX* for government commodity subsidies. By means of this, an appropriate assignment of the net commodity taxes to the sectors of production is achieved.

- $$ngutven_j[t] = \Sigma_i\, (STX_{ij}[2000]*(sgutvgn_i[t]+mwtvgn_i[t]) - SUBX_{ij}[2000]*subvgn_i[t])$$

The tax loads in constant prices are calculated by means of deflating by the price vector of intermediate inputs *pvegu*.

– $ngutver_j[t] = 100 * ngutven_j[t]/pvegu_j[t]$

The gross value added of a sector of production *j* in constant (*bwgr*) or current prices (*bwgn*) results from definition. The price indices of the gross value added *pbwg* and the levels of intermediate inputs *pvegu* then as well can be calculated:

– $bwgn_j[t] = ygn_j[t] – vegun_j[t] – ngutven_j[t]$

– $bwgr_j[t] = xgr_j[t] – vegur_j[t] – ngutver_j[t]$

– $pbwg_j[t] = 100 * bwgn_j[t]/bwgr_j[t]$

– $pvegu_j[t] = 100 * vegun_j[t]/vegur_j[t]$

Eventually, the generation of the gross domestic product in current (*BIPN*) and constant (*BIPR*) prices can be calculated by means of the sum of the gross value added of all sectors of production. In the process, the commodity taxes *NGUTVEN* or *NGUTVER* respectively levied on the final demand *NGUTFGN* or *NGUTFGR* respectively and the intermediate demand get integrated into the gross domestic product. An alternative way of calculating the gross domestic product within the context of the simulation refers to the demand side being the sum of domestic demand and external balance surplus. The price deflator of the gross domestic product results from definition:

– $BIPR[t] = BWGR[t] + NGUTFGR[t] + NGUTVER[t]$

– $BIPN[t] = BWGN[t] + NGUTFGN[t] + NGUTVEN[t]$

– $PBIP[t] = 100 * BIPN[t]/BIPR[t]$

A.4.5 Gross value added of the industries and its components

The transition from sectors of production discussed up to this point to the industries is performed by means of a *MAKE* matrix which within the rows contains the shares of a industry *j* of the production of the commodity group *i*. As a consequence, the equations below account for the gross value added in current prices *bwsn* of the industry *j* or its gross value added in constant prices *bwsr* and the corresponding price index:

– $bwsn_j[t] = \Sigma_i\, MAKE_{ij}[t=2000] * bwgn_i[t]$

– $bwsr_j[t] = \Sigma_i\, MAKE_{ij}[t=2000] * bwgr_i[t]$

– $pbws_j[t] = 100 * bwsn_j[t]/bwsr_j[t]$

In an analogue way, the nominal or real gross production *ysn* or *xsr* respectively as well as the appertaining prices *ps* are ascertained.

The other production charges minus the government subsidies *npsn* are estimated as functions of the gross production:

– $npsn_j[t] = f\{ygn_j[t]\}$

The gross wages and salaries *lsn* are ascertained by definition as being the product of the labour costs per employee *jlas* and the number of employees *bas*. The endogenisation of the total annual wages and the employees will be discussed below within the context of other variables of the labour market.

– $lsn_j[t] = 0{,}000001 * jlas_j[t] * bas_j[t]$

The consumption of fixed capital *dsn* is estimated with regard to the sum of the capital stock of equipment and construction in current prices. In the process, the capital stocks in constant prices *kasr* and *kbsr* are evaluated along with the current investments *PIA* and *PIB*, that is, at cost prices:

– $dsn_j[t] = f\{kasr_j[t] * PIA[t] + kbsr_j[t] * PIB[t]\}$

The gross operating surplus *gsn* of the sector *j* results from definition as being the remainder:

– $gsn_j[t] = bwsn_j[t] - nspn_j[t] - lsn_j[t] - dsn_j[t]$

The unit costs *uc* of the industry *j* are defined as:

– $uc_j[t] = (ysn_j[t] - gsn_j[t])/xsr_j[t]$

A.4.6 Labour market

First of all, the macroeconomic average wage rate per hour *SLS* is calculated. For this purpose, a wage function is modelled which explains in a Phillips curve approach the result of the collective bargaining negotiations. Its determinants are macroeconomic productivity, resulting from the proportion of the GDP in constant prices *BIPR* to the total number of employees *BAS*, price development – described by the consumer price index *PLH* – and the labour market situation, represented by the unemployment rate *ELQ*. The following dynamic formula proved to be superior to other approaches:

– $SLS[t] = f\{BIPR[t-1]/BAS[t-1]),PLH[t-1],ELQ[t-1])$

In combination with the exogenously determined average annual working time of an employee *JAB*, the average total annual wage *JLS* can be calculated:

– $JLS[t] = SLS[t] * JAB[t]$

Along with sector-specific variables, *JLS* then explains the sum of the gross wages and salaries per employee of the industries *jls*:

– $jls_j[t] = f\{JLS[t], \ldots\}$

As a consecutive step, the social security contribution rates of the employers *sozagsq* are ascertained. For this purpose, in each simulation year the macroeconomic rate of contribution *SOZAGSQ* in the respective first iteration is ascertained. It results from the proportion of the financial payments of the social insurances (*GSNGNS*) – retirement payments and unemployment benefits – plus the expenditures for social security benefits (*CSLN*) – expenditures of the health insurance scheme prevailing – minus the revenue of the environmental tax reform (*EGTOE*) intended for the cross financing of the pension insurance scheme – to the sum of the gross wages and salaries of private households (*BLGNH*). In the process, the results of the previous period are being referred to. In addition, there is a calibration for the year 2000 (*Const.*).

– $SOZAGSQ[t] = Const[t{=}2000] * (GSNGNS[t\text{-}1]+CSLN[t\text{-}1]$
$-EGTOE[t\text{-}1]+EGTOE[t{=}2000])/BLGSN[t\text{-}1]$

Subsequently, the contribution rates of the industries are projected with regard to the growth factor of the macroeconomic contribution rate:

– $sozagsq_j[t] = sozagsq_j[t\text{-}1] * SOZAGSQ[t]/SOZAGSQ[t\text{-}1]$

The multiplication of the sum of gross wages and salaries per employee by the social security contribution rate of the employers results in the labour costs per employee *jlas*:

– $jlas_j[t] = (1 + sozagsq_j[t]) * jls_j[t])$

The labour demand of the industry *j* – measured by means of the number of employees *bas* – is estimated with regard to the gross production of the sector and the labour costs in constant prices – deflating with the price index of the gross production according to industries *ps* – as well as, in some industries, a time trend.

– $bas_j[t] = f\{xsr_j[t], jlas_j[t]/ps_j[t], ZEIT[t]\}$

The sum of gross wages and salaries *blgsn* is the product of the sum of gross wages and salaries per employee and the number of employees.

– $blgsn_j[t] = jls_j[t] * bas_j[t]$

The social security contributions of the employers are ascertained by the multiplication of the respective rates by the sum of gross wages and salaries:

– $sozagsn_j[t] = sozagsq_j[t] * blgsn_j[t]$

The number of self-employed persons *ses* of a industry often is correlated with the number of employees. At times, however, there is a connection with the gross production or the level of the capital stock of the sector. The number of employed persons *ets* subsequently can be ascertained by definition:

- $ses_j[t] = f\{xsr_j[t], bas_j[t], (kasr_j[t] + kbsr_j[t])\}$
- $ets_j[t] = bas_j[t] + ses_j[t]$

The productivity of labour per employee *apb* or per employed person *ape* respectively in prices from 1995 result from the value added *bwsr* as follows:

- $apb_j[t] = 1{,}000{,}000 * bwsr_j[t]/bas_j[t]$
- $ape_j[t] = 1{,}000{,}000 * bwsr_j[t]/ets_j[t]$

The number of employed German nationals *ETI* is estimated with regard to the development of the number of employed persons:

- $ETI[t] = f\{ETS[t]\}$

The number of unemployed persons *EL* is explained by the development of the exogenous labour force potential *EPP*, the number of employed persons *ETS* and the volume of the exogenous job-creation measures of the Federal Employment Services *APM*:

- $EL[t] = f\{EPP[t], ETS[t], APM[t]\}$

The labour force is made up by the employed German nationals *ETI* and the unemployed persons *EL*. Subsequently, the unemployment rate *ELQ* can as well be ascertained by definition:

- $EP[t] = ETI[t] + EL[t]$
- $ELQ[t] = 100 * EL[t]/EP[t]$

Finally, the labour force reserves *STR* can be ascertained by definition by the subtraction of the number of employed German nationals and the number of unemployed persons from the exogenously determined labour force:

- $STR[t] = EPP[t] - ETI[t] - EL[t]$

A.4.7 Interest rates

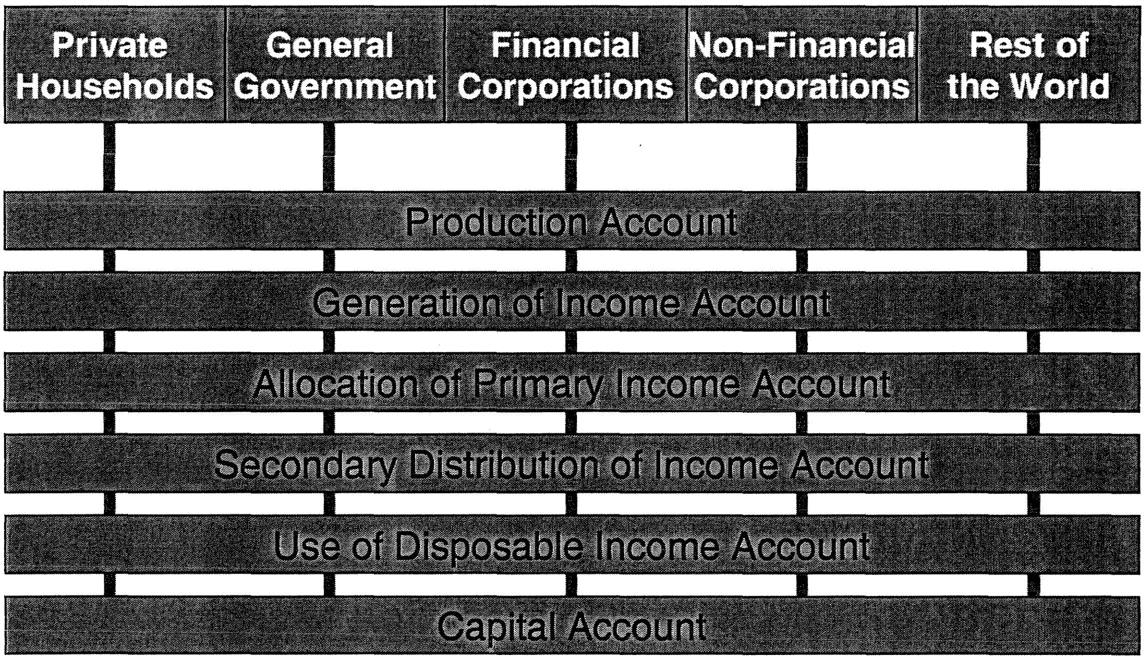
The development of interest rates is dependent on two exogenous preconditions: the effective yield of the US 10 year treasury bonds (*RUSL*) and the base refinancing rate of the European Central Bank (*RDISK*). While *RUSL*, within the previous PANTA RHEI versions, had always been exogenous, now *RDISK* is equally considered exogenous, since the decisions concerning interest rates by the European Central Bank are binding for the entire Euro zone and, as a consequence, the development in other European countries plays a significant role which, however, is not projected by PANTA RHEI.

The interest rate for consumer credits *RKONT* and the 10 year treasury bond rate *RUML* are explained with regard to the US treasury bond rate *RUSL* and the base refinancing rate of the ECB.

