An Evaluation of Taxes on Air Pollutants Emissions:
An Applied General Equilibrium Approach

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I. INTRODUCTION

All political parties in Germany agree that pollution controls by market instruments should become an increasingly important part of government regulatory activities. As environmental quality goals are sometimes in conflict with other objectives such as full employment, economic growth or price stability, there arises the question of the economic impact of these activities. At the current state of the debate, the ecological reform of the German tax system should be neutral in its effect on the income distribution, on government budget deficit, on the international competitiveness of the German industry, on location decisions and to foreign direct investment. It should, of course, provide an incentive to conserve energy, to reduce discharge of waste to the atmosphere and water, to stimulate substitution in the structure of goods and inputs; and it should be a signal for world-wide effort in environmental policy.

The objective of this paper is to identify and to measure the trade-offs between the various goals of environmental and economic policy. This requires information on the economic impacts of various environmental objectives. Since environmental quality programs have impacts on prices, and hence on supply and demand, a general equilibrium model with pollution specifications is an appropriate methodological approach to identify the economic impacts of pollution control policies. By integrating environmental variables directly into models of producers' and consumers' behavior, structural changes arising from environmental programs can be properly taken into account. Such an approach models price-responsiveness on the demand side for consumption goods and production inputs as well as endogenous changes in factor incomes in a fully closed and consistent way. In contrast to the fixed-price approach in the Leontief model where abatement activities have in any case a positive impact on growth, in a price-responsive approach higher abatement costs can dampen the growth effect or even reverse it.

Incorporating environmental regulation and its impact in general equilibrium models has by now a twenty years long tradition. In 1970, LEONTIEF extended his input-output approach to quantify environmental repercussions on the economic structure. Since then generalized input-output programming models have been developed for quantifying environmental policy packages (see THOSS and DÖLLEKES [1974], THOSS [1976], MULLER [1979]). The shortcomings of these models like fixed coefficients in technologi-

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cal processes or zero price and income elasticities of demand can be resolved by using a quantitative general equilibrium model. There are numerous articles dealing with environmental issues in simple general equilibrium models but there are not many models which have been implemented empirically. WILLETT (1985) presents an economy-wide general equilibrium model that combines an explicit representation of consumer demand behavior with activity analysis. However, the author only reports about efforts to implement his model empirically. JORGENSON and WILCOXEN have constructed a detailed model of the U.S. economy in order to study the relationship of pollution abatement costs and economic growth. They analyze the impact of environmental regulation by simulating the long-term growth of the U.S. economy with and without regulation. In a previous paper (CONRAD and SCHRÖDER [1988]) we have presented an applied general equilibrium model in 26 industries for the German state Baden-Württemberg. We have quantified the economic impact and environmental effect of a tax on emissions. We did not, however, empirically implement the impact of abatement activities on economic growth and on environmental quality. In the present paper this aspect will be one point of interest. Another one will be the treatment of capital as a quasi-fixed input and the introduction of adjustment costs in changing capacities. In spite of this methodological progress applied general equilibrium models are unsatisfactory in many respects. STEPHAN (1989) has developed an alternative approach to computable equilibrium modelling in order to incorporate time and dynamics in a more satisfactory way.

The paper is organized as follows. In section 2 we give a brief description of the structure of our temporary equilibrium model. In section 3 we present our model of producer behavior including capacity extension under adjustment costs. In section 4 we extend the model of producer behavior by introducing abatement activities and their derived demand for inputs. We also incorporate environmental policies based on standards or taxes on emission in our model of the firm for quantifying the impact on output and abatement activity. In section 5 we present our model of consumer behavior and our measure of potential welfare gain under alternative environmental policies. In section 6 we report on the results of our simulation studies.

II. A TEMPORARY EQUILIBRIUM MODEL WITH ABATEMENT ACTIVITIES

In a temporary general equilibrium model the unrealistic assumption that all variables adjust immediately to their long-run optimal values is relaxed. We treat capital as quasi-fixed in the short-run so that the economy is in a short-run equilibrium different from the long-run equilibrium. This case may occur when unexpected demand shocks or an ecologically orientated tax reform lead to under- or over-utilization of capacity. In this paper we do not set out in detail the framework and specifications of our temporary equilibrium model. This has already been done in several other papers where this approach has been adopted to quantify the economic impact of tax and energy policy proposals.[1] Here we want to present the modifications and extensions required to incorporate the impact of intermediate input and capital demand by abatement activities, to model the trade-off between tax payments for emissions and between abatement costs, to emphazise the role of consumer durables in environmental policy, and to specify abatement technologies.

