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Carbon Taxes and Joint Implementation

An Applied General Equilibrium Analysis for Germany and India

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Abstract. Germany has committed itself to reducing its carbon emissions by 25 percent in 2005 as compared to 1990 emission levels. To achieve this goal, the government has recently launched an environmental tax reform which entails a continuous increase in energy taxes in conjunction with a revenue-neutral cut in non-wage labor costs. This policy is supposed to yield a double dividend, reducing both, the problem of global warming and high unemployment rates. In addition to domestic actions, international treaties on climate protection allow for the supplementary use of flexible instruments to exploit cheaper emission reduction possibilities elsewhere. One concrete option for Germany would be to enter joint implementation (JI) with developing countries such as India where Germany pays emission reduction abroad rather than meeting its reduction target solely by domestic action. In this paper, we investigate whether an environmental tax reform *cum* JI provides employment and overall efficiency gains as compared to an environmental tax reform *stand-alone*. We address this question in the framework of a large-scale general equilibrium model for Germany and India where Germany may undertake JI with the Indian electricity sector. Our main finding is that JI offsets largely the adverse effects of carbon emission constraints on the German economy. JI significantly lowers the level of carbon taxes and thus reduces the total costs of abatement as well as negative effects on labor demand. In addition, JI triggers direct investment demand for energy efficient power plants produced in Germany. This provides positive employment effects and additional income for Germany. For India, joint implementation equips its electricity industry with scarce capital goods leading to a more efficient power production with lower electricity prices for the economy and substantial welfare gains.

Key words: computable general equilibrium modeling, energy efficiency improvement, environmental tax reform, joint implementation, productivity gaps

JEL classification: D24, D58, F20, Q25, Q28

1. Introduction

In order to promote international climate policies, Germany has already committed itself to substantial unilateral emission reductions in the early 1990s: The German government set a carbon emission reduction target of 25 percent in 2005 as compared to 1990 emission levels which has been reconfirmed several times since then. Concerns on adverse employment effects of carbon emission constraints for the national economy have induced policy makers to adopt an environmental tax reform as a key instrument for meeting the reduction target. Such a reform entails an increase in environmental taxes together with a revenue-neutral reduction in labor costs. This policy is supposed to yield a double dividend in the simultaneous reduction of harmful greenhouse gas emissions (first dividend) and alleviation of unemployment problems (second dividend). However, while the environmental dividend is generally beyond controversy, the employment dividend is not. Environmental taxes may well exacerbate rather than alleviate pre-existing tax distortions. This is because environmental taxes induce not only market distortions similar to those of the replaced taxes but in addition new distortions in intermediate and final consumption. The negative impacts on labor demand by levying additional environmental taxes (tax interaction effect) may dominate the positive impacts of using additional revenues for cuts in labor costs (revenue recycling effect). Theoretical and empirical results show that the prospect for the second dividend crucially depends on the existing inefficiencies of the tax system, labor market imperfections and the level of environmental taxes (i.e., the environmental target).[1]

The levying as well as the recycling of environmental taxes induce substitution and output effects. Under a higher emission or energy tax, employment benefits from a positive substitution effect of labor for energy. However, there is also a negative output effect due to increased prices and reduced domestic demand. The output effect could outweigh the substitution effect on labor demand. Given the latter, a policy which achieves an environmental goal with a weak negative output effect by reducing the level of environmental taxes and strengthening domestic demand is therefore of interest.