A.4.8 System of national accounts

The model projects the System of National Accounts (Eurostat et al. 1993) in the following structure for Germany: As institutional sectors financial corporations, non-financial corporations, government, private households and non-profit institutions serving households as well as the rest of the world are distinguished. For each institutional sector, the following functional accounts are valid: production, generation of income, allocation of primary income, secondary distribution of income, use of disposable income, and capital.

Figure A.5: The system of national accounts



The System of National Accounts is consistently linked with the input-output module. The behavioural hypotheses of the model concern the expenditures of the institutional sectors. The sums of the revenue of one kind of transaction as well as the account balances always are determined by definition. If the receiving sectors of one kind of transaction are not identified by the econometrically estimated expenditures, this results in an econometric estimation of the structure of revenue with the revenue of one institutional sector (the biggest, in the majority of the cases) being the remainder in order to safeguard consistency.

A.5 Energy consumption and emissions

A.5.1 Industry

A.5.1.1 Prices and tax rates

As a first step, for the 30 energy sources e, the overall basic prices *pvgeun* in Euros per physical unit are estimated. They are basically determined by the development on the international energy market, which are monitored via the corresponding import prices *pim*:

– $pvgeun_e = f(pim_j[t])$

The price matrix *PEUN*, which subdivides the overall basic prices of the 30 energy sources by 59 receiving economic sectors, within the rows is projected with the growth rates of the estimated vector *pvgeun*:

– $PEUN_{ej} = PEUN_{ej}[t\text{-}1] * pvgeun_e[t] / pvgeun_e[t\text{-}1]$

The tax matrix *EGTS* contains the tax rates per unit for the 30 sources of energy e within the 59 production sectors j, which are predetermined as exogenous variables in the respective scenario. In the process, especially the exceptions from electricity tax, fuel oil tax and natural gas tax, according to the current (environmental tax) legislation are being referred to.

By addition of basic prices and commodity taxes per physical unit, the matrix of market prices without trade and transport services and without value-added tax *PEN* can be calculated:

– $PEN_{ej}[t] = PEUN_{ej}[t] + EGTS_{ej}[t]$

In further course, the matrices of the indices of the market prices *PEI* and the basic prices *PEUI* as well as the price index vector for the basic prices *pvgeu* for the base year 1995 is calculated:

– $PEI_{ej}[t] = 100 * PEN_{ej}[t] / PEN_{ej}[1995]$

– $PEUI_{ej}[t] = 100 * PEUN_{ej}[t] / PEUN_{ej}[1995]$

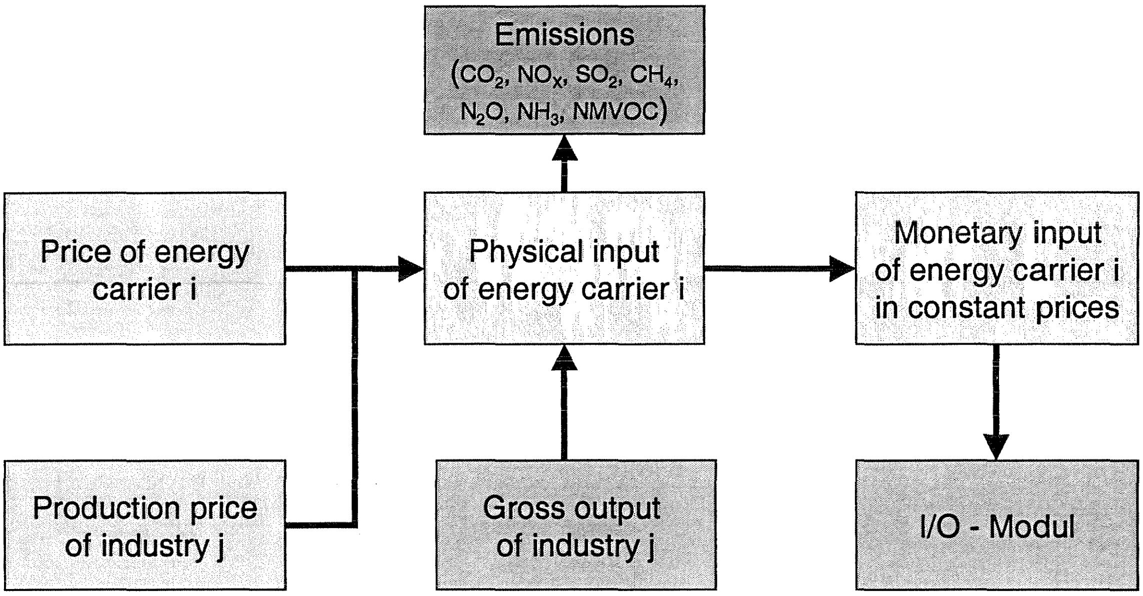
– $pvgeu_e[t] = 100 * pvgeun_e[t] / pvgeun_e[1995]$

A.5.1.2 Energy input coefficients

The energy input coefficients in joule *LEKJ* are estimated for 121 production sectors L and 30 sources of energy. In the process, the input coefficients are defined as the relation of the energy inputs in joule by the 121 production sectors and the corresponding gross production values in constant prices within the aggregated structure of the 59 production sectors. These proceedings are necessary since production figures by 121 sectors are not provided. Relative prices (price of the energy source *PEI* in relation to the basic price *pg*), capital stocks *kasr*, output *xrs* and time trends serve as explanatory variables.

– $LEKJ_{eL} = f(PEI_{ej},[t], pg_j,[t], xrs_j[t], kasr_j[t], ZEIT[t])$

Figure A.6: Modelling energy inputs



Due to the special significance of energy inputs for production, a two-tier method is applied for the production of steel and electricity. First, for the production of steel the total energy consumption is ascertained dependent on the output of the sector and a productivity trend. As a second step, consequently the shares of the single sources of energy of the total energy consumption by the sector are ascertained dependent on relative prices and trends.

The production of electricity, because of the special significance of this particular sector, will be covered in detail. The production of electricity is subdivided into, on the one hand, electricity from fossil incineration processes and nuclear energy and, on the other hand, electricity from hydroelectric power, wind power, photovoltaics and other regenerative energies not requiring incineration processes of any kind. The share of regenerative production of electricity is determined exogenously since, in this sector, the development is dominated by government aids.

The total of fossil energy input and of nuclear energy input in joule is explained with reference to the production of non-regenerative electricity, likewise measured in joule. Due to the withdrawal agreed upon, the input of nuclear energy in large part is determined exogenously, the shares of the fossil sources of energy are explained by their relative prices and time trends. The share of hard-coal is ascertained as being the remainder.

After the ascertaining of all the energy inputs for the 121 production sectors, the *LEKJ* are summed up into the energy inputs *EKJ* by 59 production sectors. Concerning the consumption of diesel and petrol, detailed information provided by the traffic segment can be used.

A.5.1.3 Energy inputs

The energy input coefficients in joule *EKJ* are translated into physical units *EKS* and, consequently, into coefficients of value in constant prices. The single steps up to that point result from definition and will be presented in further course. The *FEKSJ* are stable factors in the process of translating joule into specific units of energy:

– $EKS_{ej}[t] = EKJ_{ej}[t] * FEKSJ_e [2001]$

The evaluation of the energy input coefficients in specific units *EKS* with the total basic prices *PEUN* results in the energy input coefficients in million Euros. Furthermore, at this point there is a translation into billion Euros. The division by the corresponding price indices *pvgeu* results in the energy input coefficients *EKR* in constant prices in billion Euros:

– $EKR_{ej}[t] = (EKS_{ej}[t] * PEUN_{e}j[t]/ 1000) / pvgeu_e[t]$

The levels of the energy input in joule and physical units *ENS* are calculated by multiplication by the real gross production *xgr* of the respective sector j:

– $ENJ_{ej}[t] = EKJ_{ej}[t] * xgr_j[t]$

– $ENS_{ej}[t] = EKS_{ej}[t] * xgr_j[t]$

The corresponding vectors of the total energy demand on the side of the company sector in terajoule *enjvg*, or physical units respectively, result from the summation of the sectoral factors:

– $enjvg_{ee}[t] = \Sigma_j (ENJ_{ej}[t])$

– $ensvg_e[t] = \Sigma_j (ENS_{ej}[t])$

The figures of the energy input in Euros are calculated in respective *ENN* and in constant prices *ENR* by multiplication of the physical units by the corresponding basic prices *PEUN* and by the division of the resulting figures in respective prices by the corresponding basic price index *PEUI*:

– $ENN_{ej}[t] = ENS_{ej}[t] * PEUN_{ej}[t]$

– $ENR_{ej}[t] = ENN_{ej}[t] / PEUI_{ej}[t]$

The energy input coefficients *EKR* of the 30 sources of energy e are aggregated (*EKRV* and *EKNV*) to the four composite commodities of the input-output calculation 4 (coal, peat), 5 (mineral oil, natural gas), 17 (coke and mineral oil products), 32 (production and distribution of energy) and are adjusted to the data of the input-output calculation at the current margin. In the year 2001, factor matrices *DIFFAR* and *DIFFAN* are calculated for the purpose of translation:

– $DIFFAR_{4,5,17,32,j}[t] = AR_{4,5,17,32,j}[t] / EKRV_{4,5,17,32,j}[t]$

– $DIFFAN_{4,5,17,32,j}[t] = AN_{4,5,17,32,j}[t] / EKNV_{4,5,17,32,j}[t]$

By means of these factor matrices, the linkage of the *EKR* and *EKN* to the *AR* and *AN* matrices for all following years is performed:

– $AR_{4,5,17,32,j}[t] = DIFFAR_{4,5,17,32,j}[t] * EKRV_{4,5,17,32,j}[t]$

– $AN_{4,5,17,32,j}[t] = DIFFAN_{4,5,17,32,j}[t] * EKNV_{4,5,17,32,j}[t]$

A.5.1.4 Taxes and prices

The energy taxes *EGT* are calculated by the multiplication of the tax rates *EGTS* with the physical consumption quantities *ENS*:

– $EGT_{ej}[t] = EGTS_{ej}[t] * ENS_{ej}[t]$

The matrix *EGT* is aggregated to the tax payments of the four energy rows and is consequently posted into the vector *sgutvgn* in the respective lines. This makes sure that energy tax payments are posted as government revenues within the account system of the macroeconomic accounting.

– $sgutvgn_{4,5,17,32,j}[t] = \Sigma_e \Sigma_j (EGT_{ej}[t])$

The vector *egtvg* provides information on the tax payments, differentiated by the sources of energy:

– $egtvg_e[t] = \Sigma_j (EGT_{ej}[t])$

The average energy tax payments by companies per specific unit then result from definition:

– $egtsvg_e[t] = egtvg_e[t] / ensvg_e[t]$

In further course, the market prices of specific units *pvgen* and the corresponding price index *pvge* is ascertained:

– $pvgen_e[t] = pvgeun_e[t] + egtsvg_e[t]$

– $pvge_e[t] = pvgen_e[t] / pvge_e[1995]$

Further factors of definition are the energy consumption by companies in respective and constant market prices in million Euro with exclusive reference to the energy taxes.