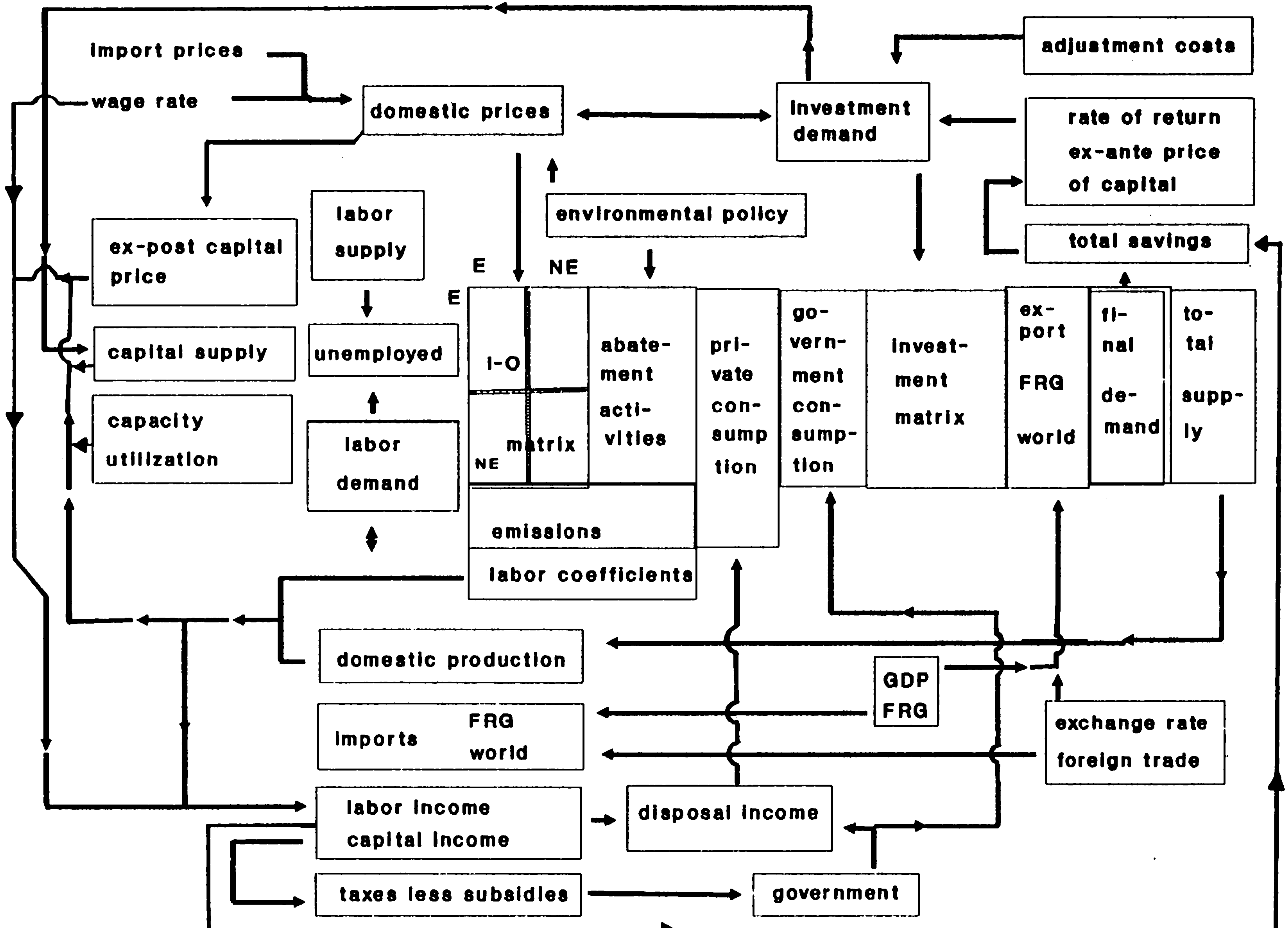
Figure 1 gives an overview of the structure of the model. The core of the temporary equilibrium model is the input-output matrix for the State Baden-Württemberg[2] containing twenty industries, a system of twenty prices as the solution of a simultaneous equation system of average cost functions, and a price dependent input structure. Each industry uses energy (E), non-energy (NE), capital and labor to produce its output. The energy aggregate consists of nine energy components and the non-energy aggregate of eleven material components. In modelling pollution a detailed disaggregation of the energy inputs is absolutely necessary since most of the pollutants originate in burning fossil fuels. The input-output table has been enlarged by a 4 x 20 sub-matrix containing emission coefficients of four air-pollutants (particulates, SO_2, NO_x and CO_2). Additional columns in the input-output matrix represent the abatement activities. These activities are, however, an integral part of the production decision of each industry and hence integrated into the structure of input demand of each industry.

A standard characteristic of these models is the decomposition of total supply into intermediate industrial goods and final goods, all expressed in constant and current market prices, including value added taxes and subsidies. Total supply from the flow-of-product account equals the value of primary and secondary inputs of factor costs using a cost-flow approach. Finally, in a regional model exports and imports have to be differentiated between foreign trade with the rest of the world (depending on the domestic/foreign price ratio and on the world trade volume) and foreign trade with other German states (depending on the state/out-state price ratio and on the out-state GDP).

Our model of producer behavior integrates factor demand with an explicit optimization of factors which are fixed in the short-run, but variable in the long run. In this dynamic cost of adjustment model the modification of the stock of quasi-fixed factors is assumed to be costly. By such an approach we consider the fact that increases in energy saving and pollution abating technologies to their new long-run optimal levels result in a loss of

1. See CONRAD (1982, CONRAD and HENSELER-UNGER (1984, 1986, 1988), HENSELER-UNGER (1986), CONRAD und SCHRÖDER (1988).

2. See "Baden-Württemberg in Wort und Zahl", Heft 7, 1985, p. 248-253. By using a regional model we can analyze the impact of environmental policy on structural changes with regional characteristics such as coal mines, heavy industry or industries depending on water ways. The results obtained from using this regional model can however easily be generalized and quantified for countries and regions of a similar structure of production and consumption.



import prices
wage rate
domestic prices
investment demand
adjustment costs
rate of return ex-ante price of capital
total savings
environmental policy
ex-post capital price
labor supply
capital supply
unemployed
capacity utilization
labor demand
E
NE
E
I-O
matrix
NE
abatement activities
private consumption
government consumption
investment matrix
export FRG world
final demand
total supply
emissions
labor coefficients
domestic production
GDP FRG
imports FRG world
exchange rate foreign trade
labor income capital income
disposal income
taxes less subsidies
government

productive efficiency. The speed of adjustment is endogenous and will be derived from dynamic cost minimization behavior including transaction costs. The point of departure for considering transaction costs is the assumption, that the introduction of a high tax on emissions will increase marginal cost depending on the speed of adjustment. This in turn implies a delay in the modification of quasi-fixed factors like the capital stock.[3] Upon specifying functional forms of the variable cost function, our model provides a system of demand equations for the variable inputs and for the quasi-fixed input for each industry. Prices equal average cost in each industry and this yields a system of interdependent prices.

Polluting firms can react to standards and/or emission taxes by factor substitution and by abatement activities. They have abatement cost functions and determine the level of the abatement activity by equating marginal cost of abatement to the uniform tax rate on emissions. Finally, abatement activities imply demand for intermediate goods, capital and labor and the accumulation of a stock of abatement capital.

The aspect of quasi-fixity of goods in the short run is also incorporated in our model of consumer behavior. Environmental regulation affects the use of consumer durables like cars, electric appliances, and heating. Hence our model of a representative consumer integrates the demand for non-durables and for services from the quasi-fixed durables, with the investment demand for modifying the stock of consumer durables towards their long-run optimal levels. This approach permits us to model the impact of an emission based motor-vehicle tax or of a higher tax on gasoline.

The advantage of our dynamic applied general equilibrium model is that we (i) integrate costs of adjustment into the dynamic models of long-run demand for quasi-fixed inputs (ii) consider the possibility of short-run equilibrium states and (iii) satisfy the Chatelier principle, i.e. long-run price elasticities exceed (in absolute terms) the short-run elasticities when measured at the temporary disequilibrium state. Finally, our model satisfies the closure rule of the ex post identity of saving and investment by calculating a social rate of return which balances investment and savings.