At the strictly domestic level, using lower environmental taxes to ameliorate negative effects on production activities and labor demand would directly trade off with higher emissions. Germany would then fall short of its stated reduction target. Yet, international treaties on climate protection allow for the supplementary use of flexible instruments to exploit cheaper emission reduction possibilities elsewhere. The concept of joint implementation has been incorporated into the Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC 1997).[2] Instead of meeting its reduction target solely by domestic action, Germany could enter joint implementation with developing countries such as India, where Germany buys part of its emission reduction from abroad.[3]

In our analysis below, we investigate whether an environmental tax reform *cum* joint implementation (JI) provides employment and overall efficiency gains as compared to an environmental tax reform *stand-alone* (ETR). We address this question in the framework of a large-scale computable general equilibrium (CGE) model for Germany and India where Germany may undertake joint implementation with the Indian electricity sector. Our main finding is that joint implementation largely offsets the adverse effects of carbon emission constraints on the German economy. Whereas strictly domestic action by Germany (i.e., ETR) implies a loss in economic performance and employment, JI reduces substantially the welfare losses and provides employment gains. JI significantly lowers the level of carbon taxes in Germany and thus reduces the total costs of abatement as well as negative effects on labor demand. In addition, JI triggers direct investment demand for energy efficient power plants produced in Germany. This provides positive employment effects and additional income for Germany. For India, joint implementation equips its electricity industry with scarce capital goods leading to a more efficient power production with lower electricity prices for the economy and substantial welfare gains.

There have been several studies on the economic and environmental effects of green tax reforms for Germany based on numerical large-scale models and real data (e.g., Conrad and Wang 1993; DIW 1994; Buttermann and Hillebrand 1996; Böhringer et al. 1997; Bach et al. 2001; Welfens et al. 2001). The evidence on employment and welfare effects is mixed, partly due to differences in the concrete tax reform scenarios considered but more so due to differences in modeling assumptions with respect to existing tax distortions, foreign closure and labor market imperfections. Our analysis complements the existing literature in several ways. From a policy point of view, it does not focus on a narrow discussion of the double-dividend hypothesis but investigates how flexibility through JI could improve the prospects for efficiency and employment gains from environmental tax reforms in Germany. From a methodological point of view, we provide an innovative application of the cost or productivity gap concept by Jorgenson and Nishimizu (1978): The effects of JI are evaluated taking into account efficiency improvements in developing countries through capital transfers.

The remainder of this paper is organized as follows. Section 2 lays out the generic model structure complemented with extensions for representing joint implementation and measuring productivity changes. Section 3 describes the policy scenarios and reports our simulation results. Section 4 entails our conclusions and lines of future research.

2. Analytical Framework

This section presents the main characteristics of a comparative-static multi-sector CGE model for the German and Indian economies. The general equilibrium approach provides a consistent and comprehensive framework for studying price-dependent interactions between the energy system and the rest of the economy. This is important since carbon abatement policies not only cause direct adjustments on fossil fuel markets but also produce indirect spillovers to other markets which in turn feed back to the economy. Therefore, computable general equilibrium models have become the standard tool for the analysis of the economy-wide impacts of greenhouse gas abatement policies on resource allocation and the associated implications for incomes of economic agents (Weyant 1999).

Table I. Overview of sectors, factors and countries

Sectors		Primary factors		Countries	
COL	Coal	CAP	Capital	GER	Germany
CRU	Crude oil	LAB	Labor	IND	India
GAS	Natural gas	RES	Sector-specific resource		
OIL	Refined oil products				
ELE	Electricity				
EIS	Energy-intensive sectors				
TRN	Transport equipment				
OME	Other machinery				
CNS	Construction				
Y	Manufactures and services				

As to our concrete model formulation, functional forms and key assumptions are standard to the CGE approach to carbon abatement policy analysis (e.g., Rutherford and Paltsev 2000; Böhringer and Löschel 2002) except for the representation of productivity gaps in the electricity sector (see Section 2.3.). In the following, we provide a non-technical model overview. Appendix A contains an algebraic model summary.

