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ENDOGENOUS INNOVATION, THE ECONOMY AND THE ENVIRONMENT: IMPACTS OF A TECHNOLOGY-BASED MODELLING APPROACH FOR ENERGY-INTENSIVE INDUSTRIES IN GERMANY

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ABSTRACT

This paper presents policy simulation results from a new modelling approach for three energy-intensive industry sectors in Germany. In this approach, technological change is explicitly portrayed and linked to actual production processes. Likewise, technology choice is modelled via investments in new production process lines. The new modelling approach is integrated into the macro-econometric model PANTA RHEI. By endogenizing technological change it also takes into account that policy interventions may affect the rate and direction of technological progress. The implications of the new modelling approach are highlighted by simulating the effects of a CO_2 tax in the new approach and in the conventional approach. For the energy- and capital-intensive industries considered, our results show that the conventional top-down approach overestimates the short-term possibilities to adapt to higher CO_2 prices in the early years. By including policy-induced technological change and process shifts, the new approach also captures the long-term effects on CO_2 emissions well beyond the initial price impulse. In the long run, the estimated costs are found to be smaller under the new approach.

Keywords: endogenous technological change; technology diffusion; energy intensive industries; economy-energy-environment models; climate change policy

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1. INTRODUCTION

The impact of policy interventions on the economy and on the environment crucially depends – among other things – on their effects on 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, until recently, environmental-economic models have typically treated technological change as exogenous, that is, endogenous technological change such as induced innovation is not captured by these models. By contrast, according to the theory of *induced innovation* developed 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 also lead to the invention of new, more energy-efficient technologies. Recent empirical work cited, for example, in the overview by Jaffe et al. (2003), also supports the view that higher energy prices induce energy-efficient innovations.

The current modelling approaches for climate policy analyses can be split into bottom-up and top-down models (Weyant, 1999 and 2000, IPCC, 2001). Bottom-up models are engineering-based partial models of the energy transforming and using sectors which explicitly model different technologies and their improvement over time to capture all energy saving possibilities. Since bottom-up models neglect market failures, uncertainty and rebound effects (Binswanger, 2001), i.e. that lower energy prices due to technological change will stimulate demand, the costs calculated for climate change policies tend to be low. These 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. Some recent dynamic bottom-up models allow for endogenous technological change via experience curves.

In contrast, top-down models represent the general economy and include all the economic effects of price changes, including income and substitution effects. In most top-down models, a trend variable typically reflects technological progress. Hence, endogenous, policy-induced technological progress is not represented. If policy-induced technological change is not taken into account in the model, costs of policy interventions will be overestimated, ceteris paribus. Another form of endogenous technological progress, which results from so-called learning-by-doing effects, implies investments in reduction measures at an early stage (Van der Zwaan et. al, 2002, Goulder and Matthai, 2000). Even in top-down models which allow for endogenous technical change such as Goulder and Schneider (1999) or Buonanno et al. (2003) and other models surveyed, for example, by Löschel (2002) or Carraro and Galleotti (2002), there is no direct linkage to the actual technologies responsible for the technological development. Similarly, Popp (2004, p. 743) criticizes that "none of the existing models make use of empirical estimates on the nature of technological change to calibrate the model". Recent research efforts also started to incorporate technological aspects into the modelling of endogenous technological change (e.g. The Energy Journal, 2006). Typically, for the electricity sector selected technologies are incorporated at a rather aggregate level in long-term endogenous growth models. At a more disaggregated level, Masui et al. (2006) link a global dynamic computable general equilibrium model and a bottom-up model for end-use energy technologies to analyse the effects of energy-saving investments on CO_2 emissions and the economy. Since the output of the bottom-up model is used as an input into the top-down model, the linking between technologies and macroeconomic variables is soft rather than integrated.

