

Innovations and Emissions - A New Modelling Approach for the German Steel Industry*

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Abstract

Starting from the observation that innovation and technical progress are only portrayed superficially in the predominant environmental economic models, and that the assumption of perfect factor substitution does not correctly mirror actual production conditions in many production sectors, this paper presents a new modelling approach. In an integrated bottom-up/top-down approach based on the example of crude steel production in Germany, it is demonstrated how technical progress can be portrayed as process-related and policy-induced and, how the technology choice between limitational processes can be explicitly modelled and implemented in the econometric input-output model PANTA RHEI. The new modelling approach presented allows a process-specific analysis of the impacts of changed frame conditions, the effects of which on the choice of technology on the one hand and the technological progress on the other can be described endogenous to the model. These features are demonstrated using two policy simulations - a CO₂ tax and reducing the price of scrap.

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1 Problem description

The economic and ecological effects resulting within the frame of policy simulations in environmental-economic models are decisively influenced by the modelling of technological progress. For example, in models calculating the costs of climate protection, varying model results can be traced back to a large extent to varying assumptions about the development of technological progress in the baseline scenarios.¹ In these models, technological progress usually is represented through a trend variable, i. e., endogenous, policy-induced technological progress as described by Hicks (1932) is not represented.² Ceteris paribus taking policy-induced technological progress into consideration results in lower avoidance costs.³ Even in models which endogenise technical change, this occurs without linkages to the technologies which are responsible for the technological development. And yet in neoclassically characterised general equilibrium models, CES production functions are explicitly assumed for the individual branches and cost-minimising

¹ cf. Weyant, J. P.: Costs of Reducing Global Carbon Emissions. In: Journal of Economic Perspectives 7, (1993) S.27-46; Jaffe, A. B./Newell, R.G./Stavins, R. N.: Technological Change and the Environment, NBER Working Paper 7970 (2000).

² cf. Hicks, J.: The Theory of Wages, Macmillan, London (1932); Jaffe, A. B./Stavins, R. N.: Energy-efficiency investments and public policy. The Energy Journal (1994a), Vol. 15, No. 2, pp. 43-65. Exceptions to this are Carraro, C.: Climate Modelling and Policy Strategies. The Role of Technical Change and Uncertainty. Energy Economics 20 (1998), p. 463-471; Nordhaus, W.: Modelling Induced Innovation in Climate-Change Policy. Paper presented at the Workshop on Induced Technological Change and the Environment. IIASA, Laxenberg, Austria, June 1999; Goulder L. H./Mathai, K.: Optimal CO₂ Abatement in the Presence of Induced Technological Change, Journal of Environmental Economics and Management 39 (2000), p. 1-38; or Buonananno, P./Carraro, C./Galeotti, M.: Endogenous Induced Technical Change and the Costs of Kyoto, Working Paper Fondazione Eni Enrico Matteio (2001). See Löschel, A.: Technological Change in Economic Models of Environmental Policy: A Survey. ZEW Discussion Paper No. 01-62, Mannheim (2001), for a more recent survey of illustrating technological progress in environmental-economic models.

³ A different form of endogenous technological progress which is not examined here results from so-called learning-by-doing effects, which in normative work imply investments in reduction measures at an early stage (Van der Zwaan, B. C. C./Gerlagh, R./Klaassen, G./Schrattenholzer, L.: Endogenous technological change in climate change modelling. Energy Economics 24 (2002), p. 1-19; Goulder/Mathai: Optimal CO₂ Abatement in the Presence of Induced Technological Change, i.c., p 1-38).

factor demand functions derived from them⁴. The changes in factor price relations triggered by price or other instruments effect substitution processes here, but technical change is still exogenous. Attempts to achieve an endogenisation of technical change via technical knowledge, which is formed through accumulated research and development expenditure, fail because the impacts on the complex input structures are unknown. More recent empirical work examines at most what influence R&D activities, recorded for example through patents or licence fees, have on the long-term production function⁵. In the neoclassical approach, technical knowledge is entered into the substitutional production function alongside the other usual variables in the form of accumulated R&D spending⁶. The R&D activities can then be endogenised via the system of factor demand functions derived from the optimisation.

Further criticism with reference to the portrayal of technological change in general equilibrium models is sparked off by the postulated type of neoclassical production functions which imply unlimited factor substitution possibilities, which *ceteris paribus* implies an underestimation of the costs of climate policies since substitution possibilities are limited in real terms. In particular the large industrial "energy consumers" such as the electricity industry, steel production, producers of non-ferrous metals, the cement industry or paper manufacturing are better characterised by limited production relations of the "putty-clay" type in the factor substitution possibilities. The share of putty-clay technologies in total industrial production is estimated at 50 % to 70 % - even higher in energy-intensive sectors⁷. For

⁴ cf. Welsch, H.: Klimaschutz, Energiepolitik und Gesamtwirtschaft. Eine allgemeine Gleichgewichtsanalyse für die Europäische Union (1996); Böhringer, C.: Allgemeine Gleichgewichtsmodelle als Instrument der energie- und umweltpolitischen Analyse. Theoretische Grundlagen und empirische Anwendung. Frankfurt (1999).