2.1. BASIC MODEL

The choice of production sectors and the nesting of functional forms captures key dimensions in the analysis of greenhouse gas abatement such as differences in carbon intensities and the scope for substitutability across energy goods and carbon-intensive non-energy goods. The energy goods identified in the model are coal (COL), natural gas (GAS), crude oil (CRU), refined oil products (OIL) and electricity (ELE). The non-energy sectors include important carbon-intensive industries such as transportation services (TRN) and an aggregate energy-intensive sector (EIS). The rest of the production side is divided into other machinery (OME), construction (CNS) and other manufactures and services (Y). Primary factors include labor, capital and fossil-fuel resources. Labor is treated as inter-sectorally mobile within each region, but cannot move between regions. Capital is sector specific and internationally immobile. A sector-specific resource is used in the production of primary fossil fuels (crude oil, coal and gas), resulting in upward sloping supply schedules for those goods. Table I summarizes the sectors, countries and primary factors incorporated in the model.

2.1.1. *Production*

Nested constant elasticity of substitution (CES) cost functions are employed to specify the substitution possibilities in domestic production between capital (K), labor (L), energy (E) and material (M) intermediate inputs.

In the production of commodities other than primary fossil fuels and electricity, intermediate non-energy goods and crude oil (used as feedstock) are employed in fixed proportions with an aggregate of energy, capital and labor at the top level. At the second level, a CES function describes the substitution possibilities between labor and the aggregate of capital and the energy composite. At the third level, capital and the energy composite trade off with a constant elasticity of substitution. The energy aggregate is, in turn, a nested CES composite of electricity and primary energy inputs. The primary energy composite is defined as a CES function of coal and a CES aggregate of refined oil and natural gas. In the production of electricity non-energy goods as well as crude oil and refined oil products, which do not constitute fossil fuel options in power generation, enter in fixed proportions with a composite of labor, energy, and capital. The latter is given as a CES function between labor inputs and a restricted CES sub-function of capital and energy. At the lower energy nest, gas and coal inputs trade off with a constant elasticity of substitution. The KLEM nesting structure for production in non-fossil fuel sectors reflects common perception of the substitution possibilities except for the trade-off between capital, labor and energy. Some models (see e.g., Manne and Richels 1992) specify a trade-off between energy and the value-added aggregate, whereas other models (e.g., Welsch 1996) choose the trade-off between labor and an energy-capital composite. The latter disaggregation has been adopted for the current model since it reflects empirical evidence that labor is a similar substitute for both energy and capital (see Burniaux et al. 1992).

In the fossil fuel production activity (crude oil, natural gas and coal), labor, capital and energy inputs enter a CES composite at the lower nest. At the top level, this aggregate trades off with the sector-specific fossil-fuel resource at a constant elasticity of substitution. The latter is calibrated in consistency with empirical price elasticities of fossil fuel supplies.

2.1.2. *Private demand*

Final private demand for goods and services in each region is derived from utility maximization of a representative household subject to a budget constraint. In our comparative-static framework, overall investment demand is fixed at the reference level. Total income of the representative household consists of factor income and transfers. Final demand of the representative agent is given as a CES composite of an energy aggregate and a non-energy consumption composite. Substitution patterns within the energy aggregate and the non-energy consumption bundle are reflected via Cobb-Douglas functions.

2.1.3. *Government demand*

The government distributes transfers and provides a public good (including public investment) which is produced with commodities purchased at market prices. In order to capture the implications of an environmental tax reform on the efficiency of public fund raising, the model incorporates the main features of the German tax system: (linear progressive) income taxes including social insurance contributions, capital taxes (corporate and trade taxes), value-added taxes and other indirect taxes (e.g., mineral oil tax). In all simulations, we impose revenue-neutrality in the sense that the level of public provision is fixed. Subject to this equal-yield constraint, additional revenues from environmental taxes get recycled through cuts in labor costs (social insurance payments). As to India, we do not incorporate details of taxation, but assume that constant public good provision is financed lump-sum by the representative consumer.