– $vgen_e[t] = pvgen_e[t] * ensvg_e[t]$

– $vger_e[t] = vgen_e[t] / pvge_e[t]$

A.5.2 Private households

A.5.2.1 Prices and tax rates

As with companies, for the private households as well the total basic prices *pcpeun* in Euros per physical unit in dependence on the import prices *pim* and the unit costs *uc* are estimated:

– $pcpeun_e[t] = f(pim_j[t], uc_j[t],\ldots)$

By means of the predetermined energy tax rates, corresponding to the current state of legislation, the tax vector per quantity unit *egtscp* can be ascertained. The vector of the market prices without trade and transport services and without value-added tax *pcpen* is ascertained by the addition of the basic prices and the vectors of the commodity taxes per physical unit *egtscp*:

– $pcpen_e[t] = pcpeun_e[t] + egtscp_e[t]$

The market prices *pcpe* and the basic prices *pcpeu* are calculated as indices with the base year being 1995:

– $pcpeu_e[t] = pcpeun_e[t] / pcpeu_e[t]$

– $pcpe_e[t] = pcpen_e[t] / pcpe_e[t]$

A.5.2.2 Energy consumption

The energy consumption of petrol and diesel fuel results from the module for the vehicle stocks. The consumption concerning the sources of energy of stable combustibles, light fuel oil and gas, utilized for heating purposes, are, as a first step, ascertained together as *HEIZJH*. For the development of the input of heating energy, the average number of square metres per apartment *WOHNQM* and the stock of apartments for one- and two- as well as three- and multi-family houses (*EINSUMB*, *ZWEISUMB*, *DREISUMB*), the degree day number (Gradtagzahl) *GTZ* and the prices of light fuel oil $pcpe_{14}$ and natural gas $pcpe_{22}$ in relation to the price index of the cost of living are statistically significant:

– $HEIZJH[t] = f((EINSUMB[t]+ZWEISUMB[t]+DREISUMB[t]) * WOHNQM[t], GTZ[t], (pcpe_{14}[t]+pcpe_{22}[t])/PLH[t])$

As a second step, consequently the shares of the single sources of energy in dependence on relative prices between the sources of energy (e and f) and trends are ascertained:

– $enjcp_e[t] = f(pcpe_e[t] / pcpe_f[t]) / ZEIT[t])$

By means of the utilization of the translation factors from joule into specific units of the companies, the consumption in specific units can be ascertained:

– $enscp_e[t] = fcpenjs_e[t] * enjcp_e[t]$

The evaluation with the market prices ascertained above results in the energy consumption of households in respective prices *cpen*. By means of deflationing by the corresponding price index *pcpe*, you get *cper*, the energy consumption of the private households in billion Euros. Moreover, an aggregation to the energy rows (11, 12, 13, 14, 26) of the purposes of consumption $cpvr_k$ is performed with reference to adjustment factors.

– $cpen_e[t] = enscp_e[t] * pcpen_e[t]$

– $cper_e[t] = cpen_e[t] / pcpe_e[t]$

– $cpvr_k[t] = fcpv_k[t] * \Sigma_e (cper_e[t])$

A.5.2.3 Prices and taxes

The calculation of the consumption by private households according to basic prices in constant *cpeur* and respective prices *cpeun* is up next. For this purpose, the energy consumption in specific units *enscp* is multiplied by the absolute prices per specific unit *pcpeun*:

– $cpeun_e[t] = enscp_e[t] * pcpeun_e[t]$

– $cpeur_e[t] = cpeun_e[t] / pcpeu_e[t]$

The tax payments according to sources of energy result from the multiplication of physical consumption *enscp* by the tax payments per quantity *egtscp*. The tax payments resulting are posted as a reversing entry at the vector of the commodity taxes of private households.

– $egtcp_e[t] = egtscp_e[t] * enscp_e[t]$

Next, the prices for the four energy rows (4~ coal and peat, 5~ mineral oil and natural gas, 17~ coke and mineral oil products, 32~ electricity) are ascertained, which determine the development of the consumption prices by composite commodities within the basic price concept *pcpu* for the rows.

– $pcpeuv_{4,5,17,32,j}[t] = cpeunv_{4,5,17,32,j}[t] / cpeurv_{4,5,17,32,j}[t]$

A.5.3 Emissions: The case of CO_2

In further course, the calculation of emissions will be described, using the example of CO_2. In the process, there is a differentiation between those emissions stipulated by energy on the side of companies, private households and those determined by process.

A.5.3.1 Industry

The energy consumption relevant to emissions are firmly linked to the consumption in joule. The matrix *LFEEJ* provides the possibility of this conversion for 30 sources of energy e and 121 production sectors L:

– $LEEJ_{eL}[t] = LFEEJ_{eL}[t] * LENJ_{eL}[t]$

A likewise constant factor *LFECO*, being the share of carbon of the sources of energy, makes it possible to derive the CO_2-emissions from the energy consumption relevant to emission. For some of the other air pollutants taken into consideration, the relations between energy consumption and emissions, the so-called emission factors, are subject to change by technological measures. Within the traffic sector, predeterminations of the TREMOD model are referred to.

– $LECO_{eL}[t] = LFECO_{eL}[t] * LEEJ_{eL}[t]$

Thus, the emissions stipulated by energy on the side of companies by sources of energy *ecovg* as well as in total CO_2U can be calculated by definition:

- $ecovg_e[t] = \Sigma_L (LECO_{eL}[t])$
- $CO_2U[t] = \Sigma_L (lecovg_L[t])$

A.5.3.2 Process-related industry emissions

Dealing with those emissions not determined by process, projections of the German Federal Environmental Office (UBA) are referred to. Should there be no data, fixed coefficients between emissions and production value in constant prices *lxgr* of the year 2001 form the assumed basis:

- $lecopr_L[t] = flecopr_L[t] * lxgr_L[t]$

Aggregation results in the sum of these emissions CO_2M:

- $CO_2M[t] = \Sigma_L (lecopr_L[t])$

A.5.3.3 Private households

For the private households, an analogue process is utilized: Here as well, the factors between the energy consumption *enjcp* and the energy consumption relevant to emission *eejcp* are constant. Every consumption of energy by private households so is relevant to emission:

- $eejcp_e[t] = feejcp_e[t] * enjcp_e[t]$

As above, the emissions then can be ascertained by means of a constant relation according to the share of carbon:

- $ecocp_e[t] = fecocp_e[t] * eejcp_e[t]$

Aggregation results in the sum of the emissions of the households:

- $CO_2C[t] = \Sigma_L (lecocp_L[t])$

A.5.3.4 Total emissions

The emissions by sources of energy *ecoet* per sector and overall result from addition:

- $ecoet_e[t] = ecovg_e[t] + ecocp_e[t]$
- $CO_2E[t] = \Sigma_L (ecoet_e[t])$

The sum of all emissions results from those stipulated by energy and those determined by process:

– $CO_2\,[t] = CO_2E[t] + CO_2M[t]$

ANNEX B: Estimation equations

In this Annex the results of the OLS-estimations of the new modules of PANTA RHEI for the steel, paper and cement industry are presented. Regression results contain among others the following information on fitness according to Almon (1994): SEE: standard error of estimate, RSQ: R^2, RBSQ: adjusted R^2, DW: Durbin-Watson statistic, Obser: number of observations, DoFree: degrees of freedom, MAPE: mean absolute percentage error, t-value: t statistics. See http://www.inforum.umd.edu/G.html for the used Software. The following variables stem from the original part of PANTA RHEI and feed into the new module:

XGST: gross production of sector iron and steel

PGST: price index of gross production of sector iron and steel

XGMB: gross production of sector non-electrical machinery

PGMB: price index of gross production of sector non-electrical machinery

PVEL: price index of electricity input in industry

PVST: price index of hard coal input in industry

PIER: import price index of sector ore production

RUML: 10 year treasury bond rate

INFL: Inflation rate

FEM: R&D expenditures of sector non-electrical machinery in Mio. €:
constant share of XGMB

XGPP: gross production of sector paper and paper products

HHIP: Herfindahl-Hirschmann-Index

XGPP: gross production of sector ceramics

PGST: price index of gross production of sector ceramics

B.1 Steel sector

B.1.1 Production

```
*************
Steel production in Mio. t
r @log(GRS) = @log(XGST), @log(PGST/PGMB)
  SEE    =        0.04 RSQ    = 0.6899 RHO =    0.09 Obser  =   21 from 1980.000
  SEE+1  =        0.04 RBSQ   = 0.6555 DW  =    1.81 DoFree =   18 to   2000.000
  MAPE   =        0.31
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(GRS)              - - - - - - - - - - - - - - - - -    10.60 - - - - - - - - - - -
  1 intercept                7.64479   249.2   0.72    3.23      1.00          14.193
  2 @log(XGST)               0.65206    64.4   0.28    1.37      4.57  0.729    5.538   20.03
  3 @log(PGST/PGMB)         -0.13247    17.2  -0.00    1.00      0.14 -0.341   -2.593    6.72
```

```
Share of EAF steel in steel production (%)
r @log(QERS) = @log(EPK/OSPK), @log(PSCH/PERZ), @log(PVEL/(PVST+PVKO))
  SEE    =        0.03 RSQ    = 0.9792 RHO =    0.10 Obser  =   16 from 1985.000
  SEE+1  =        0.03 RBSQ   = 0.9740 DW  =    1.79 DoFree =   12 to   2000.000
  MAPE   =        0.74
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(QERS)             - - - - - - - - - - - - - - - - -     3.08 - - - - - - - - - - -
  1 intercept                4.24125  1366.9   1.37   48.08      1.00          50.696
  2 @log(EPK/OSPK)           0.82299   298.3  -0.32    2.14     -1.20  1.031   13.355  188.32
  3 @log(PSCH/PERZ)         -0.16009    46.3  -0.06    1.10      1.21 -0.164   -3.701    6.85
  4 @log(PVEL/(PVST+PVKO)) -0.05213     5.0   0.01    1.00     -0.45 -0.089   -1.112    1.24
```

```
EAF steel production in Mio. t
ERS = 0.01 * QERS * GRS
```

```
BOF steel production in Mio. t
ORS = GRS  - ERS
```

```
Price index for iron ore (1995 = 100)
r PERZ = PIER
  SEE    =        4.23 RSQ    = 0.9017 RHO =    0.26 Obser  =   21 from 1980.000
  SEE+1  =        4.09 RBSQ   = 0.8965 DW  =    1.48 DoFree =   19 to   2000.000
  MAPE   =        5.36
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 PERZ                   - - - - - - - - - - - - - - - - -    63.36 - - - - - - - - - - -
  1 intercept              -24.43145    30.2  -0.39   10.17      1.00          -3.635
  2 PIER                     0.77815   218.9   1.39    1.00    112.82  0.950   13.199  174.22
```

```
Gross investment in EAF steel in Mio €
r @log(EIB) =! @log(PVEL[1]/PVST[1]), (RUML[1]-INFL[1]), @log(ERS[1]/EKK[1]), @log(EIB[1])
  SEE    =        0.35 RSQ    = 0.7186 RHO =   -0.11 Obser  =   20 from 1981.000
  SEE+1  =        0.35 RBSQ   = 0.6658 DW  =    2.22 DoFree =   16 to   2000.000
  MAPE   =        7.36
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(EIB)              - - - - - - - - - - - - - - - - -     4.39 - - - - - - - - - - -
  1 @log(PVEL[1]/PVST[1])    -1.91094    54.4  -0.06  141.10      0.13          -4.707
  2 (RUML[1]-INFL[1])       -0.21273    21.0  -0.21   15.85      4.34 -0.338   -2.728  747.19
  3 @log(ERS[1]/EKK[1])      2.01844    61.4   0.81    1.69      1.76  0.523    5.069  118.81
  4 @log(EIB[1])             0.44770    30.1   0.45    1.00      4.46  0.415    3.329   11.08
```

```
Gross investment in EAF steel in Mio. €
r @log(OIB) =! @log(PGST[2]/PGMB[2]), @log(ORS[2]/OSPK[2]), D80[5], D90FF[2]
  SEE    =        0.15 RSQ    = 0.8472 RHO =   -0.05 Obser  =   19 from 1982.000
  SEE+1  =        0.15 RBSQ   = 0.8167 DW  =    2.10 DoFree =   15 to   2000.000
```