III. THE DYNAMIC MODEL OF PRODUCER BEHAVIOR WITH ADJUSTMENT COSTS

We characterize the technology of a cost minimizing firm by a variable cost function VC,

$$VC = VC\,(x, K_{-1}, \dot{K}, q, q_L, t) \tag{1}$$

where x is output, q is the price vector of intermediate inputs, q_L is the price of labor and t represents technical change. The quasi-fixed factor capital K is given at the beginning

3. The theoretical foundation of dynamic models of firm behavior with adjustment costs stems from LUCAS (1967), LAU (1976), and MC FADDEN (1978) and BERNDT, FUSS and WAVERMAN (1977). For a survey see WALFRIDSON (1987).

of the period and its change $\dot{K}$ is an argument of the variable cost function, resulting in a loss of productive efficiency; hence $VC_{\dot{K}} > 0$. We specify the adjustment cost effect as an index of total productivity Q ($\dot{K}2$) by replacing x and $\dot{K}$ in (1) by $x{\cdot}Q$ where $Q_{\dot{K}} < 0$, and $VC_Q < 0$. We normalize Q to be one in the base year. Since the base year need not be a year of a long-run equilibrium, base year adjustment costs are included in the observed variable costs $VC = \Sigma q_i \; v_i + q_L \cdot v_L$ where v_i are the n intermediate inputs.

From Shephard's lemma we derive short-run demand functions as variable input coefficients:

$$\frac{v_i}{x} = \frac{\partial\, vc\,(\cdot)}{\partial\, q_i} \qquad i = 1, \ldots, n, L \tag{2}$$

where $vc(\cdot) = VC(Q, K_{-1}/x, q, q_L, t)$ due to our assumption of constant returns to scale (CRTS) of VC in x and K.

The shadow price or ex-post price of capital, q_K, is give by

$$-x\,\frac{\partial\, vc\,(\cdot)}{\partial\, K} = q_K \tag{3}$$

and represents the reduction in variable costs by having one more unit of capital. We assume separability of the overall production function in energy, non-energy, capital and labor inputs and choose a CES-specification of the overall cost function in corresponding prices and in the corresponding x and K_{-1} term.

For the sub-functions in the energy components and in the non-energy components we have also chosen CES-specifications. The distribution parameters can be derived from base year input coefficients, and values for the elasticities of substitution can be different for different industries.

Finally, from Euler's Theorem under CRTS of VC, we obtain:

$$\frac{\partial\, V\,C}{\partial\, x}\,x + \frac{\partial\, V\,C}{\partial\, K}\,K_{-1} = V\,C \tag{4}$$

Assuming profit maximization under perfect competition ($p = VC_x$), (4) and (3) imply zero profit under the ex post rate of return on the quasi-fixed capital stock:

$$p\,x = V\,C\,(x{\cdot}Q, K_{-1}, q, q_L) + q_K \cdot K_{-1} \tag{5}$$

or

$$p = VC\,(Q, K_{-1}/x, q, q_L) + q_K\,(K_{-1}/x) \tag{6}$$

This "price equal total average cost"-condition can be employed to determine the system of n output prices. Since the price vector q of intermediate inputs is exactly the price vector $(p_1,\ldots, p_n)$ of output prices, equation (6) for industry i is:

$$p_i = VC_i\,(Q_i, K_{i,-1}/x_i, p_1, \ldots, p_n, q_L) + q_{K,i}\,(K_{i,-1}/x_i) \tag{7}$$

Hence we can solve this system of n prices, given the beginning of year capital stock and the price of labor. Since the output levels x_i change in each round of the solution algorithm of a certain year, prices and quantities will not be determined in a recursive way.[4]

Let us now turn to the derivation of the optimal path of the quasi-fixed capital stock. Modifications of it incur costs to the firm. We assume that the stock of capital depreciates at the rate δ, which means that in order to increase the stock by $\dot{K}$ the firm has to acquire $\dot{K} + \delta \cdot K_{-1}$ units of assets. Under the assumption of static expectation the firm minimizes the present value of variable costs and capital costs[5]:

$$\min_{K,\dot{K}} \int_0^\infty e^{-rt} \left\{ VC\,(x, K, \dot{K}, q, t) + p_K \cdot K \right\} dt \tag{8}$$

where $p_K = p_I\ (r{+}\delta)$ is the ex ante price of capital, p_I is the investment goods deflator and r is the nominal rate of return.

The problem of the firm is to choose the time path of $K(t)$ and $\dot{K}(t)$ which minimizes the present value of total costs.

The Euler first order condition for a minimum of (8) is:

$$-\frac{\partial VC}{\partial K} - p_K - r\frac{\partial VC}{\partial \dot{K}} + \frac{\partial^2 VC}{\partial \dot{K}^2}\frac{d\dot{K}}{dt} = 0 \tag{9}$$

4. The wage rate is fixed in a given year and changes by the rate of inflation and by the change in labor productivity. It is realistic not to reduce the wage rate in spite of unemployment. With respect to the solution algorithm we got no problems in using the "unsophisticated" Gauss-Seidel method.

5. For further detail see TREADWAY (1974).

In the steady state, $\dot{K} = 0$ and $\frac{d\dot{K}}{dt} = 0$ as well as $\frac{\partial VC}{\partial \dot{K}} = \frac{\partial VC}{\partial Q}\frac{dQ}{d\dot{K}} = 0$ since $\frac{dQ}{d\dot{K}} = 0$ in the steady state under our specification for the productivity index $Q(\dot{K}^2)$. *Hence (9)* reduces to

$$-\frac{\partial VC}{\partial K}(x \cdot Q(0), K^*, q, q_L) = p_K . \tag{10}$$

Given the expected ex ante price of capital, this envelope condition has to be solved for the long-run optimal capital stock K^*. Under our CRTS CES specification the solution of (10) can be written as

$$K^* = x \cdot Q(0) \cdot g\,(f\,(q, q_L)/p_K) .$$

As was shown by LUCAS (1967) and TREADWAY (1971), the short-run demand for the quasi-fixed capital input generated by (10) can be approximated around the long-run equilibrium by the solution of a linear differential equation

$$\dot{K} = m \cdot (K^* - K_{-1}) \tag{11}$$

where m is an adjustment coefficient and takes the form

$$m = -\tfrac{1}{2}\left[r - \left(r^2 + \frac{4\,VC_{KK}}{VC_{\dot{K}\dot{K}}}\right)^{1/2}\right] \qquad K = K^*, \dot{K} = 0 \tag{12}$$

The adjustment rate m is a increasing function of r and is mainly determined by the curvature of the variable cost function with respect to K and $\dot{K}$. Finally, r changes over time in order to equate the ex post identity of investment and saving. If final demand exceeds total income, r will increase and investment will go down as K^* decreases in $p_K = p_I(r + \delta)$.