2.1.4. *International trade*

All commodities are traded internationally. We adopt the Armington assumption that goods produced in different regions are qualitatively distinct for all commodities. Intermediate as well as final demands are (nested CES) Armington composites of domestic and imported varieties. Germany and India are assumed to be price-takers with respect to the rest of the world (ROW) which is not explicitly represented as a region in the model. Trade with ROW is incorporated via perfectly elastic ROW import-supply and export-demand functions. There is an imposed balance of payment constraint to ensure trade balance between Germany and India on the one hand, with ROW on the other hand. That is, the value of imports from ROW to Germany and India must equal the value of exports from these countries to ROW after including a constant benchmark trade surplus (deficit).

2.1.5. *Labor market*

The analysis of the employment effects associated with an environmental tax reform requires an appropriate specification of unemployment for the German economy. In our formulation, unemployment is generated by the existence of a “wage curve”, which postulates a negative relationship between the real wage rate and the rate of unemployment. The specific wage curve employed (see Appendix B) can be derived from trade union wage models as well as from efficiency wage models (Hutton and Ruocco 1999). As to India, we assume that labor is in fixed supply and labor markets are perfectly competitive.

2.2. MODELING JOINT IMPLEMENTATION

The rationale behind joint implementation is the same as with emissions trading: cost-effectiveness requires that measures to limit greenhouse gas emissions should be taken where they are cheapest, i.e., marginal abatement costs should be equalized across different sources. However, as compared to emissions trading, JI is based on concrete projects. The JI donor country receives emission credits that may count towards its own emission targets for carrying out climate protection projects in return for funds and technology given to the JI host. The implementation of project-based JI mechanisms in top-down models where sectoral production possibilities are given by aggregate functional forms raises some difficulties. Instead of using a discrete step-function for the abatement cost curve based on bottom-up estimates, emission abatement possibilities are implicit to the flexible functional form. The challenge is to specify and calibrate the functional form in such a way that it provides a reasonable approximation for the marginal abatement costs available from engineering data. For this purpose we employ flexible CES functions with a rather sophisticated nesting of energy inputs. Energy supply and demand calibration is based on physical energy flows and energy prices (see 2.4). In the model, JI is represented as a sectoral permit trade regime where sectors in non-abating countries qualifying for JI – in our case the Indian electricity sector – are endowed with sector-specific emission budgets. The amount of permit rights is set equal to the baseline carbon emissions of the Indian electricity sector. Under JI, the donor – here Germany – will demand emission rights (credits) from the JI host – here the Indian power industry – as long as the price of the emission credit is below its marginal abatement costs at home. On the other hand, the Indian power industry will deliver emission credits to Germany as long as the marginal costs of abating carbon in the power industry are lower than the price or revenue received for the emission credit. According to this arbitrage rule, the Indian electricity sector will allocate its baseline emission rights between credits for Germany and demand for its own domestic production. Without joint implementation, the quantity of available emission rights in German is fixed. Emission credits from joint implementation enlarge the total emission budget of Germany which allows for a reduction of the domestic carbon tax while complying with the overall carbon emission constraint.

The principal JI mechanism underlying our model simulations in Section 3 is illustrated in Figure 1. The flexibility mechanisms allow a redistribution of the emission reductions between the countries, although the overall target reduction is unchanged. Given the total emission reduction requirement $\overline{A}$ in Germany, only the volume A_G will be achieved by domestic action whereas the remainder A_I will be abated by the Indian power industry.[4] The carbon price under a strictly domestic environmental tax reform P_{ETR}^{CO2} is reduced to P_{JI}^{CO2} with JI. Total efficiency gains from JI are given by the shaded area KLM. Distribution of these gains are determined here via the market solution: The JI donor country receives a net gain NLM which is equal to its savings of abatement costs adjusted for the expenditure of purchasing emission credits. The electricity industry in India receives a net gain KLN which equals the difference between the revenues from the sale of emission credits and its undergone abatement costs.