MAPE = 1.96

Variable name	Reg-Coef	Mexval	Elas	NorRes	Mean	Beta	t-value	F-Stat
0 @log(OIB)	- - - - -	- - - - -	- - - -	- - - - -	6.05	- - - -	- - - -	- - - -
1 @log(PGST[2]/PGMB[2])	3.49502	107.0	0.10	797.20	0.17		7.018	
2 @log(ORS[2]/OSPK[2])	0.74866	667.2	0.82	5.88	6.62	0.288	29.459	3981.00
3 D80[5]	1.21622	99.4	0.01	2.75	0.05	0.696	6.683	36.57
4 D90FF[2]	0.93098	65.9	0.07	1.00	0.47	1.191	5.125	26.26

Depreciation EAF steel in Mio. €

r EIA =! EKK
SEE = 0.00 RSQ = 1.0000 RHO = 0.06 Obser = 21 from 1980.000
SEE+1 = 0.00 RBSQ = 1.0000 DW = 1.89 DoFree = 20 to 2000.000
MAPE = 0.00

Variable name	Reg-Coef	Mexval	Elas	NorRes	Mean	Beta	t-value	F-Stat
0 EIA	- - - - -	- - - - -	- - - -	- - - - -	93.39	- - - -	- - - -	- - - -
1 EKK	0.06667	33145102.0	1.00	1.00	1400.83		1479550.750	

Depreciation BOF steel in Mio. €

r OIA =! OKK
SEE = 0.75 RSQ = 0.9995 RHO = 0.91 Obser = 21 from 1980.000
SEE+1 = 0.41 RBSQ = 0.9995 DW = 0.18 DoFree = 20 to 2000.000
MAPE = 0.15

Variable name	Reg-Coef	Mexval	Elas	NorRes	Mean	Beta	t-value	F-Stat
0 OIA	- - - - -	- - - - -	- - - -	- - - - -	430.23	- - - -	- - - -	- - - -
1 OKK	0.06558	57585.6	1.00	1.00	6561.18		2579.769	

Net investment EAF and BOF steel in Mio. €

EIN = EIB - EIA
OIN = OIB - OIA

Capital stock EAF and BOF steel

EKK = EKK[1] + EIN
OKK = OKK[1] + OIN

Production capacity EAF steel in Mio. t

r EPK =! EKK[2], D90FF[1]
SEE = 0.75 RSQ = 0.9024 RHO = 0.06 Obser = 19 from 1982.000
SEE+1 = 0.76 RBSQ = 0.8967 DW = 1.88 DoFree = 17 to 2000.000
MAPE = 5.76

Variable name	Reg-Coef	Mexval	Elas	NorRes	Mean	Beta	t-value	F-Stat
0 EPK	- - - - -	- - - - -	- - - -	- - - - -	11.62	- - - -	- - - -	- - - -
1 EKK[2]	0.00691	774.2	0.83	7.02	1396.54		35.810	
2 D90FF[1]	3.77154	164.9	0.17	1.00	0.53	0.779	10.116	102.34

Production capacity EAF steel in Mio. t

r OSPK =! OKK, (D90+D90[1]+D90[2]), TREND
SEE = 0.85 RSQ = 0.8026 RHO = 0.23 Obser = 16 from 1985.000
SEE+1 = 0.87 RBSQ = 0.7722 DW = 1.55 DoFree = 13 to 2000.000
MAPE = 1.71

Variable name	Reg-Coef	Mexval	Elas	NorRes	Mean	Beta	t-value	F-Stat
0 OSPK	- - - - -	- - - - -	- - - -	- - - - -	38.93	- - - -	- - - -	- - - -
1 OKK	0.00419	182.6	0.73	5.34	6802.59		9.530	
2 (D90+D90[1]+D90[2])	4.34587	121.3	0.02	1.80	0.19	0.884	7.117	28.20
3 TREND	0.10359	34.1	0.25	1.00	92.50	0.249	3.220	10.37

B.1.2 Energy consumption

```
*************
```

Best practice electricity input EAF steel in TJ/kt

```
r @log(EBS) = @log(PVEL[1]/PGST[1]), D90FF[7]
  SEE   =        0.02 RSQ   = 0.8714 RHO =   0.20 Obser  =   20 from 1981.000
  SEE+1 =        0.02 RBSQ  = 0.8563 DW  =   1.60 DoFree =   17 to   2000.000
  MAPE  =        0.17
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(EBS)              - - - - - - - - - - - - - - - - -     7.55 - - - - - - - - - - -
  1 intercept                7.54761 36498.7   1.00    7.78      1.00          1508.995
  2 @log(PVEL[1]/PGST[1])   -0.33263   104.7   0.00    5.60     -0.05 -0.648  -7.364   57.62
  3 D90FF[7]                -0.09049   136.7  -0.00    1.00      0.20 -0.778  -8.844   78.21
```

Best practice fuel input EAF steel in TJ/kt

```
r @log(EBF) = TREND
  SEE   =        0.00 RSQ   = 1.0000 RHO =  -0.62 Obser  =   21 from 1980.000
  SEE+1 =        0.00 RBSQ  = 1.0000 DW  =   3.25 DoFree =   19 to   2000.000
  MAPE  =        0.00
    Variable name     Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(EBF)       - - - - - - - - - - - - - - - - -     6.17 - - - - - - - - - - -
  1 intercept          6.93003 91190312.0   1.12 9999.99     1.00          3977942.250
  2 TREND             -0.00841 9986873.0  -0.12    1.00     90.00 -1.000 -435655.469 9999.99
```

Best practice fuel input BOF steel in TJ/kt

```
r @log(OBF) = @log(FEM/PGMB), @log(PVKO[1]/PGST[1]), D90FF[7]
:              Best practice Verbrauch fossile ET in TJ/kt, O-STahl
  SEE   =        0.02 RSQ   = 0.8430 RHO =  -0.03 Obser  =   20 from 1981.000
  SEE+1 =        0.02 RBSQ  = 0.8135 DW  =   2.07 DoFree =   16 to   2000.000
  MAPE  =        0.13
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(OBF)              - - - - - - - - - - - - - - - - -     9.78 - - - - - - - - - - -
  1 intercept               11.14874   891.7   1.14    6.37      1.00           39.466
  2 @log(FEM/PGMB)          -0.32747    58.3  -0.14    4.11      4.22 -0.498  -4.909   28.63
  3 @log(PVKO[1]/PGST[1])   -0.17471    47.0   0.00    3.25     -0.26 -1.211  -4.309   24.86
  4 D90FF[7]                -0.17998    80.3  -0.00    1.00      0.20 -1.683  -6.003   36.03
```

Best practice electricity input BOF steel in TJ/kt

```
r @log(OBE) = TREND
  SEE   =        0.00 RSQ   = 1.0000 RHO =   0.11 Obser  =   21 from 1980.000
  SEE+1 =        0.00 RBSQ  = 1.0000 DW  =   1.78 DoFree =   19 to   2000.000
  MAPE  =        0.00
    Variable name     Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(OBE)       - - - - - - - - - - - - - - - - -     6.14 - - - - - - - - - - -
  1 intercept          6.22377 65791284.0   1.01 9999.99     1.00          2609012.750
  2 TREND             -0.00093 886585.6  -0.01    1.00     90.00 -1.000 -35162.266 9999.99
```

Specific (average) electricity input EAF steel in TJ/kt

```
r @log(ESS) =! @log(ERS/EKK), @log(EBS)
  SEE   =        0.01 RSQ   = 0.9841 RHO =   0.19 Obser  =   21 from 1980.000
  SEE+1 =        0.01 RBSQ  = 0.9832 DW  =   1.61 DoFree =   19 to   2000.000
  MAPE  =        0.06
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(ESS)              - - - - - - - - - - - - - - - - -     7.60 - - - - - - - - - - -
  1 @log(ERS/EKK)           -0.01652    12.8  -0.00 9999.99      1.79          -2.276
  2 @log(EBS)                1.01038 13312.4   1.00    1.00      7.55  0.938 584.616 9999.99
```

Specific (average) fuel input BOF steel in TJ/kt

```
r OSF = !((OKK[1])*OSF[1]+OIB*OBF)/(OKK-OIA)
  SEE   =      477.65 RSQ   = 0.7568 RHO =  -0.03 Obser  =   20 from 1981.000
  SEE+1 =      477.21 RBSQ  = 0.7568 DW  =   2.05 DoFree =   19 to   2000.000
  MAPE  =        1.97
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
```

```
  0 OSF                                    - - - - - - - - - - - - - - - - - -  17931.47 - - - - - - - - - - -
  1 ((OKK[1])*OSF[1]+OIB*OBF)/(OKK-OIA)      0.86885  3659.6   1.00     1.00  20622.88  163.81
```

Specific (average) electricity input BOF steel in TJ/kt

```
r @log(OSE) = @log(OBE)
  SEE    =          0.03 RSQ   = 0.0396 RHO =    0.35 Obser  =   21 from 1980.000
  SEE+1  =          0.03 RBSQ  = -0.0109 DW  =    1.30 DoFree =   19 to    2000.000
  MAPE   =          0.36
    Variable name              Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(OSE)                - - - - - - - - - - - - - - - - -       6.19 - - - - - - - - - - -
  1 intercept                  0.05114     0.0   0.01     1.04       1.00           0.007
  2 @log(OBE)                  1.00003     2.0   0.99     1.00       6.14  0.199    0.885    0.78
```

Specific (average) fuel input EAF steel in TJ/kt

```
r @log(ESF) = @log(EBF)
  SEE    =          0.23 RSQ   = 0.0598 RHO =    0.24 Obser  =   21 from 1980.000
  SEE+1  =          0.23 RBSQ  = 0.0103 DW  =    1.53 DoFree =   19 to    2000.000
  MAPE   =          2.96
    Variable name              Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(ESF)                - - - - - - - - - - - - - - - - -       6.34 - - - - - - - - - - -
  1 intercept                 -0.75416     0.0  -0.12     1.06       1.00          -0.117
  2 @log(EBF)                  1.14868     3.1   1.12     1.00       6.17  0.245    1.100    1.21
```

Input coefficient, electricity in the steel industry in TJ/€ of output

```
r @log(ELST) = !@log(ESS*ERS/XGST),@log(PVEL/PVST)
:                        Inputkoeffizient Strom, Stahlind.
  SEE    =          0.05 RSQ   = 0.4350 RHO =   -0.09 Obser  =   16 from 1985.000
  SEE+1  =          0.05 RBSQ  = 0.3946 DW  =    2.19 DoFree =   14 to    2000.000
  MAPE   =          0.60
    Variable name              Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(ELST)               - - - - - - - - - - - - - - - - -       6.49 - - - - - - - - - - -
  1 @log(ESS*ERS/XGST)         0.53879 11499.0   1.01     2.41      12.11         433.980
  2 @log(PVEL/PVST)           -0.16902    55.3  -0.01     1.00       0.22 -0.899   -4.445   19.76
```

Input coefficient, fossil fuels in the steel industry in TJ/€ of output

```
r @log(FEST) = !@log(OSF*ORS/XGST)
  SEE    =          0.05 RSQ   = 0.5131 RHO =    0.31 Obser  =   21 from 1980.000
  SEE+1  =          0.05 RBSQ  = 0.5131 DW  =    1.38 DoFree =   20 to    2000.000
  MAPE   =          0.42
    Variable name              Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(FEST)               - - - - - - - - - - - - - - - - -       8.83 - - - - - - - - - - -
  1 @log(OSF*ORS/XGST)         0.56666 16984.8   1.00     1.00      15.59         764.041
```

Input coefficient, coke and coal in the steel industry in TJ/€ of output

```
r @log(KKST) = !@log(FEST), TREND, @log(PVKO/PGST)
  SEE    =          0.02 RSQ   = 0.9796 RHO =    0.24 Obser  =   21 from 1980.000
  SEE+1  =          0.02 RBSQ  = 0.9773 DW  =    1.53 DoFree =   18 to    2000.000
  MAPE   =          0.17
    Variable name              Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(KKST)               - - - - - - - - - - - - - - - - -       8.45 - - - - - - - - - - -
  1 @log(FEST)                 1.07143  3102.5   1.12    14.62       8.83         135.806
  2 TREND                     -0.01142   251.0  -0.12     1.22      90.00 -0.517  -14.274  122.60
  3 @log(PVKO/PGST)           -0.03362    10.4   0.00     1.00      -0.28 -0.078   -1.981    3.92
```

