NO_x Emissions and the Use of Advanced Pollution Abatement Techniques in West Germany

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I. Introduction

Nitrogen oxides (NO_x) are made responsible together with sulphur dioxide (SO_2) for acid rain and contribute indirectly - creating tropospheric ozone together with volatile organic compounds (VOC) and carbon monoxide (CO) - to photosmog and the greenhouse effect. In 1988 twelve European countries including West Germany signed on reducing NO_x emissions by 30 % up to the year 1998. The advisory board for environmental issues of the German government even proposed in 1996 a cut of national NO_x emissions of 80 % against the 1990 level until 2005. As over 99 % of the emissions are energy-related, far-reaching targets to reduce emissions can be attained by higher energy efficiency, structural change, substitution of energy carriers and, in the first place, by the use of pollution abatement techniques (end-of-pipe technologies).

The environmentally enlarged econometric input-output (IO) model PANTA RHEI II - for a former version see Meyer/Ewerhart (1997) - offers the possibility to model all these determinants of pollution development simultaneously for West Germany. The first three of these determinants are described in Meyer/Bockermann/Ewerhart/Lutz (1997 and 1998a). This paper concentrates on the use of pollution abatement techniques and the necessary steps for their integration - as different sets of emission factors - into the model structure. So the aim of the paper is threefold:

- Firstly, it shows how NO_x emissions like any other energy-related air pollutants can be calculated in an environmentally enlarged IO framework.
- Secondly, the future development of the NO_x emission factors, emissions in kg per petajoule (PJ) of used energy, representing different abatement techniques is determined. Therefore technical data out of other classification schemes and expert knowledge were transformed into the IO system. Two different sets of emission factors are described up to the year 2005, a business-as-usual (BaU) and a BAT scenario, in which the best available technologies are used in every burning process. If present control-and-command oriented environmental policy continues, the development of the emission factors is well foreseeable in the BaU case. Experts have as well good knowledge about best available end-of-pipe technologies for the next years.

If environmental policy plans to reduce emissions by market instruments, actual emission factors will develop - the question is how? - over time between the factors in the BaU and the BAT case. For the determination of these time paths a routine is developed.

– Finally, simulation runs show the economic, environmental and technological effects of policy strategies to reduce NO_x emissions. The simulation runs offer as well the opportunity to check the plausibility and the importance of the adjustment routines for the results in sensitivity analyses.

II. Calculating NO_x emissions

PANTA RHEI II is an environmentally extended version of the fully integrated 58 sector dynamic model INFORGE. It combines an econometric IO model with an endogenized account of physical air emission data, describing economy, energy flows and air pollution for West Germany.[1] The data base are time series for all variables from at least 1978 to 1990 and for some macro variables until 1994. The five energy sectors of the IO table are split into 29 energy carriers according to table 1. So the IO matrix is enlarged by additional rows (see Bockermann 1995).

The energy input coefficients in real terms EKR_{kj} of every energy carrier k into sector j are estimated in the model. Their development depends on relative prices - price *pgae* of energy carrier k and producer price pg of sector j - and on time trends (see equation 1). For *electricity* sectoral capital stocks knr_j play an important role as well. Only the energy inputs in the sectors *electric power* (3) and *iron and steel* (16) are modeled in a two stage approach. On the first stage the complete energy input is calculated and on the second stage shares for different energy carriers are estimated.

(1) $$EKR_{kj}(t) = f\left(\frac{pgae_k(t)}{pg_j(t)}, t, knr_j(t), ..\right) \qquad (k = 1,..,29;\ j = 1,2,4,..,15,17,..,58).$$

Using constant factors KF_{kj} emission-relevant energy inputs in physical terms (Petajoule) EE_{kj} can be calculated multiplying these energy input coefficients EKR_{kj} with real gross production xg of sector j:

(2) $$EE_{kj}(t) = KF_{kj} \cdot xg_j(t) \cdot EKR_{kj}(t) \qquad (k = 1,..,29;\ j = 1,..,58).$$

For private households ($j = 60$) emission-relevant energy consumption is calculated in a similiar way with price dependent consumption shares. Then energy-related NO_x emissions ENO_{kj} for 29 energy carriers and 58 sectors plus private households are the product of emission-relevant energy inputs EE_{kj} and emission factors FNO_{kj} describing emissions in tons per petajoule of used energy carriers:

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[1] Results of a new version PANTA RHEI III for Germany as a whole will be available in summer (Meyer/Bockermann/Ewerhart/Lutz 1998b).

(3) $$ENO_{kj}(t) = FNO_{kj}(t) \cdot EE_{kj}(t)$$ (k = 1,..,29; j = 1,..,58, 60).