IV. ABATEMENT TECHNOLOGIES, ABATEMENT COSTS AND THE INCLUSION OF ENVIRONMENTAL POLICY INSTRUMENTS

In our model abatement decisions are an integral part of firms decision making. The abatement technology is characterized by high fixed costs due to the capital intensity of abatement measures. A special feature of abatement technologies is a drastic increase in costs if the degree of abatement is increased. The reason for that is that abatement technologies are designed for a certain degree of abatement. We will therefore assume CRTS in abated emissions for a firm's aggregated abatement technology but will assume that costs per unit of abated emissions are convex in the degree of abated emissions. This aspect, however, will only influence the capital part of abatement costs which consist of investment in pollution abatement equipment and of operating costs of pollution control activities. We specify a Leontief abatement technology with "output" AE as abated emissions:

$$AE = \min\left\{u_i/a_i,\ i = 1, \ldots, n, L, K\right\} \tag{13}$$

where u_i are deliveries of intermediate goods and the units of a_i are in [input in DM / tons of abated emissions]. The input coefficient for capital is assumed to be convex in the degree of abatement, ae,

$$a_K = \bar{a}_K \cdot A \cdot \left[\frac{1}{(1-ae)^{1/c}} - 1\right] + \bar{a}_K \tag{14}$$

For $ae = 0$, it is $a_K = \bar{a}_K$, and for $ae \to 1$ it is $a_K \to \infty$. The parameter A and c have to be estimated.

We next specify the abatement cost function. The use of inputs entails total potential emissions TE; and abated emissions AE will depend on the degree of abatement, i.e. $AE = ae \cdot TE$. The degree ae is either legally determined or a decision variable of the firm if confronted with an emission tax. Since $u_i = a_i \cdot \mathrm{AE}$ (i = 1,..., n, L, K) are the input quantities for abatement as a function of ae, we have the following abatement cost function C_u (q, ae, TE) which is convex in ae:

$$c_u = \left(\sum q_i \cdot a_i + q_K \bar{a}_K \left[A\left(\frac{1}{(1-ae)^{1/c}} - 1\right) + 1\right]\right) AE \tag{15}$$

We will distinguish abatement cost functions with respect to the type of emissions and in some cases with respect to the industry. For solid waste we assume the same abatement cost function for all industries. For SO_2 we distinguish between electricity and the non-electricity industries as well as between old and new installed technology. The same has been done for NO_X but here we additionally differentiate between the type of input used (coal, natural gas, or fuel oil).

In order to demonstrate the effect of different environmental policy measures on output and abatement decisions of a profit maximizing firm we concentrate on a case with two inputs where only the first input causes emissions. For this case total potential emissions are $TE = e_1 \cdot v_1$ where e_1 is an emission coefficient [tons of emission / input in base year DM]. The abatement cost function is:

$$C_u(q, ae, TE) = c_u(q, ae) \cdot AE = c_u(q, ae) \cdot ae \cdot e_1 \cdot v_1 \qquad (16)$$

where the unit cost function C_u (q, ae) is the term in the round bracket given in (15).

Case 1: a regulated degree of abatement ae
The current environmental policy regulates the quality of air in the air quality act of 1986 (TA-Luft 86). User of furnaces have to adhere to limits of emissions which can be interpreted in terms of our model as a minimum degree of abatement $\overline{ae}$. Hence the problem of the firm is:

$$\max_{x} \; p \cdot x - C(x, \tilde{q}_1, q_2) \qquad (17)$$

where the price of the first input $\tilde{q}_1 = q_1 + c_u(q, \overline{ae}) \cdot \overline{ae} \cdot e_1$ has increased by the shadow price of the standard $\overline{ae}$, i.e. the cost of regulated abatement per unit of this input. Under CRTS of C in x, the price will be equal to average cost and will include the cost of abatement.

Case 2: a tax on emissions
If a tax on emissions is introduced, the problem of the firm is:

$$\max_{x, ae} \; p \cdot x - C(x, \tilde{q}_1, q_2) - t \cdot (1 - ae) \cdot e_1 \cdot v_1 \qquad (18)$$

where again $\tilde{q}_1 = q_1 + c_u$ $(q, ae)\, ae \cdot e_1$ but the degree of abatement ae is now a decision variable. Since the emission tax increases the price of factor 1, (18) is equivalent to

$$\max_{x, ae} \; p \cdot x - C(x, \hat{q}_1, q_2) \qquad (19)$$

where $\ddot{q}_1 = \tilde{q}_1 + t(1 - ae) \cdot e_1$. The first order condition with respect to ae is[6]:

$$\frac{\partial c_u}{\partial ae} \cdot ae + c_u = t \;\; ; \qquad (20)$$

6. From $-\frac{\partial C}{\partial q_1} \cdot \frac{\partial \hat{q}_1}{\partial ae} = 0$ we obtain $-v_1 \left(\frac{\partial c_u}{\partial ae} ae \cdot e_1 + c_u \cdot e_1 - t \cdot e_1 \right) = 0$ i.e. (20).

i.e. marginal costs of abatement are equal to the tax rate on emissions. Again, under CRTS, price will be equal to average cost including abatement, and the output x will be determined as part of the inter-industry input output solution.

V. THE MODEL OF CONSUMER BEHAVIOR

Since the purpose of this project is to measure the impact of environmental policy measures on producers' and consumers' behavior, we have to differentiate between durable goods and between non-durable goods in the household sector. Taxes on exhaust emissions of motor vehicles (NO_X) will affect the use and demand for cars, taxes on SO_2 affect the heating system and the corresponding inputs (oil, gas, electricity) and standards and emission taxes for the electricity producing industry affect the price of electricity and hence the use and purchase of electric appliances. Our model of consumer behavior will therefore consist of three durable goods (cars, heating, and electric appliances) and 20 non-durable goods as given by the input-output table. Energy goods like fuel or heating oil will be treated however to be in fixed proportions to the stocks of durables. This excludes the unrealistic possibility of substitution between energy and non-energy goods in the household sector.

For developing a dynamic model of consumer behavior we make use of the similarity between the dual concept in the theory of cost and production and between the dual concept of utility and expenditure functions. At the present stage of our modelling effort we do not, however, include cost of adjustment if the consumer decides to replace high energy consuming and polluting equipment by a new one.