Input coefficient, gas in the steel industry in TJ/€ of output

```
r @log(EGST) = !@log(FEST), TREND, (D90 + D90[1])
  SEE    =          0.03 RSQ   = 0.8635 RHO =   -0.05 Obser  =   20 from 1981.000
  SEE+1  =          0.03 RBSQ  = 0.8475 DW  =    2.11 DoFree =   17 to    2000.000
  MAPE   =          0.29
    Variable name              Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(EGST)               - - - - - - - - - - - - - - - - -       6.49 - - - - - - - - - - -
  1 @log(FEST)                 0.62453  1397.8   0.85    10.00       8.83          61.618
  2 TREND                      0.01092   186.1   0.15     3.07      90.50  0.903   11.052   76.52
  3 (D90+D90[1])              -0.12342    75.1  -0.00     1.00       0.10 -0.531   -5.927   35.13
```

Input coefficient, coke in the steel industry in TJ/€ of output

```
r @log(KOST) = !@log(KKST), TREND
:                         Inputkoeffizient Koks
 SEE   =        0.01 RSQ   = 0.9973 RHO =   0.28 Obser  =   21 from 1980.000
 SEE+1 =        0.01 RBSQ  = 0.9971 DW  =   1.45 DoFree =   19 to   2000.000
 MAPE  =        0.09
   Variable name          Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
 0 @log(KOST)          - - - - - - - - - - - - - - - - -       8.36 - - - - - - - - - - -
 1 @log(KKST)             1.08741  7163.5   1.10   44.26       8.45          316.578
 2 TREND                 -0.00922   565.2  -0.10    1.00      90.00 -0.283 -28.668  821.86
```

Input coefficient, coal in the steel industry in TJ/€ of output

```
SKST = KKST - KOST
```

Input coefficient, liquid gas in the steel industry in TJ/€ of output

```
r @log(FGST) = @log(FEST), D90FF[5], D90[4]
 SEE   =        0.08 RSQ   = 0.9912 RHO =   0.09 Obser  =   21 from 1980.000
 SEE+1 =        0.08 RBSQ  = 0.9897 DW  =   1.82 DoFree =   17 to   2000.000
 MAPE  =        4.05
   Variable name          Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
 0 @log(FGST)          - - - - - - - - - - - - - - - - -       1.46 - - - - - - - - - - -
 1 intercept             -4.21716     6.2  -2.90  113.95       1.00          -1.473
 2 @log(FEST)             0.59375     9.5   3.60   78.08       8.83  0.053    1.838  640.03
 3 D90FF[5]               1.71129   690.5   0.34   12.89       0.29  0.927   32.330  655.19
 4 D90[4]                -1.28153   259.0  -0.04    1.00       0.05 -0.327  -14.216  202.09
```

Input coefficient, coke gas in the steel industry in TJ/€ of output

```
r @log(KGST) =  @log(FEST),@log(PVST/PGST)
 SEE   =        0.12 RSQ   = 0.7809 RHO =   0.50 Obser  =   21 from 1980.000
 SEE+1 =        0.10 RBSQ  = 0.7565 DW  =   1.00 DoFree =   18 to   2000.000
 MAPE  =        1.48
   Variable name          Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
 0 @log(KGST)          - - - - - - - - - - - - - - - - -       6.17 - - - - - - - - - - -
 1 intercept             -7.73635     9.1  -1.25    4.56       1.00          -1.848
 2 @log(FEST)             1.58230    27.4   2.27    1.70       8.83  0.476    3.351   32.07
 3 @log(PVST/PGST)        0.36660    30.3  -0.01    1.00      -0.21  0.503    3.546   12.58
```

Input coefficient, converter gas in the steel industry in TJ/€ of output

```
r @log(GGST) =! @log(FEST)
 SEE   =        0.05 RSQ   = 0.6196 RHO =  -0.02 Obser  =   21 from 1980.000
 SEE+1 =        0.05 RBSQ  = 0.6196 DW  =   2.03 DoFree =   20 to   2000.000
 MAPE  =        0.55
   Variable name          Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
 0 @log(GGST)          - - - - - - - - - - - - - - - - -       6.75 - - - - - - - - - - -
 1 @log(FEST)             0.76447 14287.8   1.00    1.00       8.83          643.428
```

Input coefficient, heavy fuel oil in the steel industry in TJ/€ of output

```
SHST = FEST - SKST - KOST - FGST - KGST - GGST - EGST
```

B.1.3 Labour market

****

Specific labour input, EAF steel in capita/kt

```
r @log(KARES) = !@log(XGST/BST), TREND
  SEE    =        0.05 RSQ    = 0.9705 RHO =    0.19 Obser  =    21 from 1980.000
  SEE+1  =        0.05 RBSQ   = 0.9689 DW  =    1.62 DoFree =    19 to   2000.000
  MAPE   =        5.05
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(KARES)          - - - - - - - - - - - - - - - - -       -1.06 - - - - - - - - - - -
  1 @log(XGST/BST)          -0.30149   354.9  -2.07   44.40      -7.30         -19.343
  2 TREND                    -0.03626   566.3   3.07    1.00       90.00 -0.688 -28.714  824.52
```

Specific labour input, BOF steel in capita/kt

```
r @log(KAROS) = !@log(XGST/BST), TREND
  SEE    =        0.05 RSQ    = 0.9796 RHO =    0.21 Obser  =    21 from 1980.000
  SEE+1  =        0.05 RBSQ   = 0.9786 DW  =    1.57 DoFree =    19 to   2000.000
  MAPE   =       14.92
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(KAROS)          - - - - - - - - - - - - - - - - -       -0.59 - - - - - - - - - - -
  1 @log(XGST/BST)          -0.38178   521.9  -4.72   56.45      -7.30         -26.754
  2 TREND                    -0.03753   651.3   5.72    1.00       90.00 -0.646 -32.459 1053.58
```

Number of workers in EAF production

```
ARES = KARES*ERS
```

Number of workers in BOF production

```
AROS = KAROS*ORS
```

Number of workers in EAF and BOF production

```
AROES = ARES + AROS
```

Number of other workers in the steel industy

```
r @log(RARST) =  TREND
  SEE    =        0.04 RSQ    = 0.9813 RHO =    0.42 Obser  =    21 from 1980.000
  SEE+1  =        0.04 RBSQ   = 0.9803 DW  =    1.16 DoFree =    19 to   2000.000
  MAPE   =        0.30
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RARST)          - - - - - - - - - - - - - - - - -       11.36 - - - - - - - - - - -
  1 intercept               16.09624  2358.7   1.42   53.54       1.00         107.083
  2 TREND                    -0.05265   631.7  -0.42    1.00       90.00 -0.991 -31.596  998.34
```

Number of workers in the steel industy

```
ARST = RARST + AROES
```

Number of white-collar employees in the steel industry

```
r @log(ANST) = (D91+ D92+ D93), TREND
  SEE    =        0.03 RSQ    = 0.9883 RHO =    0.07 Obser  =    21 from 1980.000
  SEE+1  =        0.03 RBSQ   = 0.9870 DW  =    1.87 DoFree =    18 to   2000.000
  MAPE   =        0.20
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(ANST)           - - - - - - - - - - - - - - - - -       10.50 - - - - - - - - - - -
  1 intercept               14.37855  3266.7   1.37   85.76       1.00         142.775
  2 (D91+D92+D93)            0.19750   160.1   0.00   84.36       0.14  0.262  10.188  762.82
  3 TREND                    -0.04339   818.5  -0.37    1.00       90.00 -0.995 -38.737 1500.52
```

Employment in the steel industry

```
BST = ARST + ANST
```

B.2 Paper sector

B.2.1 Production

****

Paper production in kt

```
r @log(PPTG) = @log(XGPP), D95FF
  SEE    =        0.04 RSQ    = 0.9825 RHO =    0.16 Obser  =    21 from 1980.000
  SEE+1  =        0.04 RBSQ   = 0.9805 DW  =    1.68 DoFree =    18 to   2000.000
  MAPE   =        0.28
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(PPTG)             - - - - - - - - - - - - - - - - - -   9.36 - - - - - - - - - - -
  1 intercept                4.61278   394.0   0.49    57.07     1.00          20.523
  2 @log(XGPP)               1.23711   395.3   0.50     5.52     3.79  0.767  20.582  504.64
  3 D95FF                    0.20062   134.9   0.01     1.00     0.29  0.336   9.015   81.28
```

Share of RCP in paper production (%)

```
r @log(QRTG) = @log(RKPR/PKPR)
  SEE    =        0.01 RSQ    = 0.9972 RHO =    0.52 Obser  =    21 from 1980.000
  SEE+1  =        0.01 RBSQ   = 0.9971 DW  =    0.95 DoFree =    19 to   2000.000
  MAPE   =        0.14
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(QRTG)             - - - - - - - - - - - - - - - - - -   3.85 - - - - - - - - - - -
  1 intercept                4.52857 12291.1   1.18   358.21     1.00         540.096
  2 @log(RKPR/PKPR)          0.84858  1792.6  -0.18     1.00    -0.80  0.999  82.383 6786.99
```

RCP paper production in kt

```
RPTG = 0.01 * QRTG * PPTG
```

PFP paper production in kt

```
FPTG = PPTG  - RPTG
```

Gross investment in PFP paper production in Mio. €

```
r @log(FIBN) = @log(FPTG[1]/FKPR[1]), (D90[4]+D90[5]+D90[6])
  SEE    =        0.32 RSQ    = 0.6570 RHO =    0.31 Obser  =    17 from 1984.000
  SEE+1  =        0.32 RBSQ   = 0.6080 DW  =    1.38 DoFree =    14 to   2000.000
  MAPE   =        4.20
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(FIBN)             - - - - - - - - - - - - - - - - - -   6.63 - - - - - - - - - - -
  1 intercept                7.96607   436.0   1.20     2.92     1.00          19.704
  2 @log(FPTG[1]/FKPR[1])     9.77290    27.5  -0.17     2.80    -0.11  0.495   2.959   13.41
  3 (D90[4]+D90[5]+D90[6])    -1.20644    67.3  -0.03     1.00     0.18 -0.839  -5.018   25.18
```

Gross investment in RCP paper production in Mio. €

```
r @log(RIBN) = @log(PPTG/PKPR), D90FF, D80[9]
  SEE    =        0.22 RSQ    = 0.8804 RHO =    0.23 Obser  =    20 from 1981.000
  SEE+1  =        0.21 RBSQ   = 0.8579 DW  =    1.54 DoFree =    16 to   2000.000
  MAPE   =        2.15
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(RIBN)             - - - - - - - - - - - - - - - - - -   6.87 - - - - - - - - - - -
  1 intercept                6.86972   475.9   1.00     8.36     1.00          22.687
  2 @log(PPTG/PKPR)          7.06626    16.4  -0.09     4.97    -0.09  0.239   2.385   39.24
  3 D90FF                    1.03455   122.6   0.08     1.42     0.55  0.822   7.953   31.72
  4 D80[9]                   0.67313    19.3   0.00     1.00     0.05  0.234   2.605    6.79
```

Depreciation in PFP paper production in Mio. €

```
r @log(FABN) =! @log(FBAV), D91FF
  SEE    =        0.04 RSQ    = 0.9811 RHO =    0.44 Obser  =   21 from 1980.000
  SEE+1  =        0.03 RBSQ   = 0.9801 DW  =    1.12 DoFree =   19 to   2000.000
  MAPE   =        0.44
    Variable name            Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(FABN)             - - - - - - - - - - - - - - - - -      6.44 - - - - - - - - - - -
  1 @log(FBAV)               0.70218 12426.1   0.99     7.76      9.04          545.981
  2 D91FF                    0.19103   178.5   0.01     1.00      0.48  0.366  11.330  128.36
```