Table 1

Commodity groups and energy carriers in PANTA RHEI

	commodity group *j*		energy carrier *k*
3	electric power, steam, hot water	1	electricity
		2	heating over distance
4	gas	3	distribution of gas
		4	sewer gas, biological gas
6	coal, products of coal mining	5	hard coal
		6	hard coal coke
		7	hard coal briquettes etc.
		8	crude brown coal
		9	powdery coal and dry coal
		10	hard brown coal
		11	brown coal briquettes and coke
		12	pit gas, firedamp
		13	coke-oven gas
8	crude petroleum, natural gas	14	crude oil
		15	natural gas
10	refined petroleum products	16	gasoline
		17	diesel oil
		18	kerosine
		19	light fuel oil
		20	heavy fuel oil
		21	liquid gas
		22	refinery gas
		23	crude petrol and other light oils
		24	greases
		25	other petroleum products
9	chemical products	26	nuclear fuels
		27	other fuels (firewood etc.)
16	iron and steel	28	blast-furnace gas

	29 hydraulic power

III. Specifying NO_x emission factors in the BaU and BAT simulations

Whereas CO_2 emission factors are constant over time, some NO_x emission factors FNO_{kj} have changed considerably in the last years (see Lutz 1995). For the next years their development strongly depends on environmental policy. In the case of a BaU policy, continuing the command-and-control approach of the last decades, emission factors will especially be reduced for the use of gasoline and diesel oil. The penetration of the car market with catalytic converters and better burning technologies for diesel engines will cut emission factors between 1990 and 2005 by 35 % for diesel lorries, 45% for diesel cars and 80 % for passenger cars with spark-ignition engines (gasoline). For the use of coal in power plants no more reductions are expected after 1994. Emission factors for the use of light and heavy fuel oil in other sectors will go down slightly. Gas and liquid gas will be burnt much cleaner in the future. The second column of table 2 gives an overview of these technical developments.

Further reductions of emissions per unit of used energy are possible. Taking into account long periods of research and development and of the market penetration of new techniques - as for example heated catalytic converters - the best available technologies up to the year 2005 are known today in principle. So the invention of new techniques is neglected. Just the diffusion of currently known technologies is regarded.

Accepting this minor restriction the third column of table 2 gives the potentials to reduce NO_x emission factors until the year 2005 in comparison to 1990. Especially in car traffic, but as well for most other energy carriers huge reductions are possible. Only coal power plants offer smaller reduction potentials, as most of them already have been equipped with modern Selective Catalytic Reduction (SCR) installations between 1986 and 1990. In comparison to the BaU case, most emission factors can be at least halved once again.

Table 2

Relative change of NO_X emission factors against 1990 until 2005

energy carrier	BaU	BAT
diesel oil	- 35 to - 40 %	- 60 %
gasoline	- 80 %	- 90 %
kerosine	+ 20 %	- 20 %
coal	- 6 %	- 25 %
fuel oil	- 10 to - 20 %	- 50 to -70 %
gas	- 20 to - 50 %	- 75 %

Source: Umweltbundesamt 1996, Lutz 1997.

Putting these two sets of emission factors FNO_{kj} into equation 3, emissions for the years up to 2005 can be calculated. For comparison, in a third version the pollution abatement techniques, that is the emission factors, of 1990 are left unchanged. Table 3 shows the big differences between these three scenarios.

Table 3

NO_x emissions in kt assuming different sets of abatement techniques

emission factors	NO_x in 1990	NO_x in 2000	NO_x in 2005
abatement techniques of 1990	2393	2480	2621
BaU	2393	1606	1516
BAT	2393	800	846

Assuming that technology keeps constant between 1990 and 2005, NO_x emissions will grow by almost 10 % against the level of 1990. In the BaU case present environmental command-and-control policy is continued. Emissions will be reduced by more than one third of the level of 1990. If the best available technologies are used in every burning process, emissions can be halved again. The reduction target of the goverment until 1998 will already be reached in the BaU simulation. But far-reaching targets requested by scientists and environmental groups are not even completely accomplished in the BAT simulation. So environmental policy should better not only rely on often very expensive abatement installations, but induce by economic incentives as well a higher energy efficiency, substitution of energy carriers and structural change.