⁵ cf. Jungmittag, A./Blind, K./Grupp, H.: Innovation, Standardisation and the Long-term Production Function. A Cointegration Analysis for Germany 1960-1996. *Zeitschrift für Wirtschafts- und Sozialwissenschaften (ZWS)* Vol. 119 (1999), p. 205-222.

⁶ cf. e. g. Goulder, L. H./Schneider, S.: Induced Technological Change, Crowding Out, and the Attractiveness of CO₂ Emissions Abatement, *Resource and Environmental Economics* 21(3-4) (1999), p. 211-253.

⁷ cf. Gilchrist, S./Williams, J.: Putty-Clay and Investment: A Business Cycle Analysis. *Journal of Political Economy* 108 (5) (2000), p. 928-960.

production functions of this type, a choice can be made when making investment decisions between different limitational processes, whereas the input structures of the existing plants can no longer be altered.

To summarise, it can be concluded that, first of all, innovation and technological change are only represented superficially in the predominant models⁸, and that, secondly, the assumption of complete factor substitution does not correctly reflect the actual production processes in many production sectors.⁹

A new modelling approach is presented in this article which takes up the challenge of these criticisms in two ways. In the form of an integrated bottom-up/top-down approach:

- technological change is portrayed as process-based and policy-induced and
- the choice of technology between limitational processes is modelled explicitly.

Based on the example of the steel industry in Germany, the following sections describe how the methodologically improved representation of technological change and technology choice is effected in the econometric input-output model PANTA RHEI. The production processes of crude steel production relevant for the model's implementation are outlined in brief - the oxygen steel process based on fossil energy sources and primary materials as well as the electric arc furnace steel process based on electricity and secondary materials (i.e. scrap) which is more efficient from a primary energy viewpoint. In order to demonstrate the features of

⁸ cf. Frohn, J. /Leuchtmann, U /Kräussl, R.: Fünf makroökonomische Modelle zur Erfassung der Wirkungen umweltpolitischer Maßnahmen - eine vergleichende Betrachtung. Band 7 der Schriftenreihe Beiträge zu den Umweltökonomischen Gesamtrechnungen des Statistischen Bundesamtes, Stuttgart (1998); Hemmelskamp, J.: Umweltpolitik und technischer Fortschritt, Schriftenreihe des Zentrums für Europäische Wirtschaftsforschung, Physica-Verlag, Heidelberg (1999); FIU: Der Einfluss von Energiesteuern und -abgaben zur Reduktion von Treibhausgasen auf Innovation und technischen Fortschritt - Clearing Studie. Essen (1996), p. 65.

⁹ One exception is Vögele, S.: Analyse von Energie und Umweltpolitiken mit DIOGENES: Ein gesamtwirtschaftliches Modell und seine Anwendung auf die Elektrizitätswirtschaft in Baden-Württemberg, Physica-Verlag, Heidelberg (2001). A detailed process-oriented modelling is presented for the electricity industry of Baden-Württemberg and integrated into a simple macroeconomic model.

the new modelling approach and the modelling correlations the effects of changing frame conditions are then simulated and compared with the results of conventional modelling. The policy simulations analysed consist, first of the gradual introduction of a CO₂ tax, which can also be interpreted as a national implementation in the frame of global CO₂ trading. In the second simulation there is a continuous decline in the price of scrap which is an important determinant of the choice of technology. Such a development could be triggered by measures aiming at an increase of material efficiency in the production of crude steel via an increase of the scrap supply - e.g. by closing material loops. The impact analyses focus on the impacts on the choice of technology and the technological change.

2 Presentation of the new modelling approach for the steel industry

The econometric input-output model PANTA RHEI implies - in contrast to general equilibrium models based on CES functions - limitationality of the input factors in the individual branches. The input coefficients are modelled as price-dependent which is then interpreted not as the result of substitution but of cost-induced technological progress which results in changes in the choice of process¹⁰. Linking this up to technologies has not yet been done. In order to make the real technological conditions of the individual processes visible in the form an integrated bottom-up/top-down approach, the underlying technologies are described explicitly in the new model presented here. To do so, among others, investments, production amounts, detailed input structures and the process-specific input demand of the respective best-practice technologies (*trajectories*)¹¹ are determined for the historical observation period (1980-1996) for the different process lines (*paradigms*)¹². 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 as a function of prices and other variables. The correlations found then serve as the basis for the future-oriented policy simulations in Section 3. Before the main elements of the concrete implementation in the model can be illustrated, to start with the technological correlations of crude steel production relevant for the modelling are explained.¹³

¹⁰ cf. Meyer, B./Bockermann, A./Ewerhart, G./Lutz, C.: Marktkonforme Umweltpolitik. Wirkungen auf Luftschadstoffemissionen, Wachstum und Struktur der Wirtschaft. Physica-Verlag, Heidelberg (1999).

¹¹ A detailed documentation of the procedure of data generation and the estimates conducted are found in Schleich et al. 1.c.

¹² cf. e.g. Dosi, G.: Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change. Research Policy 11 (1982), S. 147-162; Dosi, G.: The nature of the innovative process. In: Dosi, G. Freeman, C., Nelson, R., Silverberg, G., Soete, L. (eds.): Technical Change and Economic Theory. Pinter Publishers, London and New York (1988), p. 224.