In this paper we present simulations with a new modelling approach in which technological change is explicitly portrayed and linked to actual production processes in the production of iron and steel, of cement and of pulp and paper. In addition, technology choice is modelled via investments in new production process lines. For the production relations, we assume limited production relations of the "putty-clay" type: When making investment decisions for production functions of this type, a choice can be made between different limitational processes, but the input structures of the existing plants are fixed. Production functions of the "putty-clay" type are supposed to better reflect the actual technological environment in many industrial sectors than CES functions. For example, 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. Limiting substitution possibilities leads to higher costs when modelling the effects of climate policies, ceteris paribus. By endogenizing technological change, the new modelling approach also allows a process-specific analysis of the impacts of policies, which may now affect the rate and the direction of technological progress. We present results for this new modelling approach as applied and integrated into the macro-econometric model PANTA RHEI (Meyer and Ewerhart, 1998, Lutz, 2000, Meyer, 2001, Bach et al. 2002, Bockermann et al. 2005) for three energy-intensive industries in Germany: the iron and steel industry, the pulp and paper industry, and the cement industry. For more details on the modelling of the steel industry, see Lutz et al. (2005); for the pulp and paper industry, see Nathani et al. (2004). The techno-economic background information for the implementation for the cement industry can be found in Angerer et al. (2003). In this paper, we conduct policy simulations for all three sectors combined and explore differences between the new and conventional modelling approaches in the effects of a CO_2 tax. Our findings suggest that, for the energy- and capital-intensive industries considered, the conventional top-down approach underestimates the short-term costs of adapting to higher CO_2 prices in the early years. In the long term, however, policy-induced technological change and process shifts contribute significantly to emission reductions, leading to lower long-term costs under the new approach.

The remainder of the paper is organized as follows. Section 2 presents the generic modelling procedure for all three industry sectors as well as an overview of the relevant sector-specific modelling results and the integration into PANTA RHEI. In Section 3, carbon tax simulations are conducted to explore the differences between the new and old modelling approach. Conclusions are presented in Section 4.

2. MODELLING TECHNOLOGY CHOICE AND TECHNOLOGICAL CHANGE OVER TIME

2.1 New integrated modelling approach

The conventional econometric input-output model PANTA RHEI has frequently been applied to analyse the macro-economic and environmental effects of various energy and climate policies (e.g. Lutz 2000, Bach et al. 2002 or Bockermann et al. 2005). In the conventional model, which is also described in more detail in the Appendix, technical change is not directly modelled. Instead, a time series of input coefficients from typical input-output tables implicitly reflects the impact of technical change. These input coefficients are modelled as price-dependent based on the results from reduced-form type econometric estimations. Changes in input coefficients in response to price changes are then interpreted, not as the result of substitution, but of cost-induced technological progress, i.e. of changes in limitational production processes. However, the conventional approach does neither explicitly nor implicitly allow for a link to the underlying technologies.

In this paper we no longer regard technological change and changes in production processes which translate into changes in the input-output coefficients as being a black box. For three energy-intensive industries, the iron and steel industry, pulp and paper manufacturing and the cement industry, we choose a more disaggregated structural-form type approach. In terms of innovation, these sectors are typically characterized as being "supplier dominated" (Pavitt 1984) that is, they contribute relatively little to innovation itself. Instead, technical progress 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 and processes (also Silverberg 1988). Thus, rather than specifically modelling the innovation processes within the industries considered, we follow the innovation literature and treat technological progress as being incorporated in the relevant capital goods, i.e. in the new process lines.

In the conventional form of PANTA RHEI, the three considered industries belong to the 59 industries distinguished in the model. In the new approach each industry is characterised by its main production process lines and their respective best-practice technologies, which are described in detail by their main technical and economic parameters. The best-practice technologies can evolve over time (e.g. leading to reduced energy consumption) and gradually diffuse into the capital stock via new investments, thus improving the average process technology. Furthermore the choice between process lines at the time of investment is explicitly modelled.

The parameters reflecting this change of process technologies are linked to driving parameters of PANTA RHEI in a consistent way. At the same time, parameters of PANTA RHEI such as energy input coefficients are calculated bottom-up from the process lines. Energy input coefficients of the industries under consideration depend explicitly on the weighted energy input structures of the alternative process lines. Other parameters like investments and prices are similarly derived by aggregating data from the process lines. With this particular approach of linking bottom-up and top-down data a high level of model integration is achieved and a more realistic analysis of policy scenarios becomes possible, where the effects can be traced back to individual technologies.