IV. Specifying NO_x emission factors in NO_x tax simulations

In economic theory mostly economic incentives such as taxes or pollution rights are prefered to cut emissions. At least concerning national reduction targets a command-and-control policy is considered to be less efficient and thus more expensive.[2] The important question to be answered here is, how the emission factors will change, when the price for the emission of NO_x is raised. So the price dependency of the use of different pollution abatement techniques has to be clarified. An econometric estimation of the emission factors is impossible. There is neither enough sectoral data on investment for the past nor does the estimation of technical developments started by regulations seem to make much sense.

The OECD (1994) tried in another way to specify emission factors in their GREEN model. They assumed a unified exponential adjustment. Best available technologies will

[2] For a distinguished comparison of the two approaches see for example Cropper/Oates (1992).

be reached in the year 2050. The rate of autonomous improvement in emission factors was calibrated in such a way, that emissions were 20% lower in the year 2000 than in 1985. This is obviously a simple assumption to calculate emissions in a global model, but specific information cannot be used and - even worse - technological change is not price dependent and remains exogenous.

Instead of this, all the information about different energy carriers and sectors is used to calculate technological adjustment in PANTA RHEI II. As European law prevents technical standards to decline, emission factors will develop between the BaU and the BAT level. Which time path - for example *T 1*, *T 2* or *T 3* - will be realized after introducing a every year linearly growing NO_x tax rate in t_0, depends on the tax rate, its development over time and specific determinants for every emission factor FNO_{kj} (see Figure 1).

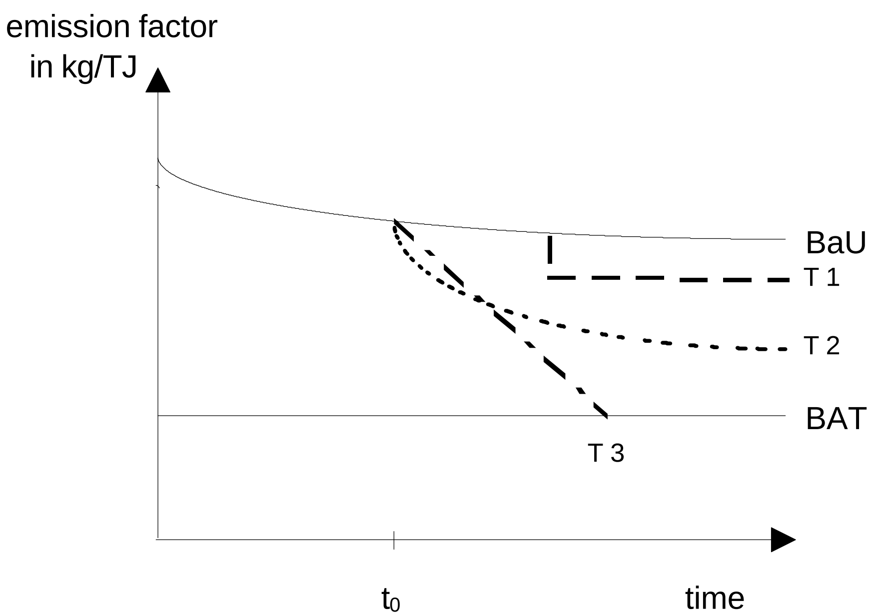

Figure 1: Possible time paths of an emission factor under an emission tax

It is plausible to assume that the tax rate in relation to the energy costs will play an important role for the development of NO_x emission factors. Technical components should be considered as well. Power plants, often running for 40 years or more, offer other reduction potentials than passenger cars that are substituted after about ten to twelve years. Another important point is the extent of the installation of the BAT. If already sophisticated abatement techniques are installed, further reduction will be very expensive. Finally, the renewal of sectoral capital stocks should be considered. Some sectors with high rates of investment will adapt more easily to new technologies than others. Only for gasoline, diesel oil and kerosine the technological standards of cars and airplanes are supposed to be independent of sectoral variables. Equation 4 shows the technological adjustment structure in general.

Except the specification of the technological factors all other variables are calculated in the model PANTA RHEI. A technological factor tn_{kj} of 1.0 means that, if for example costs for the emissions reach 10 % of the energy costs of energy carrier *k* in sector *j* and the capital stock of sector *j* is renewed every ten years, the emission factor FNO_{kj} will decline against the year before by 1 % of its potential decline in comparison to the BAT. In the following simulations these factors are set at a small level (see Lutz 1998 for a sensitivity analysis of the technological factors tn_{kj}).