To begin with the description of the consumer part of the model of applied general equilibrium, our representative consumer receives disposable income within the model solution and allocates part of it to expenditure e by using a macroeconomic consumption function. Expenditure e refers only to non-durable goods $\underline{x}$, i.e. $e = \Sigma\, p_i\, x_i$. Expenditure behavior is characterized by an expenditure function $e\ (\bar{u}, p, z_{-1})$, giving the minimal expenditure to be able to afford the utility level $\bar{u}$, given the price vector p and the vector of quasi-fixed stocks of consumer durables z_{-1}. From the corresponding indirect utility function $v\ (p, e, z_{-1})$ we can calculate this utility level $\bar{u}$. The expenditure function $e(\cdot)$ has the following properties:

$$e_{p_i}(\bar{u}, p, z_{-1}) = x_i \quad (i=1, \ldots, n)\ , \ e_{z_j} < 0, e_{z_j z_j} > 0 \quad (j=1, 2, 3) \tag{21}$$

The first property is Shephard's lemma and the second one states that the purchase of durables will reduce expenditures for non-durables given the standard of living $\bar{u}$. We can evaluate user's shadow price of the quasi-fixed durables by

$$q_j = -\frac{\partial\, e\ (\bar{u}, p, z_{-1})}{\partial\, z_j} \tag{22}$$

The ex-post price q_j gives the reduction in expenditure for non-durables by having one more unit of the stock of durable j, given utility $\underline{u}$. The optimal stock of durables can be derived from an intertemporal minimization of expenditure, consisting of expenditure for non-durables, of purchases of new durables as net investment ($p_{I,j} \cdot \dot{z}j$), of purchases for replacement ($p_{I,j} \cdot \delta_j \cdot z_j$) and of taxes on durables like a motor vehicle tax ($p_{I,j} \cdot \tau_j \cdot z_j$ where τ - tax rate). The minimization problem can be stated as

$$\min_{\dot{z}, z} \int_0^{\infty} e^{-rt} \left\{ e\,(\overline{u}, p, z) + \sum_{j=1}^{3} p_{Ij}\,(\dot{z}_j + z_j\,(\delta_j + \tau_j)) \right\} dt \tag{23}$$

The long-run optimal stock z^* of consumer durables follows from:

$$p_{zj} = - \frac{\partial\, e\,(\overline{u}, p, z^*)}{\partial\, zj} \quad j = 1, 2, 3 \tag{24}$$

where $p_{zj} = p_{Ij}\,(r + \delta_j + \tau_j)$ is the ex ante user cost of the durable good (p_{Ij} is the acquisition price index of durable j). If p_z increases because of a higher τ_j, for example, then consumer's user cost is higher than the shadow cost under z^*, i.e. the required reduction in non-durable expenditures to be able to afford the marginal unit of z_j. Hence the consumer will reduce its desired stock of durables. Similar to the dynamic adjustment model in the producer model we could include cost of adjustment into the expenditure function.

To summarize, we conclude that we will compare the shadow price q_j with the user cost p_{zj} . If both are equal, the household will only purchase durables for replacement. If p_{zj} is smaller than q_j, the household will decide to invest in durable j. Stocks of durables change according to

$$z_t = (\dot{z}_t + \delta \cdot z_{t-1}) + (1 - \delta)\, z_{t-1}$$

with $\dot{z}_t = z_t^* - z_{t-1}$. Private consumption is

$$C = e\,(\cdot) + \sum P_{zj}\,(z_{-1,j} + \dot{z}_j) \tag{25}$$

and savings will be influenced by the decision to buy durables. Saving is equal to disposable income minus consumption C and affects the level of the interest rate r via the ex post identity of savings and investment.

For a specification of our demand system we choose the linear expenditure system. Since gasoline (G), electricity (E), and heating energy (H) is linked to the stock of durables, we use a composition of these goods into a linked part and into a disposable part (see CONRAD [1984]). The demand functions for non-durables are:[7]

$$x_i = \gamma_i + \frac{\beta_i}{p_i}\left(e - \sum_{i=1}^{n} p_i \gamma_i\right) \quad (i = 1, \dots, n) \tag{26}$$

where γ_i are the subsistence requirements.

The shadow prices of the quasi-fixed durables follow from (22):

$$q_j = \frac{\eta_j \cdot e\,(\overline{u}, p, z_{-1})}{\overline{z}_j - \varepsilon_j} \tag{27}$$

The optimal stocks are the solution of (24), i.e.

$$z_j^* = \varepsilon_j + \frac{\eta_j \cdot e\,(u, p, z^*)}{p_{zj}} \tag{28}$$

Again, most of the parameters will be estimated from base year data. Other parameters like income elasticities, will be taken from other studies.

The models of producers' and consumers' behavior constitute the main parts of the interindustry model with final demand for consumption and investment goods. Total supply for intermediate and for final demand will be determined by the Leontief inverse; this generates also income from labor and capital. The objective of our modelling effort is to simulate growth paths of the economy under different environmental policy measures.

VI. EMPIRICAL RESULTS

The final goal of our modelling effort is to evaluate quantitatively the economic consequences of environmental policy measures. An obvious measure of the welfare change involved in moving from a base case with prices p^0 and income y^0 to an economy with emission taxes with prices p^1 and income y^1 is the difference in indirect utility. As the money equivalent we choose the money metric utility function as a measure of utility

7. The Stone-Geary utility with quasi-fixed durables is $u = \prod_{i=1}^{n} (x_i - \gamma_i)^{\beta_i} \prod_j (z_j - \varepsilon_j)^{\eta_j}$ with $\sum_i \beta_i + \sum_j \eta_j = 1$. Then the variable expenditure function is $e = \sum \gamma_i p_i + u \prod_j (z_j - \varepsilon_j)^{-\eta_j} \prod_i p_i^{\beta_i} \beta_o$ where $\beta_o = \prod (\beta_i)^{-\beta_i}$.

differences. We will employ Hick's measure of equivalent income variation (EV), defined as

$$EV = e(u^1, p^o) - e(u^o, p^o) . \tag{29}$$

It gives the income change at the base case prices that would be equivalent to the policy implied change in utility. If $EV < 0$, welfare after the policy measure is lower than in the base case. The consumer would be willing to pay the maximum amount $/EV/$ at the fixed budget level $y^o = e(u^o, p^o)$, to avoid the decline of utility from u^o to u^1. Similarly, if $EV > 0$, the consumer would be willing to pay the maximum amount EV to see the change in environmental policy implemented. With $y^1 = e(u^1, p^1)$, (29) can be re-written to be:

$$EV = e(u^1, p^o) - e(u^1, p^1) + y^1 - y^o \tag{30}$$

The first difference results from a price effect and the second difference from an income effect. If we use for presentation expenditure for non-durables and income synonymously, then the difference in income is

$$y^1 - y^o = \sum_{i=1}^{n} \left(q^1_{L,i} L^1_i - q^o_{L,i} L^o_i \right) + \sum_{i=1}^{n} \left(q^1_{K,i} - q^o_{K,i} \right) K_{i,-1}$$

$$- \left(\sum_i q^1_{z,i} \cdot z^1_{i,-1} - \sum_i q^o_{z,i} \cdot z^o_{i,-1} \right)$$

The second line of the formula, the difference in the fixed expenditures on the three durable goods, reduces total income (expenditure) to variable expenditure $e(u,p)$.