¹³ The new modelling approach can only be presented for the most important correlations. A detailed description is found in Schleich et al.: Innovationen und Luftschadstoffemissionen a.a.O. For a description of the PANTA RHEI model used see, Meyer et al.: Marktkonforme Umweltpolitik. Wirkungen auf Luftschadstoffemissionen, Wachstum und Struktur der

2.1 Technological paradigms and technology development

The two most important paradigms on crude steel production in Germany are¹⁴

- *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), as well as
- *electric arc furnace steel production*, i. e. the process of producing secondary materials primarily in electric arc furnaces (to a lesser extent in induction furnaces) based on smelted down scrap¹⁵.

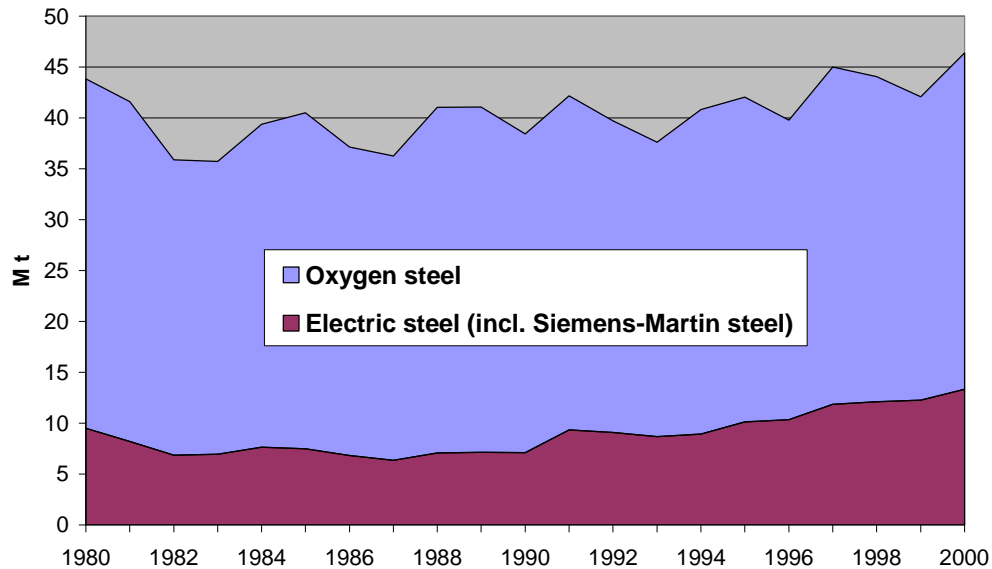
The subsequent procedural steps consist of *ladle metallurgy* to treat the liquid crude steel (adjustment of the material features and alloy composition) and the casting and rolling process which are excluded from the model-based examination made here. The production of electric arc furnace steel is more attractive from an energetic viewpoint, since it requires less than half the primary energy demand of the blast furnace-oxygen steel route. The development of the production amounts in Germany is shown in Figure 1 differentiated according to method.

Wirtschaft, I.c.; Lutz, C.: NO_x Emissions and the Use of Advanced Pollution Abatement Techniques in West Germany, in: Economic Systems Research, 12 (2000), p. 305–318.

¹⁴ Two other methods used to produce crude steel were not included in the detailed process illustration in the model due to their low significance in the period under observation: the basic Bessemer process has not been operative in Germany since the second half of the seventies and the open hearth process was phased out at the beginning of the eighties, and in the former German Democratic Republic, shortly after reunification.

¹⁵ Scrap is also used (in small amounts) in oxygen steel production to regulate the temperature of the exothermic conversion process in the converter. Primary materials can also be used when producing electric arc furnace steel. One example, which is practised at only one location in Germany, is the *direct reduction* using natural gas of iron ore to *sponge iron* (DRI direct reduced iron) which is used in the electric arc furnace steel process.

Figure 1: Process lines of crude steel production



Source: Wirtschaftsvereinigung Stahl / VDEH, div. Jahrgänge 1.c.

Whereas the production of oxygen steel fluctuated around 30 M t/a over the last twenty years, the production of electric arc furnace steel has increased continuously from around 6.5 M t/a in 1980 to over 13 M t/a in the meantime. The technical development in the steel industry was characterised in the past by a 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 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 29¹⁶.

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 reducing agent in

¹⁶ See WV Stahl/VDEH (Wirtschaftsvereinigung Stahl/Verein Deutscher Eisenhüttenleute; Hrsg.): Statistisches Jahrbuch der Stahlindustrie, diverse Jahrgänge. Verlag Stahleisen Düsseldorf; VDEH (Verein Deutscher Eisenhüttenleute): personal communication 2001 and 2002.

iron making - e. g. by partly substituting coke with injected pit coal, fuel oil or scrap plastics - 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 works¹⁷.

2.2 Choice of technology

The choice of technology takes place in the new modelling approach via the new investments in both process lines of crude steel production. The investments in turn are estimated as a function of the paradigm-specific outputs, the existing production capacities, relative input prices, and of the real interest rate.