Depreciation in RCP paper prodcution in Mio. €

```
r @log(RABN) = @log(RBAV)
  SEE    =        0.05 RSQ    = 0.9933 RHO =    0.50 Obser  =   21 from 1980.000
  SEE+1  =        0.04 RBSQ   = 0.9930 DW  =    0.99 DoFree =   19 to   2000.000
  MAPE   =        0.60
    Variable name            Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RABN)             - - - - - - - - - - - - - - - - -      6.26 - - - - - - - - - - -
  1 intercept               -3.00097   306.4  -0.48   149.43      1.00         -17.170
  2 @log(RBAV)               1.04493  1122.4   1.48     1.00      8.87  0.997  53.105 2820.16
```

Net investment in PFP and RCP in Mio. €

```
FINN = FIBN - FABN
RINN = RIBN - RABN
```

Capital stock PFP in Mio. €

```
id FBAV = FINN + FBAV[1]
```

Capital stock RCP in Mio. €

```
id RBAV = RINN + RBAV[1]
```

Production capacity PFP in kt

```
r @log(FKPR) =! @log(FBAV), D90FF[1]
  SEE    =        0.04 RSQ    = 0.8462 RHO =    0.13 Obser  =   20 from 1981.000
  SEE+1  =        0.04 RBSQ   = 0.8377 DW  =    1.74 DoFree =   18 to   2000.000
  MAPE   =        0.37
    Variable name            Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(FKPR)             - - - - - - - - - - - - - - - - -      8.84 - - - - - - - - - - -
  1 @log(FBAV)               0.98724 13887.9   1.01     6.75      9.07          593.437
  2 D90FF[1]                -0.21712   159.9  -0.01     1.00      0.50 -0.962 -10.177  103.57
```

Production capacity PFP in kt

```
r @log(RKPR) =! @log(RBAV), D90FF[1]
  SEE    =        0.05 RSQ    = 0.9844 RHO =    0.22 Obser  =   21 from 1980.000
  SEE+1  =        0.05 RBSQ   = 0.9835 DW  =    1.55 DoFree =   19 to   2000.000
  MAPE   =        0.44
    Variable name            Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RKPR)             - - - - - - - - - - - - - - - - -      8.66 - - - - - - - - - - -
  1 @log(RBAV)               0.98795 11605.9   1.01     5.19      8.87          510.230
  2 D90FF[1]                -0.22235   127.8  -0.01     1.00      0.48 -0.270  -8.921   79.58
```

Production capacity paper industry in kt

```
PKPR = FKPR + RKPR
```

B.2.2 Energy consumption

```
*************
```

Best practice fuel input PFP without structural effect in TJ/kt

```
r @log(FBBVS) = @log(PVPBG/PGPP), D95FF, D80FF[6], D80FF[8]
  SEE   =        0.01 RSQ   = 0.9555 RHO =  -0.12 Obser  =   21 from 1980.000
  SEE+1 =        0.01 RBSQ  = 0.9444 DW  =   2.24 DoFree =   16 to   2000.000
  MAPE  =        0.52
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(FBBVS)           - - - - - - - - - - - - - - - - -     1.97 - - - - - - - - - - -
  1 intercept               2.17331  1531.3   1.10   22.49      1.00          65.127
  2 @log(PVPBG/PGPP)       -0.18679    36.9  -0.02   10.99      0.21 -0.886  -3.737   85.94
  3 D95FF                  -0.05402    83.1  -0.01    3.76      0.29 -0.396  -6.137   53.28
  4 D80FF[6]               -0.14197    55.2  -0.05    2.71      0.71 -1.040  -4.750   22.04
  5 D80FF[8]               -0.06985    64.5  -0.02    1.00      0.62 -0.550  -5.225   27.30
```

Best practice fuel input PFP in TJ/kt

```
r @log(FBBV) = @log(RAFP*FBBVS)
  SEE   =        0.02 RSQ   = 0.9480 RHO =   0.47 Obser  =   18 from 1983.000
  SEE+1 =        0.02 RBSQ  = 0.9448 DW  =   1.06 DoFree =   16 to   2000.000
  MAPE  =        0.97
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(FBBV)            - - - - - - - - - - - - - - - - -     1.82 - - - - - - - - - - -
  1 intercept               0.33884    39.5   0.19   19.25      1.00           3.891
  2 @log(RAFP*FBBVS)        0.82748   338.7   0.81    1.00      1.79  0.974  17.087  291.95
```

Best practice electricity input PFP without structural effect in TJ/kt

```
r @log(FBEVS) = @log(FEM/PGMB), D92FF, D95FF
  SEE   =        0.00 RSQ   = 0.9735 RHO =  -0.04 Obser  =   21 from 1980.000
  SEE+1 =        0.00 RBSQ  = 0.9689 DW  =   2.08 DoFree =   17 to   2000.000
  MAPE  =        0.11
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(FBEVS)           - - - - - - - - - - - - - - - - -     1.42 - - - - - - - - - - -
  1 intercept               1.80294  1188.3   1.27   37.77      1.00          52.956
  2 @log(FEM/PGMB)         -0.08768   181.5  -0.26   31.02      4.21 -0.434 -10.848  208.38
  3 D92FF                  -0.01423   137.6  -0.00    4.32      0.43 -0.519  -8.885  255.13
  4 D95FF                  -0.01321   107.8  -0.00    1.00      0.29 -0.439  -7.512   56.43
```

Best practice electricity input PFP without structural effect in TJ/kt

```
r @log(FBEV) = @log(RAFP*FBEVS)
  SEE   =        0.02 RSQ   = 0.9413 RHO =  -0.10 Obser  =   21 from 1980.000
  SEE+1 =        0.02 RBSQ  = 0.9382 DW  =   2.20 DoFree =   19 to   2000.000
  MAPE  =        0.94
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(FBEV)            - - - - - - - - - - - - - - - - -     1.36 - - - - - - - - - - -
  1 intercept               0.35919    74.5   0.26   17.04      1.00           6.234
  2 @log(RAFP*FBEVS)        0.79037   312.8   0.74    1.00      1.27  0.970  17.459  304.81
```

Specific (average) fuel input PFP without structural effect in TJ/kt

```
r @log(FSBVS) =! @log((FBAV[1]*FSBVS[1]+FIBN*FBBVS)/(FBAV[1]+FIBN)), D90[1]
  SEE   =        0.03 RSQ   = 0.9262 RHO =   0.09 Obser  =   20 from 1981.000
  SEE+1 =        0.03 RBSQ  = 0.9221 DW  =   1.81 DoFree =   18 to   2000.000
  MAPE  =        1.01
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(FSBVS)           - - - - - - - - - - - - - - - - -     2.20 - - - - - - - - - - -
  1 @log((FBAV[1]*FSBVS[1]+FIBN*FBBVS)/(FBAV[1]+FIBN))     0.99520  7542.3   1.00     2.16
2.20      324.207
  2 D90[1]                  0.13846    47.0   0.00    1.00      0.05  0.292   4.570   20.89
```

Specific (average) fuel input PFP effect in TJ/kt

```
r @log(FSBV) = @log(RAFP*FSBVS)
  SEE   =        0.02 RSQ   = 0.9734 RHO =   0.43 Obser  =   18 from 1983.000
  SEE+1 =        0.02 RBSQ  = 0.9717 DW  =   1.14 DoFree =   16 to   2000.000
```

```
  MAPE  =        0.63
    Variable name               Reg-Coef  Mexval  Elas    NorRes      Mean   Beta  t-value  F-Stat
  0 @log(FSBV)                - - - - - - - - - - - - - - - - -       2.07 - - - - - - - - - - -
  1 intercept                   0.46863   103.3   0.23    37.55       1.00          7.081
  2 @log(RAFP*FSBVS)            0.79258   512.8   0.77     1.00       2.01  0.987  24.184  584.85
```

Specific (average) electricity input PFP without structural effect in TJ/kt

```
r @log(FSEV) = @log(FBEV*RAFP)
  SEE    =       0.01 RSQ   = 0.9678 RHO =   0.43 Obser  =  21 from 1980.000
  SEE+1  =       0.01 RBSQ  = 0.9661 DW  =   1.15 DoFree =  19 to   2000.000
  MAPE   =       0.86
    Variable name               Reg-Coef  Mexval  Elas    NorRes      Mean   Beta  t-value  F-Stat
  0 @log(FSEV)                - - - - - - - - - - - - - - - - -       1.42 - - - - - - - - - - -
  1 intercept                   0.68290   416.7   0.48    31.05       1.00         22.098
  2 @log(FBEV*RAFP)             0.60681   457.2   0.52     1.00       1.21  0.984  23.893  570.88
```

Best practice fuel input RCP in TJ/kt

```
r @log(RBBV) = @log(PVPBG/PGPP), D80FF[6], D80FF[8], D95FF
  SEE    =       0.01 RSQ   = 0.9550 RHO =  -0.11 Obser  =  21 from 1980.000
  SEE+1  =       0.01 RBSQ  = 0.9438 DW  =   2.22 DoFree =  16 to   2000.000
  MAPE   =       0.67
    Variable name               Reg-Coef  Mexval  Elas    NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RBBV)                - - - - - - - - - - - - - - - - -       1.67 - - - - - - - - - - -
  1 intercept                   1.88158  1211.3   1.13    22.25       1.00         52.298
  2 @log(PVPBG/PGPP)           -0.19980    36.3  -0.03    10.89       0.21 -0.884  -3.708   84.98
  3 D80FF[6]                   -0.15228    54.8  -0.07     7.90       0.71 -1.040  -4.725   52.76
  4 D80FF[8]                   -0.07424    63.0  -0.03     3.36       0.62 -0.545  -5.151   55.21
  5 D95FF                      -0.05832    83.3  -0.01     1.00       0.29 -0.398  -6.145   37.76
```

Best practice electricity input RCP in TJ/kt

```
r @log(RBEV) = @log(FEM/PGMB), @log(HHIP), D95FF
  SEE    =       0.00 RSQ   = 0.9833 RHO =   0.33 Obser  =  21 from 1980.000
  SEE+1  =       0.00 RBSQ  = 0.9804 DW  =   1.34 DoFree =  17 to   2000.000
  MAPE   =       0.16
    Variable name               Reg-Coef  Mexval  Elas    NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RBEV)                - - - - - - - - - - - - - - - - -       0.97 - - - - - - - - - - -
  1 intercept                   1.20809   715.1   1.25    59.97       1.00         33.354
  2 @log(FEM/PGMB)             -0.08494   192.8  -0.37    49.33       4.21 -0.372 -11.348  334.18
  3 @log(HHIP)                  0.03254   199.2   0.12     1.28       3.67  0.770  11.625  410.79
  4 D95FF                      -0.00491    13.2  -0.00     1.00       0.29 -0.145  -2.184    4.77
```

Specific (average) fuel input RCP in TJ/kt

```
r @log(RSBV) =! @log((RBAV[1]*RSBV[1]+RIBN*RBBV)/(RBAV[1]+RIBN)), D90[1], D100
  SEE    =       0.03 RSQ   = 0.9341 RHO =   0.14 Obser  =  20 from 1981.000
  SEE+1  =       0.03 RBSQ  = 0.9263 DW  =   1.72 DoFree =  17 to   2000.000
  MAPE   =       1.14
    Variable name               Reg-Coef  Mexval  Elas    NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RSBV)                - - - - - - - - - - - - - - - - -       1.92 - - - - - - - - - - -
  1 @log((RBAV[1]*RSBV[1]+RIBN*RBBV)/(RBAV[1]+RIBN))       1.00222  6628.7   1.00     2.80
1.91         277.401
  2 D90[1]                      0.13520    47.3   0.00     1.55       0.05  0.277   4.462   15.31
  3 D100                       -0.09271    24.6  -0.00     1.00       0.05 -0.190  -3.063    9.38
```