Since the capital stock is quasi-fixed, any increase in the ex post price of capital will have a positive effect on the welfare change. The price-affected change in welfare is for our expenditure function, derived from the Stone-Geary utility function:

$$e(u^1, p^o) - e(u^1, p^1) = \sum \gamma_i (p^o_i - p^1_i)$$

$$+ (y^1 - \sum \gamma_i p^1_i) \left[\prod_{i=1}^{n} \left(\frac{p^o_i}{p^1_i} \right)^{\beta_i} \cdot \prod_{j=1}^{3} \left(\frac{z^1_j - \varepsilon_j}{z^o_j - \varepsilon_j} \right)^{\eta_j} - 1 \right]$$

If prices p^1 increase under the policy measure, the price affected welfare change is negative.

We now compare the economic effects of three simulations.

(1) In the first simulation (= base run) we implement the emission standards given by the air quality acts TA-Luft and GFAVO. [8] The standards define the permitted emissions per m^3 used air of a power station, for example. These emission standards can be converted into the permitted emissions per unit of input.

The regulated inputs are hard coal and different types of fuel oil and gas. We consider emissions of sulphur dioxide, nitrogen oxides, and particulates.

The emission standards are valid for new vintages only. The older vintages have to be adjusted within a given time period.

For the *electricity sector* we assume the years from 1985 to 1988 as adjustment period. After 1988 the emission standards are constant for the rest of the simulation period.

For the *industrial sectors* regulated by the air quality acts the adjustment period starts in 1988 and ends in 1991.[9]

The simulation period is 1985 - 1996.

(2) In the second simulation we implement an efficient environmental policy. Therefore instead of emission standards a uniform emission tax for each pollutant is used to reduce the emissions.

The emission taxes are levied on all pollutants. The same sectors that are regulated by emission standards in the base run are now taxed. This means that within these sectors the marginal costs of pollution avoidance are equalized.[10]

There are still other polluters such as services or the consumers that are not regulated in the base run. They therefore have to pay no taxes on pollution. Hence it would be possible to model a more general case of efficient environmental policy by levying taxes on all polluters.

The emission taxes have been calculated such that the emissions will be the same as in the base run. Since the environmental impact is the same, this permits a cost-effectiveness-analysis. Hence it is possible to compare directly the economic costs of this simulation with the base run.

The emission tax revenues are redistributed to the consumers by a lump-sum transfer.

8. Technische Anleitung Luft from 1986 and Großfeuerungsanlagen-Verordnung from 1983. For detailed information on the construction of emission coefficients, on estimation of the parameters of the abatement cost functions and on the calibration of the model see SCHRÖDER (1989).

9. The regulated industrial sectors are: chemicals, mineral oil refining, pottery & glass, iron & steel, machinery, motor vehicles and equipment, paper & pulp, and leather & clothing.

10. The term "pollution avoidance" includes all activities that are capable to reduce emissions in our model. These are: substitution of emission-intensive inputs and the installation of end-of-pipe technologies. With "pollution abatement" only the latter is meant.

(3) The third simulation shows the performance of the economy of Baden-Württemberg without any environmental policy. The installed equipment represents the state of art of technology but there are no additional regulations. The emissions are now higher than in the former simulations so that a cost-effectiveness-analysis is not possible. A comparison with the other simulations however reveals possible economic effects caused by environmental policy.

In the following we present and interpret the differences in the economic effects under our three simulations. Each of the tables and diagrams include for a better comparison the results of all three simulations.

Table 1 shows the effects of environmental policy on the main economic aggregates for the two years 1990 and 1996. The first two columns show the absolute values of the base run. The following columns contain the differences in absolute terms of the values under a simulation and the base run.

Emission standards vs. emission taxes

The figures for real GNP show that an efficient environmental policy results in an increase of 0.5 billion DM in 1990 and of 1.8 billion DM in 1996. But this means only an increase of 0.2% in 1990 and of 0.6% in 1996 compared with the base run.

The effects on unemployment are more significant: by using emission taxes the unemployment decreases by 5% in 1990 and by 14% in 1996. The gain in efficiency reduces average costs and hence all prices. This increases the purchasing power of income, and consumers as well as producers will be better off. Since all non-abated emissions are taxed, prices will be higher than under the emission standard case. However, the refund of the emission tax offsets this effect and produces the positive impact on consumers' purchasing power.

Induced by higher domestic prices and the increase in GNP, imports rise so that the trade balance decreases by 0.5% in 1990 and by 4.7% in 1996. For measuring the difference in social welfare we use the equivalent variation. We find that the gain in welfare under the emission tax simulation amounts to 623 million DM in 1990 and to 2765 million DM in 1996. The positive difference in welfare is due to the inefficiency in resource allocation in case of emission standards. If the degree of substitutability among inputs is high, the cost of environmental regulation is low and the welfare measure will be small. A low degree of substitutability implies high costs of environmental regulation and the welfare measure will be large.

As already mentioned, the GNP price index is higher under emission taxes. This has mainly two reasons: first, the emissions of all pollutants have been taxed, i.e all inputs that cause emissions are now more expensive for the user of these inputs. Under emission standards, however, only some selected inputs are regulated and induce a higher price for the user.

Table 1

	emission-standards (base run)		emission-taxes		no environmental policy	
	1990	1996	1990	1996	1990	1996
real GNP (10^9 DM)	233.7	303.6	+ 0.5	+ 1.8	+ 1.0	+ 13.5
unemployment (10^3)	156.3	221.1	- 8.2	- 30.8	- 30.0	- 112.5
production (10^9 DM)	477.4	617.8	+ 0.0	+ 2.5	+ 3.8	+ 35.2
investment (10^9 DM)	48.9	84.8	+ 0.5	+ 1.4	+ 1.6	+ 15.6
consumption (10^9 DM)	127.6	171.8	+ 0.4	+ 1.4	+ 1.3	+ 12.8
welfare (10^6 DM)	0.0	0.0	622.7	2765.4	1857.1	24290.6
trade balance (10^9 DM)	55.0	42.2	- 0.3	- 1.9	- 2.2	- 27.5
GNP price index[10]	1.516	1.916	1.523	1.926	1.531	2.028
capital price index	1.282	1.659	1.289	1.663	1.304	1.803
labor price index	1.713	2.103	1.719	2.112	1.733	2.207
emission tax revenue (in 10^6 DM)	0.0	0.0	+706.7	+986.5	0.0	0.0

11. The price indices are 1.0 in 1978.

Second, as already mentioned, an efficient policy implies a higher GNP, employment, income, etc. The consequence is a higher marginal product of capital so that the price of capital, and hence the GNP price index, increases in addition to the impact from the emission tax.