Firstly, the crude steel production is econometrically estimated from the gross output of the steel industry which is explained in the model PANTA RHEI by the demand of the 58 branches. The share of electric arc furnace steel production in total production can then be estimated as a function of the relation of the price of electricity and coke as well as the relative capacity share of both process lines. Splitting the production is then done proportionally to the capacity development for electric arc furnace steel and oxygen steel and the share of electric arc furnace steel in crude steel production decreases with an increase of the relative energy input

¹⁷ A comprehensive energetic evaluation of the oxygen steel production and its CO₂ emissions is given by Aichinger, H. M./Mülheims, K./Lüngen, H. B./Schierloh, U./Stricker, K. P.: Ganzheitliche Bewertung und Potentiale der CO₂-Emission bei der Hochofen-Konverter-Route. *Stahl und Eisen* 121 (2001), Nr. 5, p. 59-65. A detailed examination of the electrical energy consumption of electric arc furnace steel production (arc furnaces) is found in Köhle, S.: Einflussgrößen des elektrischen Energieverbrauchs und des Elektrodenverbrauchs von Lichtbogenöfen. *Stahl und Eisen* 112 (1992) Nr. 11, p. 59-67, and Köhle, S.: Improvements in EAF operating practices over the last decade. *Electric Furnace Conference Proceedings*. Iron & Steel Society, Warrendale, PA (1999).

prices of the two paradigms¹⁸. The amounts of electric arc furnace steel and oxygen steel produced are then given by definition from the total production of crude steel.

The real gross investments of electric arc furnace steel technology can be estimated as a function of the real rate of interest, the ratio of the scrap price to the price of ore as well as the relation of the demand for electric arc furnace steel and production capacity for electric arc furnace steel. The real gross investments in oxygen steel technology are determined in the model by the ratio of the demand for oxygen steel to production capacity. This modelling step makes it possible to describe the changes in production structure and thus the input consumption of crude steel production resulting from a change in the process lines used via the choice of technology. In the next step, the development of technological change is regarded which is reflected in a change of the specific input consumption.

2.3 Development of 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 correlation between the development over time of the best-practice energy consumption of the electric or oxygen steel production respectively and a number of price variables as well as the R&D expenditure of the steel industry and the mechanical and electrical engineering sectors is econometrically estimated. The hypothesis behind including the R&D spending of the mechanical and electrical engineering sectors is that the producers of investment goods target their research efforts within the scope of the

¹⁸ In a regression of the share of electric arc furnace steel in total crude steel production for the period 1970 to 1994 for the old federal states, Schleich, J.: The impact of fuel prices on energy intensity in the West German manufacturing sector. Paper presented at the International Summer School on Economics, Innovation, Technological Progress, and Environmental Policy, Seeon, September 2001, also concludes that the price of electricity has a significant negative influence on the share of electric arc furnace steel.

given respective paradigm to offering where possible those investment goods which minimise the production costs in the demand sectors¹⁹.

In the concrete implementation of the model the best-practice technology can be estimated with regard to the electricity consumption of electric arc furnace steel production through the ratio of electricity price to output price in the current and previous three periods. The best-practice technology with regard to the consumption of fossil fuels in oxygen steel production is determined using the interest rate in real terms, the ratio of coke price and output price for crude steel as well as the R&D spending of the mechanical engineering sector.

In both cases, 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 oxygen 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 - 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". The individual influence of R&D spending might show statistical significance over a longer observation period. The results are however consistent with the hypothesis that the companies are to be regarded as "supplier-dominated firms" with regard to the characterisation of technical change. The innovation process mainly consists of the diffusion of best-practice capital goods and takes place primarily through the technology choice of the investment decision²⁰.

¹⁹ See Erdmann, G.: Elemente einer evolutorischen Innovationstheorie. Tübingen (1993), p. 69ff.. This assumption is supported, for example, by the results of the empirical work of Grupp, H.: Umweltfreundliche Innovation durch Preissignale oder Regulation? Eine empirische Analyse für Deutschland. Jahrbücher für Nationalökonomie und Statistik (1999) Vol. 219/5+6, the development of the relative prices has a significant influence on patent applications of resource and energy conservation.

²⁰ See Dosi: The nature of the innovative process, l.c., p. 232.

The extrapolation of the input structures is explained using the example of the electricity consumption of electric arc furnace steel production. The average specific electricity consumption taken over all the investment vintages is determined - in accordance with the putty-clay approach - as a weighted average of the coefficients of the preceding year and the best-practice coefficients with the capital stock of the previous year and the current investments as weights²¹. The input coefficient for the total electricity use in the steel industry is then illustrated using the input coefficients for the electric arc furnace steel method as well as a constant term which covers the share of electricity consumption in the steel sector not used for electric arc furnace steel production.

²¹ When modelling the investment decision it is implicitly assumed that if a putty-clay technology is present, the companies are not far behind the best-practice technology in their choice of technology within the scope of their investment decision. See Silverberg, G.: Modelling economic dynamics and technical change: Mathematical approaches to self-organisation and evolution. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (eds.): Technical Change and Economic Theory. Pinter Publishers, London and New York (1988).