To integrate the actual production processes into the model, time series of variables such as investments, production amounts, detailed input structures (especially electricity and fuel consumption) and the process-specific input demand of the respective best-practice process technologies are determined for the historical observation period 1980-2000 for the main process lines (also termed technological paradigms in the innovation literature, see e.g. Dosi, 1982, 1988). The necessary data were compiled via detailed sector studies, which relied on existing statistics, technology and cost information from the technical literature and expert interviews (for details see Schleich et al., 2006). Based on these data, the process-specific investments, i.e. the choice of process lines and the development of technical change for each process line can be estimated econometrically as functions of "explanatory" variables. Data for these variables was either taken from PANTA RHEI or collected separately. The correlations found then serve as the basis for the policy simulations as described in section 3. Due to data limitations of the time series, we define technologies at a medium level of aggregation, where a process line may consist of a bundle of individual technologies.

Next, we describe the setup of the model and the relations between model variables in more detail. First, production levels for steel, paper or cement in physical units are derived from the gross production value of the respective industry, which in PANTA RHEI depends on intermediate demand by the other industries and final demand. Then, a time series of production shares of the main process lines is regressed on a set of variables which generally includes material and energy input prices as well as the relative capacity share of the various process lines. Relative production capacities may be interpreted as a proxy for capital obsolescence or path dependence since sunk costs associated with existing capacities are considered to be a barrier to the diffusion of the newer technologies. Then, real gross investments in the process lines are econometrically estimated as a function of the real rate of interest, energy and material input prices, and demand relative to production capacities. This modelling step allows us to describe the changes in the production structure and thus in the structure of input consumption for the various process lines as a result of investment decisions (technology choice).

To capture the development of technological change, we then regress best-practice fuel and electricity use of the alternative process lines on a set of determinants which reflects factors affecting the costs and benefits of new technologies to the adopters as well as factors affecting the technical development of energy efficiency. The set of determinants generally consists of relative energy and material input prices and R&D expenditures by the industry sectors and by the mechanical engineering and electrical engineering sectors. Expenditure for R&D in the latter two sectors was included to test the hypothesis that the producers of investment goods take the production costs of their customers, i.e. the energy intensive process industries, into account when targeting their research efforts. In addition, indices reflecting industry concentration 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 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, have better access to capital markets to finance the adoption of new technologies, or may be able to better spread the potential risks associated with the new technologies because they tend to be more diversified. On the other hand, larger firms may be more bureaucratic and suffer from so-called X-inefficiencies. Due to the lack of data, other determinants which may affect the choice of process lines such as risk, option value or intangible costs could not be included in the model.

Further details on the actual implementation of this approach for the selected industry sectors are presented in the following subsection.

2.2 Application to the steel, pulp and paper and cement industries

2.2.1 Overview of process technologies

In the new modelling approach, the decision in favour of new process lines (adoption and diffusion) takes place via investments in the alternative process lines. This section gives a brief overview of the process lines in the three considered industries (see Schleich et al., 2006 for more details). For the production of steel, the two most important process lines for crude steel production in Germany are (i) blast oxygen furnace (BOF) steel production, i. e., the process of producing primary steel 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. the process of producing secondary steel primarily in electric arc furnaces (to a lesser extent in induction furnaces) based on scrap. The production of EAF steel 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 is processed from wood, whereas recycled pulp is processed from waste paper. Then a specific mixture of the different kinds of pulp and other mainly mineral substances (e.g. fillers and coatings), which depends upon the desired paper characteristics, is further processed to paper. Energy use differs significantly across processes. The manufacturing processes need electricity and steam which are either generated on-site or – especially in the case of electricity – purchased from other suppliers. In the German paper industry, a significant share of heat and electricity is delivered by co-generation. When modelling the main process lines, we apply a "composite technology" approach, where the various process combinations are integrated into two alternative process lines. We distinguished between (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 technologies and also an average energy supply technology.