Specific (average) electricity input RCP in TJ/kt

```
r @log(RSEV) =! @log(RBEV)
  SEE    =       0.02 RSQ   = 0.2405 RHO =   0.68 Obser  =  21 from 1980.000
  SEE+1  =       0.01 RBSQ  = 0.2405 DW  =   0.64 DoFree =  20 to   2000.000
  MAPE   =       1.61
    Variable name               Reg-Coef  Mexval  Elas    NorRes      Mean   Beta  t-value  F-Stat
  0 @log(RSEV)                - - - - - - - - - - - - - - - - -       1.02 - - - - - - - - - - -
  1 @log(RBEV)                  1.05362  4940.9   1.00     1.00       0.97        225.392
```

Fuel inputs in PFP in TJ

```
id FGBE = 0.001 * FSBVS * FPTG
```

Fuel inputs in RCP in TJ
RGBE = 0.001 * RSBV * RPTG

Fuel inputs in paper in TJ
PABE = FGBE + RGBE

Electricity inputs in PFP in TJ
FGEL = 0.001 * FSEV * FPTG

Electricity inputs in RCP in TJ
RGEL = 0.001 * RSEV * RPTG

Electricity inputs in paper in TJ
PAEL = FGEL + RGEL

Share of hard coal in the fuel input of paper production

```
r @log(SEPSK) = @log(PVSTK/PGPP), @log(TREND)
  SEE    =       0.08 RSQ   = 0.7835 RHO =   0.42 Obser  =   17 from 1984.000
  SEE+1  =       0.07 RBSQ  = 0.7526 DW  =   1.16 DoFree =   14 to   2000.000
  MAPE   =       3.61
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(SEPSK)         - - - - - - - - - - - - - - - - -     -1.64 - - - - - - - - - - -
  1 intercept              8.94223    51.4  -5.46    4.62      1.00          4.256
  2 @log(PVSTK/PGPP)      -0.59250     9.4   0.01    2.80      0.03 -0.243  -1.659   25.33
  3 @log(TREND)           -2.33664    67.2   6.45    1.00      4.52 -0.733  -5.015   25.15
```

Share of gas in the fuel input of paper production

```
r @log(SEPEG) = @log(PVGA/PVSTK), @log(TRENDS), D90
  SEE    =       0.05 RSQ   = 0.9668 RHO =  -0.06 Obser  =   17 from 1984.000
  SEE+1  =       0.05 RBSQ  = 0.9591 DW  =   2.12 DoFree =   13 to   2000.000
  MAPE   =       5.11
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(SEPEG)         - - - - - - - - - - - - - - - - -     -0.62 - - - - - - - - - - -
  1 intercept             -0.90698  1088.0   1.46   30.12      1.00         -42.684
  2 @log(PVGA/PVSTK)      -0.31457    56.1   0.02   28.27      0.04 -0.219  -4.321  126.20
  3 @log(TRENDS)          -0.21228   429.3  -0.47    2.12     -1.36 -0.991 -18.741  177.23
  4 D90                    0.21416    45.8  -0.02    1.00      0.06  0.203   3.823   14.62
```

Share of waste-based fuels in the fuel input of paper production

```
r @log(SEPEB) = @log(PVGA/PGPP), D93FF
  SEE    =       0.13 RSQ   = 0.9260 RHO =  -0.09 Obser  =   13 from 1988.000
  SEE+1  =       0.13 RBSQ  = 0.9112 DW  =   2.19 DoFree =   10 to   2000.000
  MAPE   =       3.36
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(SEPEB)         - - - - - - - - - - - - - - - - -     -3.35 - - - - - - - - - - -
  1 intercept             -3.85011  1480.4   1.15   13.52      1.00         -49.878
  2 @log(PVGA/PGPP)        0.82916    19.3  -0.01    5.29      0.03  0.244   2.059   62.60
  3 D93FF                  0.77444   130.0  -0.14    1.00      0.62  0.777   6.551   42.92
```

Energy inputs in paper production in TJ

```
hard coal:         EPSK = SEPSK*PABE
brown coal:        EPBK = SEPBK*PABE
heavy fuel oil:    EPSH = SEPSH*PABE
gas:               EPEG = SEPEG*PABE
waste-based fuels: EPEB = SEPEB*PABE
```

 # Weighted fuel input price index in the paper industry
PVPBG = (EPSK * PVSTK + EPEB * PVEB + EPSH * PVSH + EPEG * PVGA)/100

B.3 Cement sector

B.3.1 Production

```
*************
```

Cement production in Mio. € 1995

```
r @log(ZPWR) = @log(XGBA), @log(PZPW/PGBA)
  SEE    =       0.04 RSQ   = 0.9241 RHO =    0.43 Obser  =   21 from 1980.000
  SEE+1  =       0.04 RBSQ  = 0.9157 DW  =    1.13 DoFree =   18 to   2000.000
  MAPE   =       0.36
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(ZPWR)            - - - - - - - - - - - - - - - - -      8.53 - - - - - - - - - - -
  1 intercept               6.13761   364.1   0.72   13.18       1.00           19.227
  2 @log(XGBA)              0.40442   102.9   0.28    3.87       5.91  0.565    7.489  109.61
  3 @log(PZPW/PGBA)        -0.79663    96.7   0.00    1.00      -0.00 -0.542   -7.188   51.66
```

Cost of cement production in Mio. €

```
ZGKZ = ZRHB+ZBLG+ZAEN+ZEKG
```

Price Index of cement production (1995 = 100)

```
r @log(PZPW) =! @log(ZGKZ[1]/ZPZG[1]), D80FF[7], @log(ZHHI[1]), D90FF[5]
  SEE    =       0.04 RSQ   = 0.8655 RHO =    0.18 Obser  =   20 from 1981.000
  SEE+1  =       0.04 RBSQ  = 0.8402 DW  =    1.64 DoFree =   16 to   2000.000
  MAPE   =       0.81
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(PZPW)            - - - - - - - - - - - - - - - - -      4.44 - - - - - - - - - - -
  1 @log(ZGKZ[1]/ZPZG[1])    0.69378   113.1   0.69    3.54       4.43            7.528
  2 D80FF[7]                0.11295    49.0   0.02    1.74       0.70  0.450    4.421   13.57
  3 @log(ZHHI[1])           0.26719    27.0   0.28    1.69       4.67  0.326    3.129    5.94
  4 D90FF[5]                0.12942    29.9   0.01    1.00       0.30  0.515    3.315   10.99
```

Cement production in Mio. € 1995

```
ZPWN = 0.01 * ZPWR * PZPW
```

Cement production in Mio. t

```
r @log(ZPZG) = @log(ZPWR)
  SEE    =       0.00 RSQ   = 1.0000 RHO =    0.40 Obser  =   18 from 1983.000
  SEE+1  =       0.00 RBSQ  = 1.0000 DW  =    1.19 DoFree =   16 to   2000.000
  MAPE   =       0.00
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(ZPZG)            - - - - - - - - - - - - - - - - -      3.38 - - - - - - - - - - -
  1 intercept             -5.14196 39960496.0  -1.52 9999.99      1.00          -1271587.375
  2 @log(ZPWR)             1.00000 66274288.0   2.52 1.00    8.53  1.000 2108919.500 9999.99
```

Clinker production in Mio. t

```
r @log(KPTG) = @log(ZPZG), @log(ZAZS*ZPZG)
  SEE    =       0.01 RSQ   = 0.9969 RHO =    0.31 Obser  =   21 from 1980.000
  SEE+1  =       0.01 RBSQ  = 0.9966 DW  =    1.38 DoFree =   18 to   2000.000
  MAPE   =       0.05
    Variable name           Reg-Coef  Mexval  Elas   NorRes      Mean   Beta  t-value  F-Stat
  0 @log(KPTG)            - - - - - - - - - - - - - - - - -     10.11 - - - - - - - - - - -
  1 intercept               7.25078  3939.8   0.72  325.27       1.00          171.342
  2 @log(ZPZG)              1.17922  1008.6   0.40   10.24       3.39  1.300   46.843 2918.43
  3 @log(ZAZS*ZPZG)        -0.18252   220.0  -0.11    1.00       6.25 -0.358  -12.894  166.27
```

Gross investment in cement in Mio. €

```
r @log(ZIBG) = @log(ZPZG/ZPKA), D91FF, D90[5]
  SEE    =       0.13 RSQ   = 0.8347 RHO =    0.38 Obser  =   19 from 1982.000
  SEE+1  =       0.12 RBSQ  = 0.8016 DW  =    1.24 DoFree =   15 to   2000.000
  MAPE   =       1.83
```

```
  Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
 0 @log(ZIBG)            - - - - - - - - - - - - - - - - -    5.63 - - - - - - - - - - -
 1 intercept              5.82526   773.8   1.03    6.05      1.00          33.620
 2 @log(ZPZG/ZPKA)        1.10654    23.1  -0.07    3.25     -0.35  0.361    2.779   25.24
 3 D91FF                  0.30571    35.6   0.03    1.96      0.53  0.470    3.550   16.91
 4 D90[5]                 0.59402    40.0   0.01    1.00      0.05  0.409    3.792   14.38
```

Depreciation cement in Mio. €

```
r @log(ZAEN) =! @log(ZPKA), D95FF
 SEE   =        0.13 RSQ   = 0.8308 RHO =   0.51 Obser  =   21 from 1980.000
 SEE+1 =        0.12 RBSQ  = 0.8219 DW  =   0.99 DoFree =   19 to   2000.000
 MAPE  =        1.75
  Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
 0 @log(ZAEN)            - - - - - - - - - - - - - - - - -    5.94 - - - - - - - - - - -
 1 @log(ZPKA)             1.55422  3568.9   0.98    3.64      3.73         159.866
 2 D95FF                  0.48061    90.8   0.02    1.00      0.29  0.671    7.081   50.14
```

Net investment cement in Mio. €

```
ZING = ZIBG - ZAEN
```

Capital stock cement in Mio. €

```
KSTZ[t] = KSTZ[t-1] + ZIBG[t]
```

Production capacity cement in Mio. €

```
r @log(ZPKA) = @log(KSTZ/PGGK), D98FF
 SEE   =        0.02 RSQ   = 0.9674 RHO =  -0.03 Obser  =   18 from 1983.000
 SEE+1 =        0.02 RBSQ  = 0.9630 DW  =   2.06 DoFree =   15 to   2000.000
 MAPE  =        0.35
  Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
 0 @log(ZPKA)            - - - - - - - - - - - - - - - - -    3.73 - - - - - - - - - - -
 1 intercept             -0.16694     2.7  -0.04   30.63      1.00          -0.900
 2 @log(KSTZ/PGGK)        0.96029   451.8   1.05    3.97      4.08  1.065   21.018  222.24
 3 D98FF                 -0.07705    99.3  -0.00    1.00      0.17 -0.338   -6.676   44.56
```

Labour input cement in Mio. hours

```
r @log(ZAST) = @log(ZBLG/ZPWP), @log(TRENDS), D93, D94
 SEE   =        0.03 RSQ   = 0.8918 RHO =  -0.21 Obser  =   14 from 1987.000
 SEE+1 =        0.02 RBSQ  = 0.8437 DW  =   2.41 DoFree =    9 to   2000.000
 MAPE  =        0.77
  Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
 0 @log(ZAST)            - - - - - - - - - - - - - - - - -    2.53 - - - - - - - - - - -
 1 intercept              3.96086   399.7   1.57    9.24      1.00          14.688
 2 @log(ZBLG/ZPWP)       -0.90780   109.4  -0.67    9.13      1.86 -1.877   -5.520   18.54
 3 @log(TRENDS)          -0.15006   125.8   0.10    2.20     -1.65 -2.094   -6.073   24.38
 4 D93                    0.09665    36.0   0.00    1.51      0.07  0.324    2.767    5.39
 5 D94                    0.07227    22.9   0.00    1.00      0.07  0.242    2.145    4.60
```