3 Policy simulations

In the following, the results of two simulation calculations for the steel industry are presented which demonstrate the features of the new modelling approach and its correlations. In order to examine the impacts of price instruments, to start with a tax policy measure was simulated. Accordingly, from 2005 a CO₂ tax is introduced in progressive stages. In its ecological impact, this can be interpreted as a national implementation in the frame of global CO₂ trade with a progressive tightening of the emission target. In the second simulation, a continuous decrease in the price of scrap is simulated which is one important determinant of the choice of technology. Such a development could be triggered for example by regulations aiming at closing material loops. The increased supply of scrap then results *ceteris paribus* in an extension of scrap utilisation via the lower scrap price and thus in an improvement of the material efficiency in crude steel production.

3.1 CO₂ tax

In the first policy simulation, a CO₂ tax is introduced from 2005 which increases from 5 € to 25 € per ton CO₂ in 2010. The CO₂ tax is levied on all fossil energy supplies according to their carbon content so that the use of coal is much more heavily taxed than oil or gas. Because the tax burden is at least partly passed on, electricity will also become more expensive. It must be considered that electricity, which is obtained from CO₂-free energy sources such as nuclear energy or renewables, is still burdened although not affected by the CO₂ tax. Since electricity is today already burdened to a greater extent than coal due to the electricity tax, coal is more strongly affected by the CO₂ tax than electricity. Figure 2 shows the economic and ecological impacts of this tax on the steel industry as percentage deviations from the reference development. In comparison to this, the CO₂ tax triggers a clear shift of production from oxygen steel to the economically comparatively more attractive electric arc furnace steel. This shift is also accompanied by a clear increase of investments in the electric arc furnace steel

process. Over time, the capacities thus also shift in the direction of electric arc furnace steel. It can be inferred from Figure 3 that there is a slight decrease in steel production and investments in general as a result of the CO₂ tax.

With reference to the innovation impulses triggered by the CO₂ tax, it can be seen that the best-practice electric arc furnace steel technology develops somewhat faster than in the reference scenario. On the one hand, innovation pressure grows due to the increased electricity prices. On the other hand, the simultaneously growing output price for steel dampens this development because the electric arc furnace steel producers orient their innovation efforts on the ratio of electricity price and output price in accordance with the empirically verified cost pressure hypothesis²². Overall, the best-practice technology gains by around 2 % up to 2010. The specific electricity consumption of electric arc furnace steel production does not fall as steeply since the stock is composed of lower efficiency plants.

The innovation effects are much more obvious for the oxygen steel technology. The comparatively greater burdening of the energy source coal increases the innovation pressure which results in a significant improvement of the best-practice technology by approx. 6 % up to 2010. Since old plants are closed down faster than in the reference development, the specific consumption of fossil energy sources also drops by the same order of magnitude (and thus faster than is the case for electric arc furnace steel).

Finally, the CO₂ tax leads to a clear reduction of the CO₂ emissions which are to be allocated to steel production either directly (oxygen steel) or indirectly via electricity generation (electric arc furnace steel).²³ As shown in Figures 2 and 3, on the one hand, there is an increase in the CO₂ emissions from electricity generation for electric arc furnace steel. The emission-reducing effect from the improved energy efficiency is therefore exceeded by the emission-increasing effect of the

²² See section 2.3.