(4) $$FNO_{kj}(t+1) = FNO_{kj}(t)\cdot(1 - tn_{kj}\cdot\frac{KNO_{kj}(t)}{ENN_{kj}(t)}\cdot\frac{FNO_{kj}(t) - FNM_{kj}}{FNO_{kj}(t)}\cdot\frac{iar_j(t) + ibr_j(t)}{knr_j(t)})$$

$(tn_{kj} > 0;\ k = 1,..,29;\ j = 1,..,58, 60).$

FNO_{kj}: NO_x emission factors
KNO_{kj}: NO_x tax burden on the use of energy carrier *k* in sector *j*
ENN_{kj}: energy inputs in monetary terms
FNM_{kj}: NO_x emission factors of the best available technologies
tn_{kj}: technological factors
iar_j: equipment investment in sector *j*
ibr_j: construction investment in sector *j*
knr_j: capital stock of sector *j*

V. Modeling a NO_x tax

A tax on NO_x emissions can be integrated in the same way into PANTA RHEI II as for example a CO_2 tax (see Lutz 1998, Meyer/Ewerhart 1997 and Meyer/Bockermann/ Ewerhart/Lutz 1998a): All producers and importers of fossil energy have to pay for the emissions combined to the use of energy. This raises the prices of all energy carriers according to their emission factors. Relative prices in the economy change, inducing a change in volumes as well. The government uses the tax revenues to reduce the gross wages in all sectors by funding employers social security contributions. Thus labour inputs are becoming cheaper, whereas energy inputs more expensive. Energy intensive production and consumption are burdened, labour intensive production relieved. Emission factors react according to equation 4 to growing NO_x prices.

So the development of the pollution abatement techniques and thus of the emissions depends for some energy carriers directly on economic variables. For all energy carriers the costs of air pollution influence energy prices, energy flows and via wages the whole economic system. As economy and energy flows are linked by five IO sectors (see table 1), economy, energy flows and air pollution are modeled interdependently and simultaneously in PANTA RHEI II (see Figure 2).

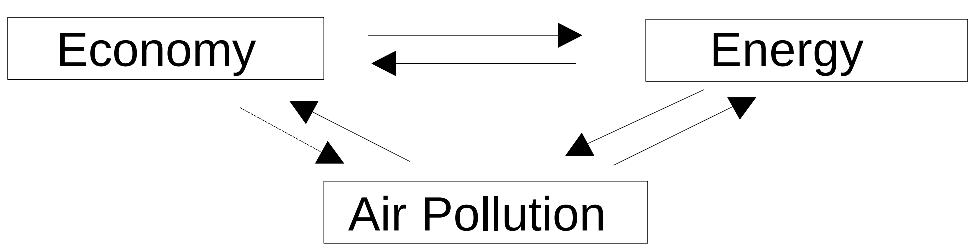

Figure 2: The interdependence of model parts in PANTA RHEI II

Slight emission reductions are reached almost without negative effects on the macro level. Figure 3 shows that reductions down to 1300 kt - though assuming slow technical adjustment - almost have no macroeconomic effect. And even emissions of 1000 kt of NO_x can be reached without unbearable avoidance costs. But huge cuts of emissions in only a few years reduce GDP substantially. As the technological and structural adjustment capacity is overstrained, the macroeconomic level has to be reduced.

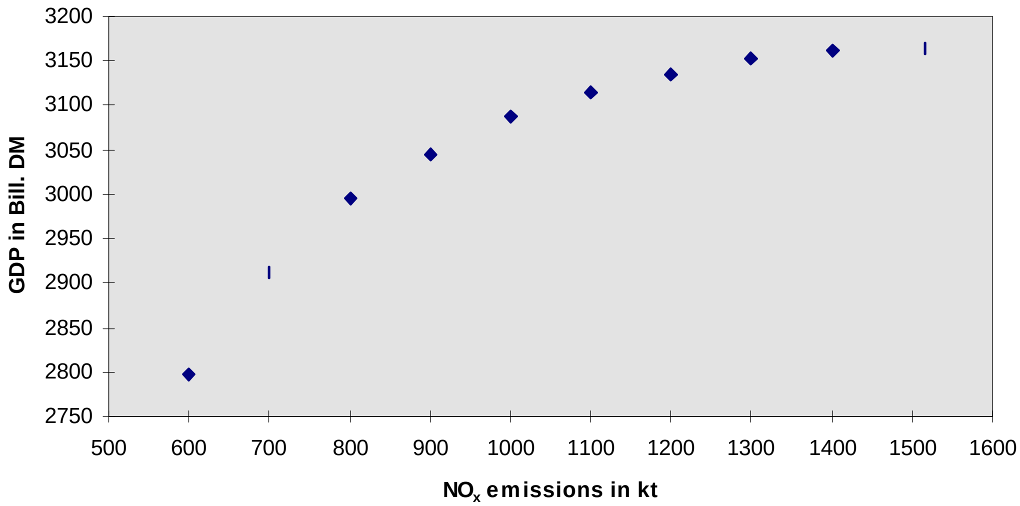

Figure 3: GDP in constant prices and NO_x emissions in NO_x tax simulations in the year 2005