Labour costs in € per hour, cement production

```
r @log(ZAKH) =! @log(SLS), D93FF
 SEE   =        0.04 RSQ   = 0.8577 RHO =   0.41 Obser  =   10 from 1991.000
 SEE+1 =        0.03 RBSQ  = 0.8399 DW  =   1.17 DoFree =    8 to   2000.000
 MAPE  =        0.70
  Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
 0 @log(ZAKH)            - - - - - - - - - - - - - - - - -    4.47 - - - - - - - - - - -
 1 @log(SLS)              1.35414  5323.1   1.05    8.51      3.45         153.363
 2 D93FF                 -0.26436   191.7  -0.05    1.00      0.80 -1.082   -7.750   60.07
```

Wages in Mio. €, cement production

```
ZBLG  = ZAST * ZAKH
```

Raw material costs in Mio. €, cement production

```
r @log(ZRHB) = @log(ZPZG[1]), D99FF
 SEE   =        0.07 RSQ   = 0.9186 RHO =   0.15 Obser  =   16 from 1985.000
 SEE+1 =        0.07 RBSQ  = 0.9060 DW  =   1.70 DoFree =   13 to   2000.000
 MAPE  =        0.86
```

	Variable name	Reg-Coef	Mexval	Elas	NorRes	Mean	Beta	t-value	F-Stat
0	@log(ZRHB)	- - - - - - - - - - - - - - - - - - -				6.70	- - - - - - - - - - - -		
1	intercept	0.96361	14.3	0.14	12.28	1.00		1.998	
2	@log(ZPZG[1])	1.70679	244.2	0.86	1.73	3.38	1.046	11.873	73.32
3	D99FF	-0.20464	31.4	-0.00	1.00	0.12	-0.271	-3.073	9.44

B.3.2 Energy consumption

```
*************
```

Cumulated R&D expenditures in Mio. €, cement industry

```
KFEZ = KFEZ[1] + FEZ
```

Best practice fuel input in clinker production in TJ/kt

```
r @log(KBBV) = @log(KFEZ)
  SEE   =        0.00 RSQ   = 0.9987 RHO =    0.90 Obser  =   21 from 1980.000
  SEE+1 =        0.00 RBSQ  = 0.9986 DW  =    0.20 DoFree =   19 to   2000.000
  MAPE  =        0.01
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KBBV)             - - - - - - - - - - - - - - - - -     8.05 - - - - - - - - - - -
  1 intercept                8.48617 52538.6   1.05   745.47     1.00        2294.275
  2 @log(KFEZ)              -0.07370  2630.3  -0.05     1.00     5.96 -0.999 -118.923 9999.99
```

Specific (average) fuel input in clinker production in TJ/kt

```
r @log(KSBV) = @log(KBBV), @log(PVZG/PGGK), D80[8], D80[9]
  SEE   =        0.02 RSQ   = 0.8402 RHO =    0.04 Obser  =   21 from 1980.000
  SEE+1 =        0.02 RBSQ  = 0.8003 DW  =    1.92 DoFree =   16 to   2000.000
  MAPE  =        0.20
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KSBV)             - - - - - - - - - - - - - - - - -     8.24 - - - - - - - - - - -
  1 intercept              -11.25307    52.7  -1.36     6.26     1.00          -4.618
  2 @log(KBBV)               2.42187   123.6   2.36     4.13     8.05  1.174    8.001   21.04
  3 @log(PVZG/PGGK)         -0.18552    70.0   0.00     2.36    -0.05 -0.815   -5.499   16.69
  4 D80[8]                  -0.08697    33.6  -0.00     1.44     0.05 -0.369   -3.542   10.89
  5 D80[9]                   0.06414    20.2   0.00     1.00     0.05  0.272    2.667    7.11
```

Fuel input in cement production in TJ

```
r @log(ZGBE) = @log(KPTG*KSBV), D95FF, D90, D90[1], D90[2]
  SEE   =        0.04 RSQ   = 0.9083 RHO =    0.20 Obser  =   21 from 1980.000
  SEE+1 =        0.04 RBSQ  = 0.8777 DW  =    1.60 DoFree =   15 to   2000.000
  MAPE  =        0.59
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(ZGBE)             - - - - - - - - - - - - - - - - -     4.49 - - - - - - - - - - -
  1 intercept               -9.88463    73.9  -2.20    10.90     1.00          -5.509
  2 @log(KPTG*KSBV)          0.78278   129.2   3.20     5.98    18.35  0.715    7.988   29.71
  3 D95FF                    0.10771    55.5   0.01     2.74     0.29  0.402    4.613   18.67
  4 D90                     -0.10042    15.2  -0.00     2.57     0.05 -0.177   -2.212    8.68
  5 D90[1]                  -0.18281    40.6  -0.00     1.87     0.05 -0.322   -3.829   11.80
  6 D90[2]                  -0.17249    36.7  -0.00     1.00     0.05 -0.303   -3.612   13.05
```

Specific (average) electricity input in cement production in TJ/kt

```
r @log(KSEV) = @log(KFEZ)
  SEE   =        0.01 RSQ   = 0.6384 RHO =    0.03 Obser  =   16 from 1985.000
  SEE+1 =        0.01 RBSQ  = 0.6126 DW  =    1.95 DoFree =   14 to   2000.000
  MAPE  =        0.16
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KSEV)             - - - - - - - - - - - - - - - - -     5.96 - - - - - - - - - - -
  1 intercept                6.31343  2248.2   1.06     2.77     1.00          87.782
  2 @log(KFEZ)              -0.05865    66.3  -0.06     1.00     6.09 -0.799   -4.972   24.72
```

Specific (average) electricity input in cement production in TJ/kt

```
r @log(ZEEL) = @log(KSEV*ZPZG), D93FF
  SEE   =        0.03 RSQ   = 0.9575 RHO =    0.46 Obser  =   21 from 1980.000
  SEE+1 =        0.03 RBSQ  = 0.9527 DW  =    1.07 DoFree =   18 to   2000.000
  MAPE  =        0.96
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(ZEEL)             - - - - - - - - - - - - - - - - -     2.52 - - - - - - - - - - -
  1 intercept               -3.17986    44.7  -1.26    23.51     1.00          -4.440
  2 @log(KSEV*ZPZG)          0.60423   109.6   2.24     3.56     9.34  0.562    7.813  202.59
  3 D93FF                    0.14346    88.7   0.02     1.00     0.38  0.488    6.790   46.10
```

Input coefficient, hard coal in clinker production in TJ/€ of output

```
r @log(KZESK) =  @log(PVSTK/PVZG), D90FF[3]
  SEE   =        0.13 RSQ   = 0.7761 RHO =    0.22 Obser  =   19 from 1982.000
  SEE+1 =        0.12 RBSQ  = 0.7481 DW  =    1.57 DoFree =   16 to    2000.000
  MAPE  =        4.47
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KZESK)            - - - - - - - - - - - - - - - - -     2.30 - - - - - - - - - - -
  1 intercept                2.66444   518.2   1.16     4.47     1.00          24.404
  2 @log(PVSTK/PVZG)        -0.60327     8.4  -0.06     4.13     0.23 -0.230   -1.669   27.73
  3 D90FF[3]                -0.53146   103.2  -0.10     1.00     0.42 -0.977   -7.078   50.10
```

Input coefficient, brown coal in clinker production in TJ/€ of output

```
r @log(KZEBK) =  @log(PVBR[1]/PZPW[1]), D90FF[4]
  SEE   =        0.10 RSQ   = 0.8123 RHO =    0.08 Obser  =   19 from 1982.000
  SEE+1 =        0.10 RBSQ  = 0.7888 DW  =    1.84 DoFree =   16 to    2000.000
  MAPE  =        5.69
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KZEBK)            - - - - - - - - - - - - - - - - -     1.45 - - - - - - - - - - -
  1 intercept                1.25723   800.3   0.87     5.33     1.00          35.789
  2 @log(PVBR[1]/PZPW[1])   -0.56372    18.8   0.01     5.21    -0.03 -0.312   -2.562   34.62
  3 D90FF[4]                 0.46785   128.3   0.12     1.00     0.37  1.001    8.210   67.41
```

Input coefficient, heavy fuel oil in clinker production in TJ/€ of output

```
r @log(KZESH) =  @log(PVSH/PVZG)
  SEE   =        0.14 RSQ   = 0.8965 RHO =    0.14 Obser  =   18 from 1983.000
  SEE+1 =        0.14 RBSQ  = 0.8901 DW  =    1.72 DoFree =   16 to    2000.000
  MAPE  =       52.02
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KZESH)            - - - - - - - - - - - - - - - - -     0.05 - - - - - - - - - - -
  1 intercept                0.58267   172.4  12.65     9.66     1.00          10.136
  2 @log(PVSH/PVZG)         -1.05230   210.9 -11.65     1.00     0.51 -0.947  -11.774  138.63
```

Input coefficient, gas in clinker production in TJ/€ of output

```
r @log(KZEEG) =  @log(PVGA/PVZG), D93FF, D80FF[7]
  SEE   =        0.18 RSQ   = 0.8940 RHO =    0.16 Obser  =   21 from 1980.000
  SEE+1 =        0.18 RBSQ  = 0.8753 DW  =    1.69 DoFree =   17 to    2000.000
  MAPE  =       51.16
    Variable name            Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(KZEEG)            - - - - - - - - - - - - - - - - -    -1.18 - - - - - - - - - - -
  1 intercept               -0.17884     9.5   0.15     9.44     1.00          -1.844
  2 @log(PVGA/PVZG)         -1.73092   147.1   0.38     5.90     0.26 -0.758   -9.319   47.80
  3 D93FF                    0.23324    13.3  -0.08     5.41     0.38  0.209    2.198   41.61
  4 D80FF[7]                -0.95264   132.6   0.54     1.00     0.67 -0.830   -8.659   74.97
```

Input of hard coal in clinker production in TJ

ZESK = 0.001 * KZESK * ZPWR

Input of brown coal in clinker production in TJ

ZEBK = 0.001 * KZEBK * ZPWR

Input of heavy fuel oil in clinker production in TJ

ZESH = 0.001 * KZESH * ZPWR

Input of gas coal in clinker production in TJ

ZEEG = 0.001 * KZEEG * ZPWR

Input of waste-based fuels in clinker production in TJ

ZEEB = ZGBE - ZESK - ZEBK - ZESH - ZEEG

Weighted price index of fuel input in clinker production

```
PVZG = (ZESK * PVSTK + ZEBK * PVBR + ZESH * PVSH + ZEEG * PVGA)/100
```

Costs for energy inputs in clinker production in Mio. €

```
r @log(ZEKG) = @log(PVZG), ZEEB, D91FF
  SEE    =        0.06 RSQ    = 0.8448 RHO =    0.26 Obser  =    21 from 1980.000
  SEE+1  =        0.06 RBSQ   = 0.8174 DW  =    1.47 DoFree =    17 to   2000.000
  MAPE   =        0.73
    Variable name           Reg-Coef  Mexval  Elas   NorRes     Mean   Beta  t-value  F-Stat
  0 @log(ZEKG)            - - - - - - - - - - - - - - - - -     6.70 - - - - - - - - - - - - -
  1 intercept              4.14691   146.6   0.62    6.44      1.00            9.296
  2 @log(PVZG)             0.59141    74.4   0.39    3.57      4.42  0.569    5.889   30.85
  3 ZEEB                  -0.01989    87.2  -0.02    2.13      7.95 -0.993   -6.525   21.85
  4 D91FF                  0.20441    45.9   0.01    1.00      0.48  0.662    4.383   19.21
```