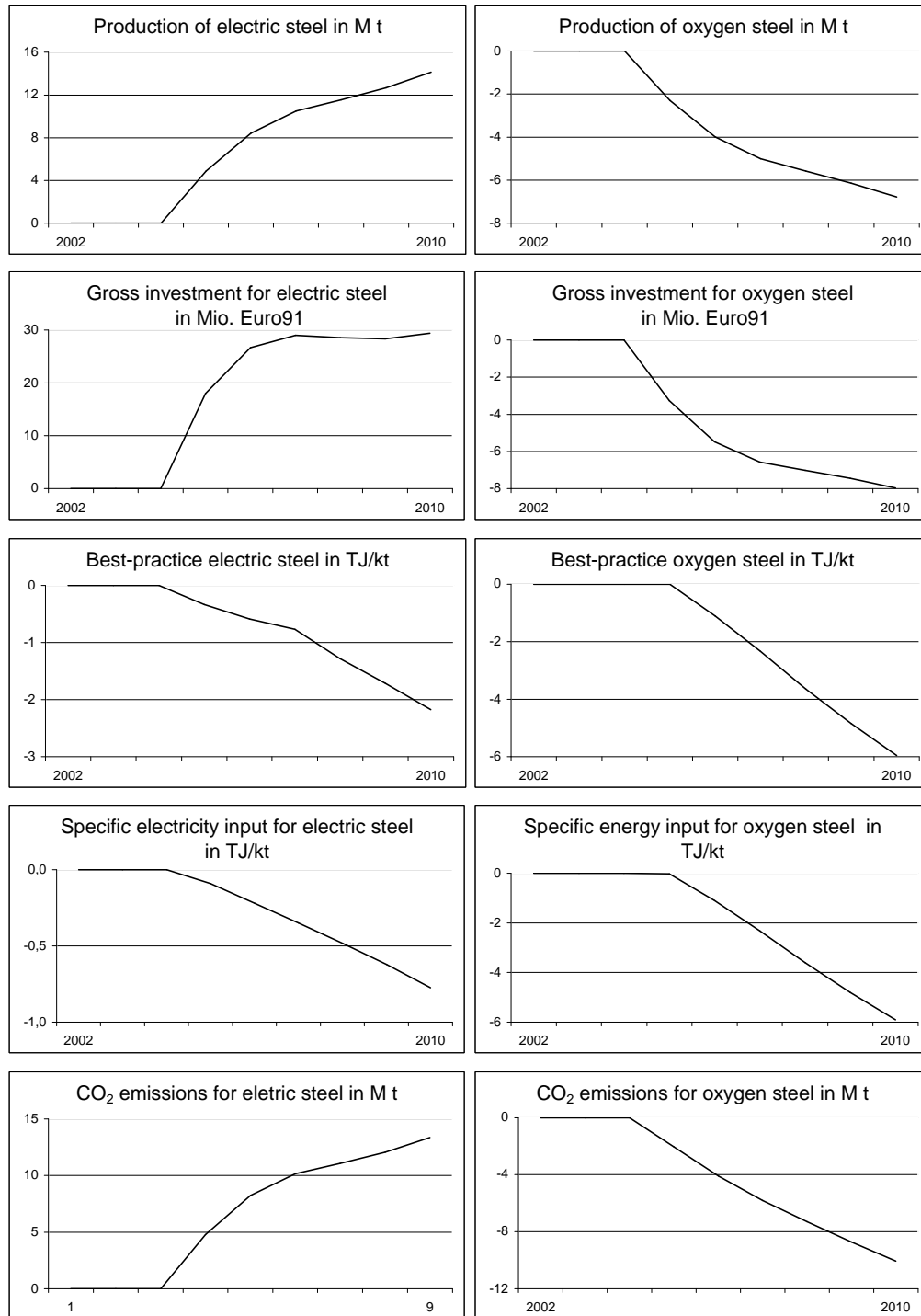
²³ For the calculations it was assumed that the electricity generation for electric arc furnace steel has the same CO₂ intensity as the average electricity generation in Germany.

risen demand for electric arc furnace steel. On the other hand, there is a drop in the direct CO₂ emissions from oxygen steel production. This is due to the drop in oxygen steel production and thus the use of coke. Also, there is a decrease in the specific energy demand of the best-practice technologies and the stock. Taken altogether, the emission reductions from oxygen steel production outweigh the emission increases from electric arc furnace steel production. On balance, therefore, there is a clear reduction of CO₂ emissions from the steel industry of over 3 M t in 2010 compared with the reference development.

The effects differ in comparison to conventional modelling without technology choice and process-specific endogenous technical progress as follows: in the new model, the increase of the price of steel and the drop in steel production are more pronounced. Much more significant is the drop in CO₂ emissions of the steel industry which is almost double that in conventional modelling. Conventional modelling obviously overestimates the substitution possibilities between the energy sources and as a result underestimates the economic consequences.²⁴ The explicit modelling of the technologies shows that the CO₂ tax accelerates the technical progress in the energy consumption of oxygen steel production in particular and also - albeit weaker - the technical progress in the energy consumption of electric arc furnace steel production. Compared to conventional models, the much lower CO₂ emissions in the new modelling approach imply that the emission-reducing effect of the additional technical progress more than compensates for the emission-increasing effect of limited substitutability. The results also show that the tax rate necessary to achieve the predetermined environmental target is much lower under the new model.

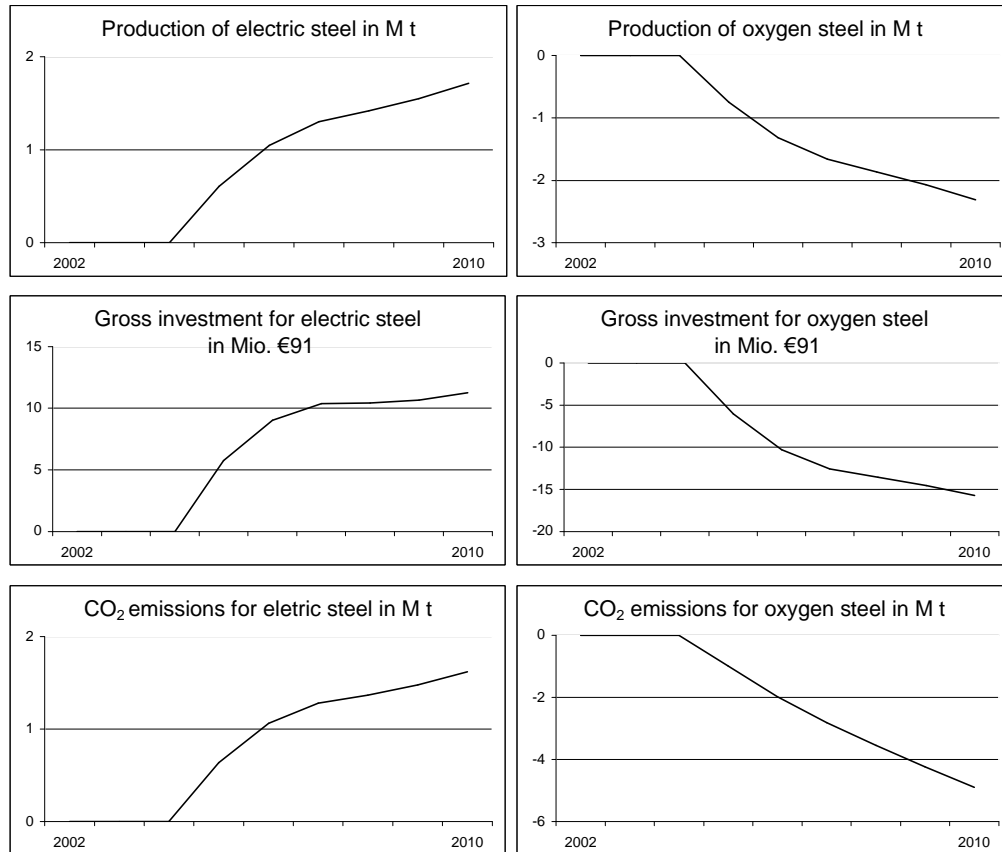
²⁴ In conventional modelling the energy use in the steel industry was modelled in two stages. First, the input coefficient for the total energy use was determined using the relative price of energy (weighted average price of the energy mix using the output price). Second, the substitution possibilities between energy sources were portrayed as a function of the relative prices. For more detail, see Meyer et al.: Marktkonforme Umweltpolitik. Wirkungen auf Luftschadstoffemissionen, Wachstum und Struktur der Wirtschaft, I.c., p. 40.