Different raw materials are used to produce cement, the most important of which is limestone. In general, these materials may either be prepared in wet or in dry processes, but the German cement industry makes almost exclusive use of dry processes. Then the raw materials are processed in rotary kilns under very high temperatures, thus yielding 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 remarkably over the last two decades.

2.2.2 Estimation results

This section contains an overview of selected estimation results for the steel and the pulp and paper industry. Since we only observe one paradigm for the cement industry, its results are not reported here due to space limitations (see Angerer et al., 2003 for details).

We estimate the share of EAF in total steel production 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 (Table 1). The price ratios are included to reflect relative differences in unit costs.

For example, in the model, an increase in the scarcity of scrap iron would be captured by higher scrap prices, but the scrap market itself is not explicitly modelled. The ratio of EAF capacity to BOF capacity is included to reflect actual output potentials. Estimation results in Table 1 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 the scrap/iron ore price ratio.

The price ratio of electricity to coal 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 to be not statistically significant at the 10 % level. Similar results are obtained by Schleich (2001) for the West German steel industry and for a different time horizon.

Table 1: Selected Regression Results for the Steel Industry (t-statistics in parentheses)

		Dependent variable				
Regressors	Lags	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/non-electrical machinery	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 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

The actual choice of processes takes place via new investments in both process lines of crude steel production. The real gross investments in the EAF steel process line 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 non-electrical machinery sector (reflecting expected profitability of the investment). To explain technological change, we regress the best-practice specific energy use of electric or oxygen steel production, respectively, on a set of price variables which includes the prices of the main energy inputs in relation to output prices as well as R&D expenditure of the steel industry and the non-electrical and electrical machinery sectors. In the concrete implementation of the model, specific energy use of the best-practice EAF process lines can be estimated by the lagged ratio of electricity price to steel output price. The best-practice processes with regard to the consumption of fossil fuels in BOF steel production are determined by the R&D spending of the mechanical engineering sector and the price relation of coal, the most important energy input, to steel output. As a general feature, for years with strong energy price decreases such as 1986, dummy variables are added to prevent energy saving technological progress being revoked when energy prices decrease.

For the pulp and paper industry, the choice of process line is modelled via new investments in both process lines of paper production (see table 2).

Table 2: Selected Regression Results for the Paper Industry (t-statistics in parentheses)

		Dependent variable				
Regressors	Lags	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

The real gross investments in PFP and RCP process lines can be estimated as a function of the ratio of actual production to the installed capacity (reflecting the pressure to expand). Unlike the steel industry, relative input prices were not found to be statistically significant for the choice of process lines in the paper industry.

To some extent, this reflects the hypothesis that investment in RCP was primarily driven by waste paper regulation. As in the steel industry, the development of the best practice fuel inputs in both paper paradigms can be explained by the ratio of fuel input prices to the output price of the industry. The best-practice input for electricity in RCP may best be explained by R&D expenditures in the mechanical engineering sector and by concentration in the paper industry. In the paper industry, higher concentration appears to facilitate the adoption of new electricity-saving technologies. However, electricity prices turned out not to play a role, which – at least to some extent – may be due to the relatively low variation of electricity prices over the considered time horizon.