Environmental policy vs. no environmental policy

The differences between the simulation with no environmental policy and the two simulations with environmental policy described above are much greater than the differences between the simulations with emission standards versus emission taxes. However one has to keep in mind that in case of no environmental policy the state of the environment is worse and this does not enter into our welfare measure. Therefore the big gain in welfare without environmental policy only evaluates the economic effects and does not mean that environmental policy should be abolished.

Without environmental policy we have a 0.4% higher real GNP in 1990 and 4.4% in 1996.[12] The effects on unemployment are more drastic: the environmental policy causes 19% more unemployment in 1990 and 50% in 1996. As can be seen from table 1 the change in unemployment is only due to the change in production. The real wage rate is almost the same in all simulations. Since investment in pollution control devices crowds out investment for capital accumulation this further reduces economic growth under the environmental policy.

Hence we conclude that environmental policy has not the often emphasized positive effect on employment (see also JORGENSON and WILCOXEN (1989) on that point).

The other differences equal in sign to those between emission taxes and emission standards but have much higher absolute values. Remarkable is the higher GNP price level; this is mainly the result of the increase in capital prices. And the capital prices increase as a result of the higher economic activity.

The following three diagrams illustrate the effects on welfare, real GNP and unemployment by showing the whole time series from 1985 to 1996. A comparison of the time series for welfare shows an increase in the distance between each simulation over the time. The same can be seen by looking at the time series of real GNP.

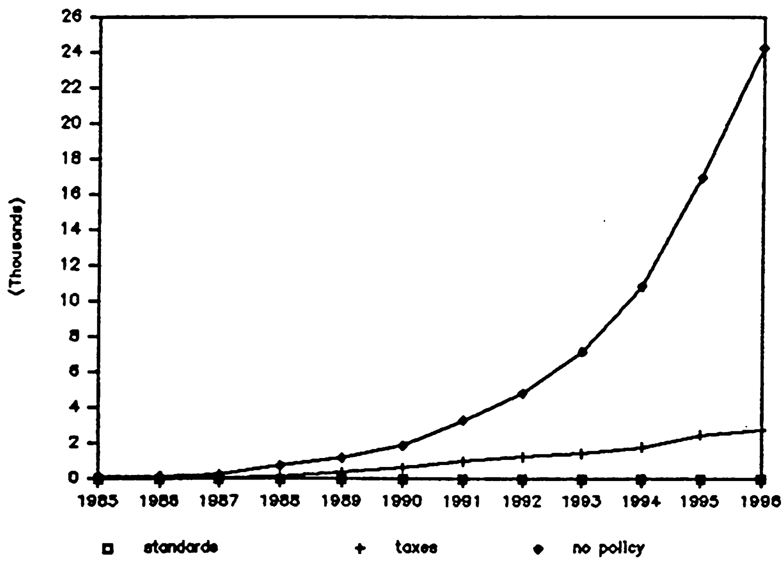
This increasing distance is caused by a greater distortion in resource allocation. It can also be recognized in the diagram for unemployment.

The following *table 2* shows some effects on the industry level.

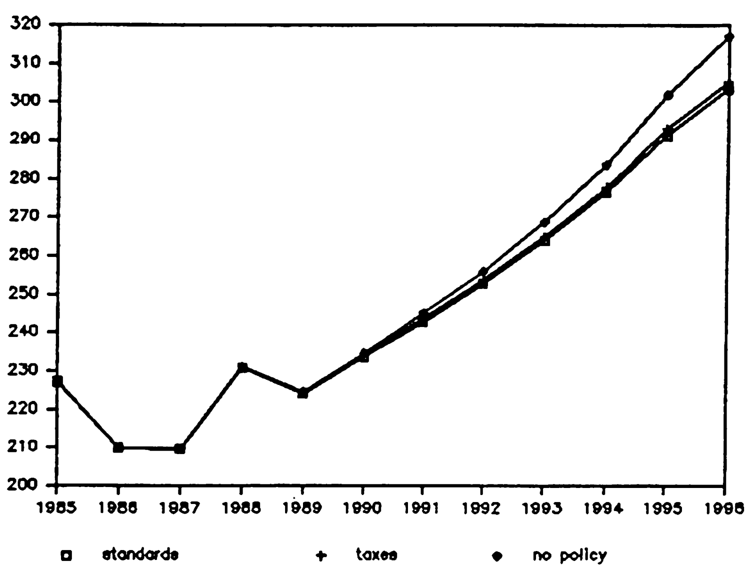
The table contains the figures for output and for price indices for four selected sectors that are regulated by environmental policy.

12. The economic performance under no environmental policy is compared with the effects under emission standards now in force.

Welfare
(in million DM)



Real GNP
(in billion DM)



The introduction of emission taxes leads to an increase in the output of the electricity sector (compared with the results under emission standards). In case of emission standards this sector has to bear the main load of emission reduction costs. With emission taxes the output increases by 0.7% in 1990 and by 0.8% in 1996.

Under emission taxes the load of emission reduction costs is distributed more equally among all regulated sectors. Hence the outputs of the industrial sectors increase much less than the output of the electricity sector or even decrease. The output of sector 7 decreases in 1990 by 0.1% and increases in 1996 by only 0.15% compared to 0.6 % of GDP growth. In case of no environmental policy it is again the electricity sector which benefits more than the industrial sectors.

The other figures do not deviate very much from the figures already explained for table 1.

The next diagrams show the time series for the pollutant emissions.[13]

The emissions of particulates are reduced significantly by environmental policy. The emissions are always below the emissions in case of no environmental policy, although from 1990 on the emissions begin to rise again.

13. The diagrams show only two graphs: one for environmental policy and one for no environmental policy. In case of environmental policy the emissions under emission standards are the same than under emission taxes.