Figure 2: Effects of the CO₂ tax –
Deviations from the basic solution in %



Source: own calculations

Figure 3: Effects of the CO₂ tax –
Absolute deviations from the basic solution



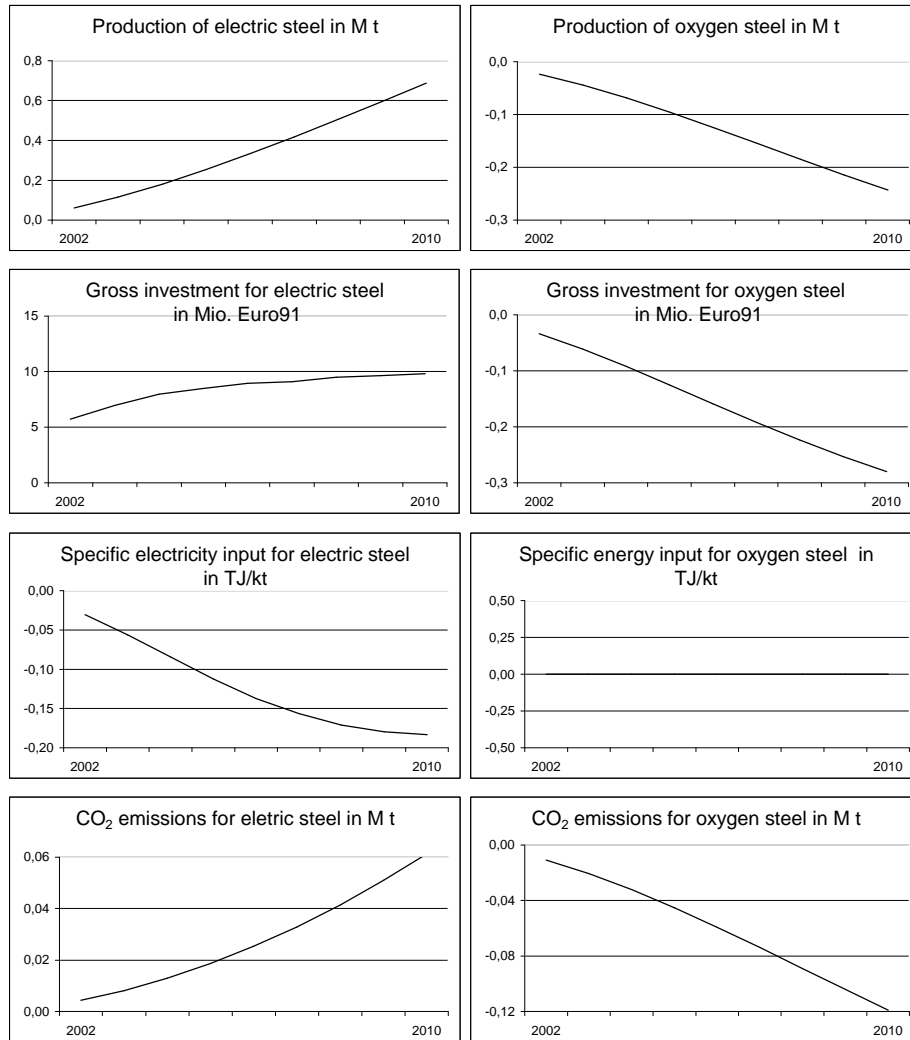
Source: own calculations

3.2 Lowering the price of scrap

In the second policy simulation the price of scrap, which is an important determinant of the technology choice in the steel industry, is reduced between 2002 and 2010 by 3 % annually in comparison to the initial year. Lowering the scrap price results in a shift of investments, production and capacities in the direction of electric arc furnace steel (see Figure 4). The production of crude steel however remains at about the original level. The increased investments in electric arc furnace steel result in an accelerated diffusion of the best-practice technology so that the average energy efficiency of the stock is improved. In contrast to the simulation with the CO₂ tax, there are no additional effects with reference to the technical progress since the input prices of the energy sources, which are decisive for the development of the energy efficiency of the best-practice technologies, remain unchanged.