3. POLICY SIMULATIONS

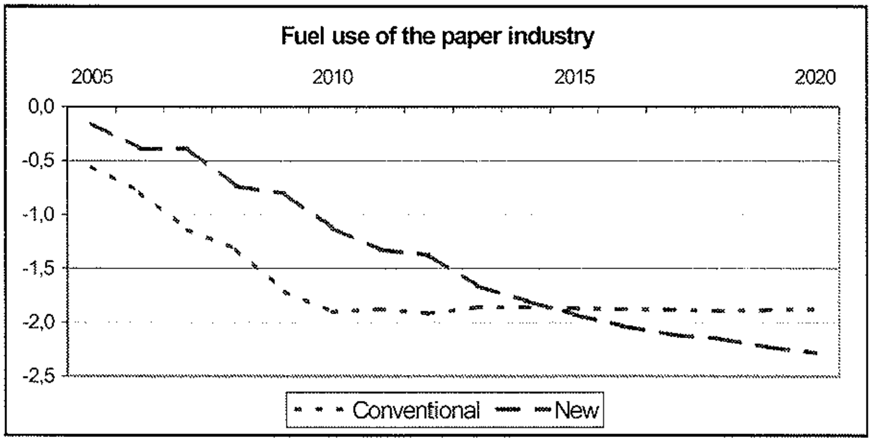
In this section we compare the results of simulating the introduction of a CO_2 tax or, alternatively, a CO_2 emissions trading system between the conventional and the new modelling approach. In total, two simulations were conducted for each approach: base scenarios without a CO_2 tax, and policy scenarios, where a CO_2 tax is introduced in 2005, which increases from 5 € to 20 € per ton CO_2 in 2010. These price levels correspond to a price per ton of carbon of more than 73 Euro in 2010 and are in the range of recent model estimates for CO_2 market prices (Springer and Varilek, 2003). From 2011 on, the tax rate is kept constant at 20 € per ton CO_2. The CO_2 tax is levied on all fossil energy carriers based on their carbon content, so that the use of coal is more heavily taxed than the use of oil or gas. As the tax burden is at least partly passed on, electricity will also become more expensive. Coal prices are also affected to a greater extent than electricity, because electricity is already taxed in Germany and because some electricity production (from nuclear and renewable sources) is carbon free. Since we model the CO_2 trading system as part of a global CO_2 trading system, similar price increases in competing countries can be expected. The tax revenue or, alternatively, the revenue from auctioning off the CO_2 allowances, will be used to lower labour costs. For the simulation analyses, we assume that the structural equations which are estimated based on historical data remain unchanged until the final year of the analysis, 2020. In particular, parameter estimates are assumed to be invariant to possible policy changes.

For the policy scenario with the new modelling approach, the tax policy results in a reduction of CO_2 emissions by 3.3 % in 2020 compared to the base scenario, but the macroeconomic effects of the CO_2 tax are almost negligible: GDP increase, mainly driven by recycling of the tax revenues, is below 0.2 % in 2020 and very close to results with the conventional approach (Bach et al. 2002). Thus, besides leading to lower emissions ("first dividend"), the tax scheme also results in a very small "second dividend", in terms of GDP (and also employment) gains. Such double dividends may result if the revenues are used to alleviate distortions in the economy resulting in an improvement in the overall efficiency of the economy. This result indicating the small macroeconomic effects of climate policy is also consistent with the literature (IPCC 2001).

As an example for the effects on individual sectors, we discuss the results for the German paper industry. Results for the steel industry are similar to Lutz et al. (2005). The German paper and paper products industry will suffer almost no trade losses; instead the main effect of the CO_2 tax is 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. This leads to a CO_2 reduction of approximately 9 % in the year 2020. Further significant CO_2 reductions due to fuel mix shifts are not to be expected in the case of higher CO_2 prices, as the fuel share of gas and biomass already exceeds 90 % in the CO_2 tax scenario in 2020. Paper product prices increase slightly by 1 %, but the impact on paper production is negligible.

We next compare the effects under the new and the conventional modelling approaches. To highlight the differences between the two approaches, we first look at the overall fuel use of the paper industry (see Figure 2). In the conventional approach, the effect on fuel use is driven by econometrically estimated (low) price elasticities. An increase in fuel prices via the CO_2 tax reduces fuel inputs in the years 2005 to 2010, when the tax rate increases steadily.