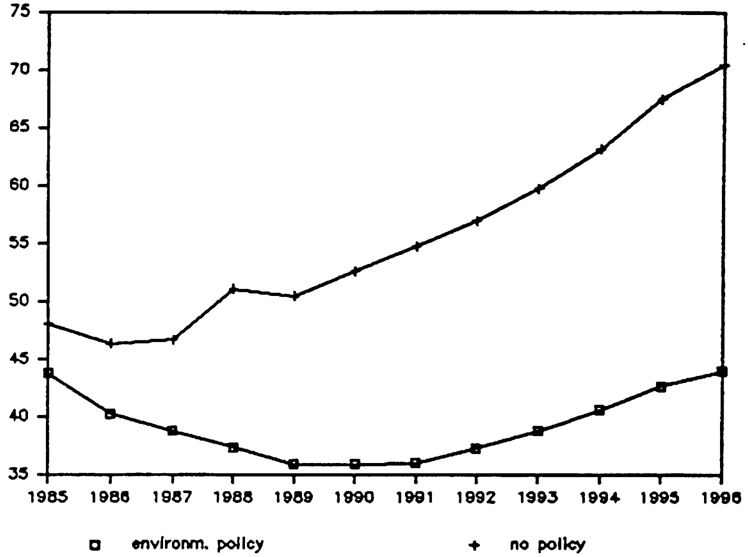
Table 2

	emission-standards (base run)		emission-taxes		no environmental policy	
(output in million DM)	1990	1996	1990	1996	1990	1996
output sector 2	7699.8	9657.8	+60.2	+80.1	+341.2	+868.1
price index sector 2	1.491	1.868	1.486	1.872	1.461	1.926
output sector 7	13469.0	17089.9	-17.0	+27.1	+441.1	+1264.6
price index sector 7	1.584	1.976	1.596	1.990	1.600	2.077
output sector 9	39605.7	50137.1	0.0	+120.2	+232.3	+1893.4
price index sector 9	1.628	2.196	1.638	2.215	1.650	2.444
output sector 15	16413.8	19096.3	-3.8	+21.7	+110.1	+452.7
price index sector 15	1.564	1.943	1.571	1.952	1.579	2.031
denotation of the sectors: 2 = electricity, 7 = iron & steel, 9 = motor vehicles and equipment, 15 = leather & clothing.						

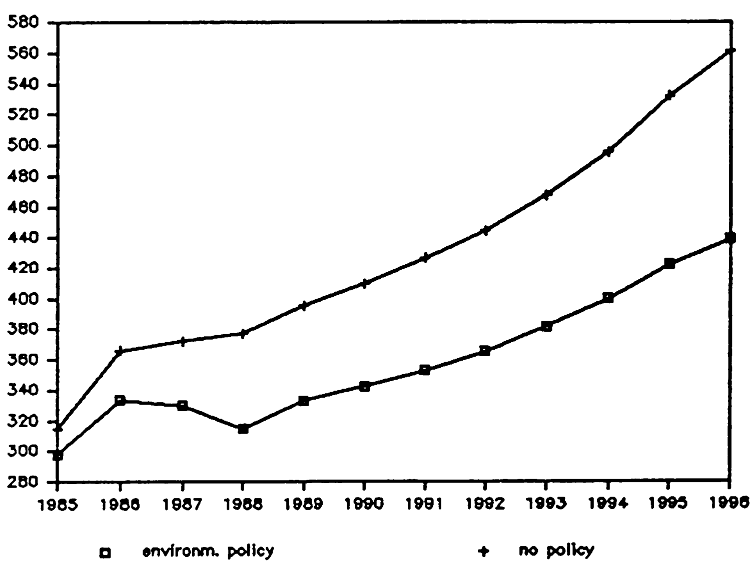
The time series graph for emissions of SO_2 and NO_x look quite similar. The emissions decrease absolutely only from 1986 to 1989. From 1990 on the emissions rise nearly parallel to the emissions in case of no environmental policy. If we choose for example the year 1996, it can be seen that the emissions in case of environmental policy will reach the same level than without environmental policy with a lag of four years.

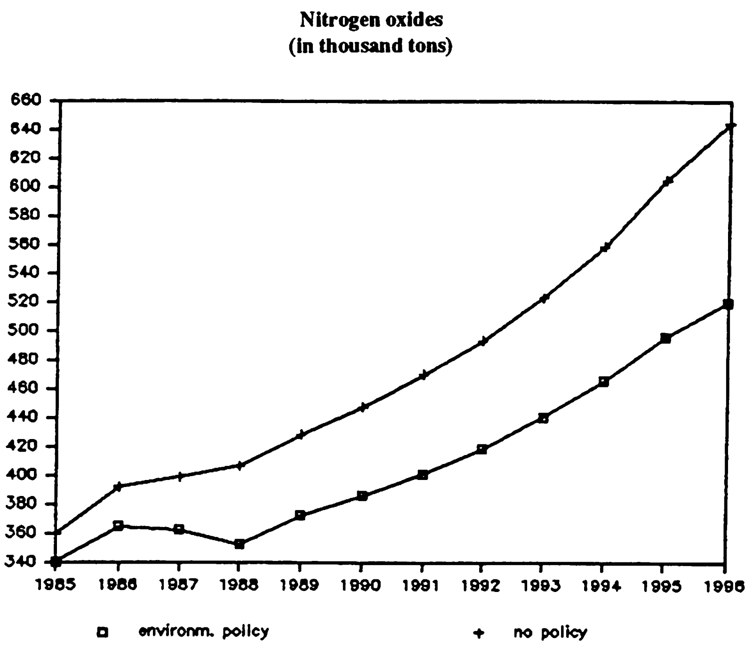
Hence we conclude, that the environmental policy of emission standards now in force is not an appropriate measure to reduce air pollutant emissions effectively. The main reason for the failure of this kind of environmental policy is the construction of the emission standards. Emission standards define the permitted emissions per unit of input.

Particulates
(in thousand tons)



Sulphur dioxide
(in thousand tons)





If the economy is growing, there is no upper bound for the emission of pollutants: an increase in the use of emission-intensive inputs by simultaneously complying with the emission standards results in an increase in emissions. An effective environmental policy has to implement upper bounds for the emissions of a region.[14] This however would cause much higher economic costs.

Table 3 shows an interesting difference between emission standards and emission taxes. In case of emission taxes a greater part of the emissions is reduced by input substitution and hence less pollution abatement has to take place.[15]

The reason is that under emission taxes emission-intensive inputs like hard coal and oil become more expensive than under emission standards. Hence the increased substitution of these inputs causes less emissions.

14. The emissions of a region could be limited by defining bubbles. Within these bubbles, an upper bound of immissions, and hence of emissions, is fixed. The rights to emit pollutants could be allocated to the polluters by using emission licenses.

15. The firms use end-of-pipe technologies to abate pollutant emissions.

Table 3

	emission-standards (base run)		emission-taxes		no environmental policy	
(in thousand tons)	1990	1996	1990	1996	1990	1996
SO2 emis-ssions	342.5	439.0	342.5	439.5	+67.2	+122.4
abated emis-sions	37.4	50.2	-28.3	-32.5	-	-
NOx emis-sions	386.5	520.1	386.5	520.1	+61.5	+124.9
abated emis-sions	37.6	50.4	-4.2	-4.0	-	-
particu-lates emis-sions	35.9	44.0	35.9	44.0	+16.8	+26.5
abated emis sions	11.8	16.6	-1.1	-1.6	-	-

We therefore conclude that an environmental policy with emission taxes induces a less emission-intensive production structure whereas an environmental policy with emis-sion standards induces more abatement activities.

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