A closer look on the simulation results of a tax of 51 DM/kg - growing linearly from 8 DM/kg in 1996 - in the year 2005, that reduces emissions to 1200 kt, reveals macro-economic, sectoral and technical effects of this kind of environmental policy. GDP and gross production in constant prices are only slightly lower than in the BaU simulation. as prices go up very moderately. Lower gross wages even induce higher employment. Together with NO_x, CO_2 and SO_2 emissions can be reduced substantially because of lower energy inputs. So a double dividend of more employment and less air emissions is reached by this market oriented environmental policy.

Table 4

Macro effects in the tax against the BaU simulation
- Percentage differences in 2005 -

Tax rate in DM/kg	51.0
GDP	- 0.7
Producer prices	+ 0.3
NO_x	- 20.0
CO_2	- 9.5

SO_2	- 17.2
Employment in 1000 workers	+ 398.2

On the sectoral level the energy sectors and traffic related sectors are effected mostly. Their producers prices grow in comparison to the BaU Simulation. Due to high emission factors *refined petroleum products*, *coal* and *other transport services* suffer the biggest losses in production against the BaU simulation. On the other hand, *railway services*, *machinery*, *other market services* and the *automobile industry* profit from the new environmental policy approach. Even the production of *gas* and *electric power* are not effected as these energy carriers become more competitive in comparion to *coal* and *petroleum products* (see table 5 and Lutz 1998 for more details on sectoral effects).

Table 5

Sectoral effects in the tax against the BaU simulation
- Percentage Differences in 2005 -

	Sector	producer prices	gross production
10	Refined petroleum products	+ 86.4	- 28.6
6	coal	+ 67.4	- 16.2
4	gas	+ 17.5	+ 0.3
3	Electric power, steam, hot water	+ 7.7	- 1.5
48	Other transport services	+ 3.7	- 2.3
16	Iron and steel	+ 3.7	- 2.3
45	Railway services	+ 0.6	+ 2.2
9	Chemical products	- 0.2	- 0.2
21	Machinery and Equipment	- 0.4	+ 0.2
23	Road vehicles	- 1.1	+ 1.1
56	Services of central and local government	- 1.9	- 1.6
55	Other market services	- 5.0	+ 1.8
	all commodity groups	+ 0.3	- 0.7

On the technological level, a tax on NO_x emissions induces lower emissions per unit of energy input (see equation 4). Diesel lorries are emitting 13.6% less NO_x per litre in comparison to the BaU simulation, and passenger cars between 3.1% (gasoline) and 9.3% (diesel) less. In coal power plants the development is not that fast (-0.8 to -1.3%), as modern filter technologies had already been installed about ten years ago.

VI. Summary and outlook

If environmental policy plans to reduce emissions of global or transboundary air pollutants, environmentally enlarged IO models like PANTA RHEI II offer the possibility to combine in a consistent way environmental and economic (SEEA) data on the sectoral and the macro level. To calculate NO_x emissions in the model the development of the emission factors must be specified. If control-and-command oriented policy will continue, the development in the following years can be described in a BaU scenario. There is as well good knowledge about the best available abatement technologies BAT for this period.

If policy relies on economic incentives, the forecast of the emission factors will be more complicated. Therefore a plausible routine for their adjustment over time has to be developed. Simulations of taxes on NO_x emissions show a considerable reduction of NO_x emissions without severe macroeconomic effects. Only a few emission intensive sectors are burdened, whereas most sectors - especially the key sectors of the German economy - even take advantage of the lower social security contributions.

The installation of new abatement techniques needs investment. In this model version, it is supposed that no additional investment takes place. As every sectors decision to invest is endogenously modelled in PANTA RHEI, investment for lower emissions displaces completely other investment. Thus, from this component of final demand there are no positive effects on GDP in tax simulations. But what effects can be expected, if investment is additional? The statistical offices of Germany and the Netherlands have recently published such data in form of abatement cost curves for NO_x (see Federal Statistical Office, Germany/Statistics Netherlands 1996). The data has in another study been integrated into PANTA RHEI. First results show that assuming additional investment further reduces macroeconomic avoidance costs (see Meyer/Bockermann/Ewerhart/Lutz 1998a). So environmentally enlarged IO models seem to be an useful and still expansible instrument for evaluating different - particularly market oriented - environmental policy strategies by using sectoral SEEA data.

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