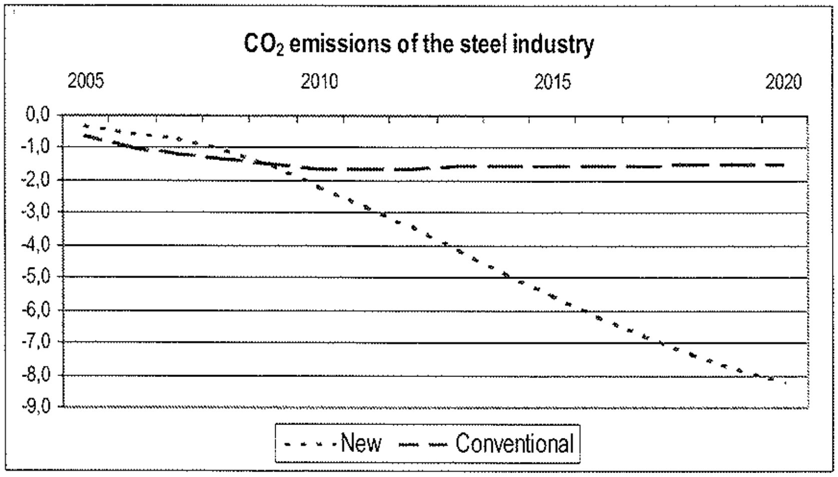
Figure 2: Effects of a CO_2 Tax – Percentage Deviations from the Base Scenarios



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. Therefore, in the first years of the CO_2 tax, the effect on fuel use is smaller compared to the conventional approach, reflecting the time needed to adapt to the higher energy prices (see estimation results in Table 2). However, in the new approach, further energy savings result after 2010, better reflecting the influence of the higher energy price level after 2010 compared to the respective base scenario. This result spotlights the importance of modelling the time needed for adaptation to changed price relations when analysing the impact of policies in sectors with high capital costs.

Compared to the paper industry, the steel industry has more options to react to higher energy prices, as one of the process lines is based on coal use (BOF) whereas the other uses electricity (EAF). The production costs for both BOF- and EAF-steel increase as a result of the introduction of the CO_2 tax. But EAF-steel becomes relatively more attractive because the CO_2 tax increases the costs for coal use more than the costs for electricity use. The increase in electricity costs is relatively lower because electricity is also generated from non-coal fuels - the current share of coal in electricity generation in Germany is about 47 % - and because the electricity price also includes costs for transmission and distribution and for subsidizing electricity generation from renewables and combined heat and power. The drop in CO_2 emissions from steel production in response to the CO_2 tax is shown for both modelling approaches in Figure 3.

Figure 3: Effects of a CO_2 tax – Percentage Deviations from the Base Scenarios in the Steel Sector



The observed emission reductions in the iron and steel industry can be traced back to five distinct factors (see also Lutz et al. 2005): i) a reduction in steel production because of lower demand in response to higher steel prices, ii) energy saving technical progress via more energy-efficient best-practice technologies (cost pressure hypothesis), iii) faster implementation of best practice technologies via greater investment (higher adoption rate) because substituting old plants becomes more profitable if new plants are more energy efficient, iv) a long-term shift from more carbon-intensive BOF production to EAF production (process shift), 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 from coal-based BOF production to electricity-based EAF production turned out to be the most important factor for CO_2 reduction in the year 2020 with a share of 50% growing from 15% in 2010, while fuel shift was found to be only a minor option. In the longer perspective to 2020, technical progress for the BOF technology also accounts for an additional 25% of CO_2 reduction. In the conventional approach, the process shift is not explicitly modelled. Instead it is only implicitly captured via the substitution of energy carriers used in the steel industry.

In the first years of the tax increase up to 2010, the conventional approach shows higher emissions reductions compared to the base scenario. Apparently, the conventional approach implicitly inhibits a higher substitution potential than suggested by the new modelling approach. But in the long run, the process shift towards less carbon-intensive electric (EAF) steel production and cost-induced efficiency improvements in both processes in the new approach offer a much greater CO_2 reduction.