Overall the simulated fall in the price of scrap leads to a slight reduction in the CO₂ emissions of the steel industry. It is true that the indirect emissions from electricity generation increase as a result of the increased electric arc furnace steel production, but these are compensated by the drop in direct CO₂ emissions from coke use resulting from decreased oxygen steel production (see Figure 4).

Figure 4: Effects of lowering the scrap price – deviations from the basic solution in %



Source: own calculations

4 Summary and outlook

Starting from the observation that innovation and technical progress are only portrayed superficially in the predominant environmental economic models, and that the assumption of perfect factor substitution does not correctly mirror actual production conditions in many production sectors, this paper presents a new modelling approach. In an integrated bottom-up/top-down approach based on the example of crude steel production in Germany, it is demonstrated how technical progress can be portrayed as process-related and policy-induced and, how the technology choice between limitational processes can be explicitly modelled and implemented in the econometric input-output model PANTA RHEI. The actual technological conditions are explicitly portrayed in the form of the most important input coefficients for both main production lines of electric arc furnace steel and oxygen steel. The paradigm-specific investments, i.e. the technology choice and the development of technical progress can then be econometrically estimated from this in the model as a function of prices and other variables. The realisation of technical progress occurs in the model primarily through investments in new best-practice technologies' plants and equipment.

Using two policy simulations, the features of the new modelling approach and its correlations are then demonstrated. In the first simulation, the progressive introduction of a CO₂ tax between 2005 and 2010, which has a greater comparative effect on the energy input for oxygen steel production, i.e. coal, than the energy input for producing electric arc furnace steel, i.e. electricity, results in a clear shift of production, capacity and investment shares in favour of electric arc furnace steel. In the electric arc furnace steel sector, the breakthrough of the best-practice technology is accelerated due to the investments in new plants and equipment. In addition, the slightly risen

electricity-output price ratio increases the innovation pressure so that technical progress speeds up minimally. Both effects reduce the specific energy consumption of the electric arc furnace steel capital stock. In the oxygen steel sector, old plants are closed down faster and the considerable rise in the cost pressure results in a significant improvement of the best-practice energy consumption. Both effects bring about a reduction of the specific energy consumption in the oxygen steel capital stock. Overall, the CO₂ tax causes a clear reduction of the CO₂ emissions directly or indirectly attributable to the steel industry by approx. 3 M t.

A comparison of the simulation results of the new modelling approach with the results of conventional modelling shows that technical progress and the avoided CO₂ emissions are clearly underestimated by the old models due to their overestimation of the substitution possibilities between energy sources. The emission-reducing effect of the additional technological progress thus clearly exceeds the emission-increasing effect of limited substitutability. The results also indicate that the tax rate applied to achieve the predetermined environmental target (or the price appearing for tradable emission permits) is much lower in the new modelling.

The second simulation examines the impacts of a strategy to increase material efficiency which causes a continuous drop in the price of scrap. The result is an increase in the production, investment and capacity of electric arc furnace steel to the detriment of oxygen steel. Since the increased electric arc furnace steel production which raises electricity consumption is more or less balanced by the accelerated breakthrough of more energy-efficient electric arc furnace steel technologies via investments in new equipment, the electricity consumption and the associated indirect CO₂ emissions of the steel industry hardly change. The drop in the production of oxygen steel and the associated direct CO₂ emissions then

result in a decrease of the overall CO₂ emissions of the steel industry. In comparison to the CO₂ tax, lowering the price of scrap does not have any direct effects on technological progress since the input prices of energy sources remain more or less unchanged.

The new modelling approach presented makes it possible to do a process-specific analysis of the impacts of altered frame conditions whose effects on the choice of technology on the one hand and on technological progress on the other can be described endogenous to the model. Diverse extensions are conceivable for future applications. The illustration of the actual technological conditions could be further improved for modelling the steel industry. For example, the assumption of perfect substitutability of both types of steel 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.²⁵ Taking into account the actual limited substitutability of both types of steel for some applications makes it possible to analyse what effects on the choice of technology and technical progress result from demand-induced structural change which can, in turn, be policy induced. 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. Finally, other simulations are conceivable to analyse for example the exploitation of time slots resulting from investment cycles or the influence of soft context factors such as, e.g. policy credibility²⁶.

²⁵ 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 on the steel markets in conjunction with the availability of scrap and energy. See Ameling, D./Aichinger, H. M.: Beitrag von Wirtschaft und Stahlindustrie zur Minderung klimawirksamer Emissionen in Deutschland im Kontext der Klimavorsorgepolitik. *Stahl und Eisen* 121 (2001), No. 7, p. 61-70.

²⁶ See Erdmann, G.: Zeitfenster beachten. Möglichkeiten der Ökologisierung der regulären Innovationstätigkeit. In: *Ökologisches Wirtschaften*. H. 2 (1999).