Figure 4: Effects of a CO_2 Tax – Percentage Deviations from the Base Scenarios

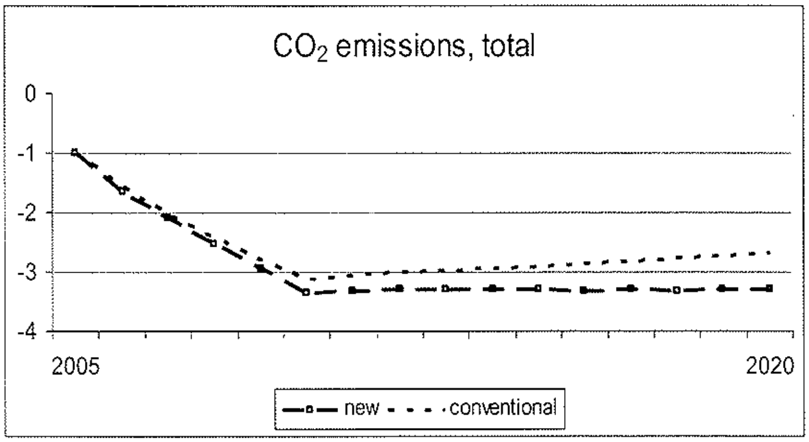


Figure 4 displays the impact of the CO_2 tax on total CO_2 emissions in the conventional and the new approach. The difference between the two approaches is very small at the beginning but then grows significantly. In 2020, the difference corresponds to 0.6 percentage points in terms of total CO_2 emissions. As the effect on GDP is more or less the same under both approaches, it can be concluded that economic costs for the same CO_2 reduction are lower in the new approach than in the conventional approach. The different development in Figure 3 compared to Figure 4 can be explained by the low share of the steel industry in overall emissions.

4. CONCLUSIONS

This paper presents an integrated top-down/bottom-up approach for energy-intensive German industries which has been designed to improve the representation of (energy saving) technological progress in the environmental-economic model PANTA RHEI. The existing top-down approach is enhanced by integrating a technology-based, detailed bottom-up approach taking into account capital vintage structure and process characteristics. The representation of different energy-intensive industries such as steel and paper is based on time series analysis. For two paper technologies, paper manufacturing based on primary fibres and recycled paper, 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. The same approach is applied to two paradigms of steel production, coal-based oxygen steel and electric steel production. These adaptations make it possible to simulate energy consumption and emissions in a more appropriate manner, especially regarding the technological and internal structural characteristics of a particular industrial sector. At the same time, the interdependencies of the considered sector with the overall economy are taken into account in a consistent way.

This new integrated bottom-up/top-down modelling approach allows a process-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 process lines, in particular if they are affected asymmetrically by policy intervention. Analyses of a CO_2 tax using the new modelling approach suggest that raising the costs of carbon/energy use would – at least for some industry sectors – 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 CO_2 emissions trading system, which was launched in 2005 for more than 11,000 installations of energy-intensive companies in the European Union. Evaluations of such policies also have to consider long investment cycles in energy-intensive industries which typically need time to adapt to new policies.

Simulation results from the new and the conventional approach also show that, in the conventional approach, price changes mainly induce different input structures in the respective sectors. In this respect, the new modelling approach can distinguish three different effects. First, intra-sector substitution between different process lines may take place. Second, this process shift leads to changes in the fuel mix and in the carbon intensity of production. Third, efficiency progress within the process lines can occur, which in turn depends on general economic conditions such as energy and other input prices. Concerning the time needed to adapt to higher CO_2 prices, the simulations of a CO_2 tax scenario with and without the new modelling approach are relevant for policy making and for policy evaluation. Our results suggest that, in energy and capital intensive industries, the conventional top-down approach overestimates the short-term possibilities of adapting to higher CO_2 and energy prices in the first years. By contrast, substitution possibilities in the first years are rather limited in the new approach. This results in higher costs of climate policy. In the long run, higher energy prices induce process shifts and technological change that will continue to reduce CO_2 emissions many years after the initial price impulse. Thus, emission reductions will be larger and cheaper than under the conventional approach. Therefore, our findings imply that compared to the conventional approach, the long-run cost-reducing effects stemming from modelling induced technological change outweigh the short-run cost-increasing effects from introducing limited intra-sector technological substitution in the new modelling approach.

In terms of mitigation costs, the findings suggest that the tax policy leads to almost the same small changes in GDP. Finally, since the new approach results in (significantly) higher emission reductions than the conventional approach, the estimated costs of the climate policy are lower.

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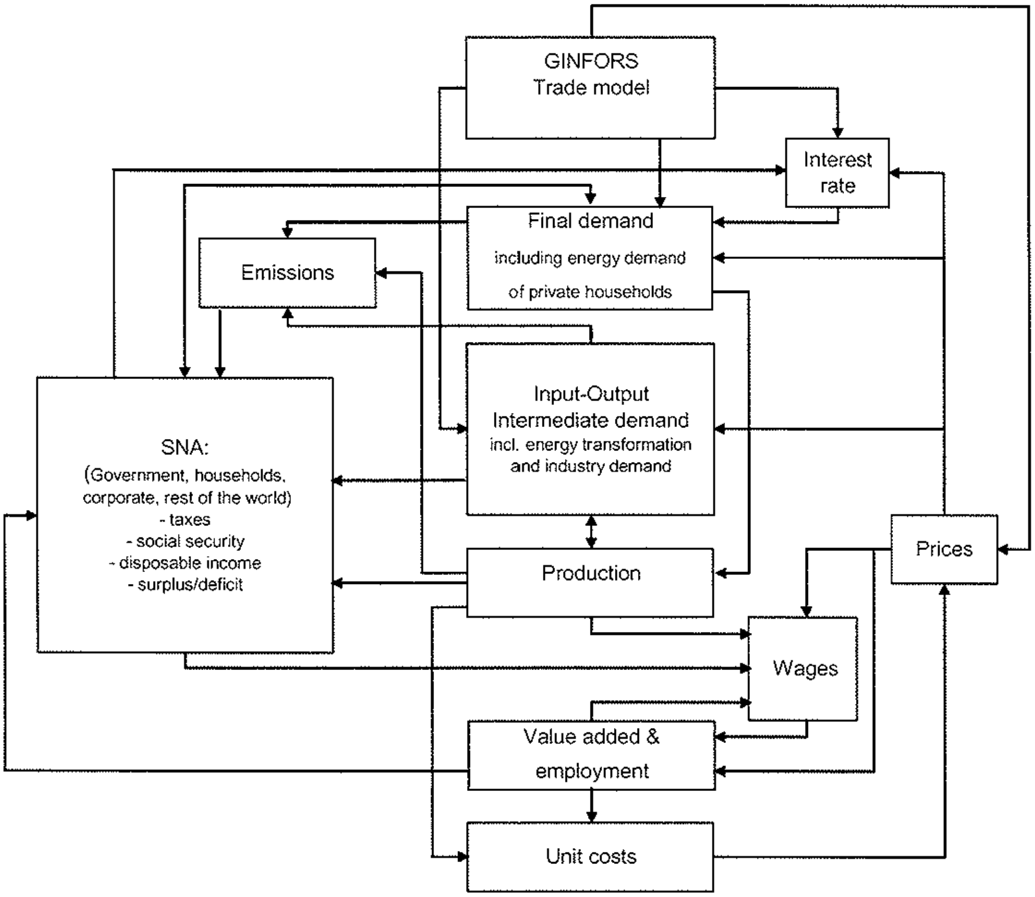
APPENDIX:

The Model PANTA RHEI

Figure 1: The Model Structure of PANTA RHEI



PANTA RHEI - the name means "all things flow" and stems from the Greek philosopher Heraclitus - is an environmentally extended version of the econometric simulation and forecasting model INFORGE (INterindustry FORecasting GErmany). Its performance is founded on the INFORUM philosophy (Almon, 1991), which maintains 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, 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, that are represented by the GINFORS model (Meyer et al., 2005).

In addition, PANTA RHEI contains a deeply disaggregated energy and air pollution module which distinguishes 30 energy carriers and their inputs in 121 production sectors and households as well as the related CO_2 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.

The parameters in all equations in PANTA RHEI are estimated econometrically using OLS. Of course, from a theoretical point of view, simultaneous equation estimation techniques would have to be applied. However, this is not feasible due to the large number of about 5000 estimated variables in PANTA RHEI. Model specification is based on conventional hypothesis testing (t-statistics, R^2). The model has been used in many studies to explain the structural effects of environmental policy measures, to forecast energy and carbon emissions and to explain the effects of abatement technologies on emissions and the economy (Lutz et al., 2005, Bach et al., 2002, Meyer, 2001, Lutz, 2000).

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