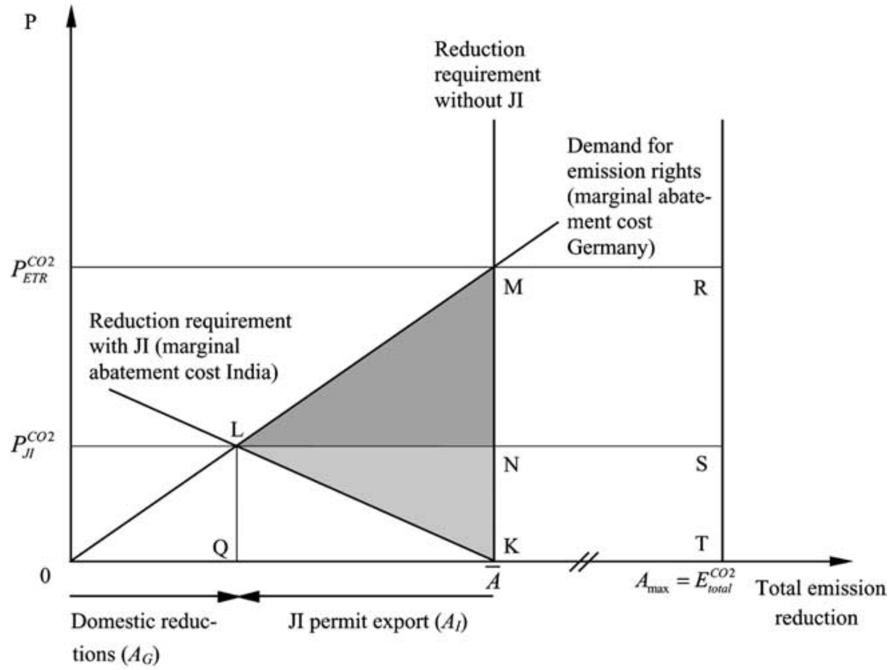

Figure 1. Joint implementation mechanism.

Reflecting the project character of JI, the electricity industry in India uses the revenues from the sale of emission reductions to buy capital goods directly from Germany. The German capital goods (coal or gas power plants) increase the capital stock in the Indian electricity sector. This direct investment exerts a positive effect on employment in the German manufacturing industries. Additional revenues from permits reduce the electricity price in India. Tax revenue in Germany for reducing non-wage labor cost is the area MKRT before JI. After JI tax revenue is only LQST where LQNK is the amount of money paid by Germany for emission credits. The area NKST is now left for reducing non-wage labor costs.

2.3. JOINT IMPLEMENTATION UNDER PRODUCTIVITY GAPS IN THE ELECTRICITY PRODUCING INDUSTRY

Reflecting empirical evidence we assume that there are productivity differences between Germany and India in the electricity sector. Since energy efficiency of fossil fuel fired power plants in Germany is significantly higher than in India, the German industry could invest in Indian power plants to reduce the productivity difference, hereby improving India's energy efficiency. In other words, India's energy producers use the JI revenues received from Germany for replacement of older inefficient power plants with new highly efficient gas or coal power plants.[5] This results ceteris paribus in a decrease in variable costs or an increase in output.

The cost or productivity gap must be taken into account when assessing joint implementation projects based on capital transfer to improve efficiency. To measure such a cost or productivity gap between the German and the Indian power sector, we employ the measurement of productivity differences as introduced by Jorgenson and Nishimizu (1978). Our approach is similar to the measurement of total factor productivity over time, but will be applied to measure spatial differences. We use the dual concept of measuring a cost gap.

The point of departure is a joint restricted CES sub-cost function in both countries which describes production of the energy-capital aggregate *EK* in the electricity sector from a fossil fuel composite *E* and capital *K:*

$$C = C(PE, EK, K, D) \tag{1}$$

where *PE* is the price of fossil fuel, *EK* the output, *K* the capital stock, and *D* a dummy variable. The restricted cost function incorporates the short-run impact of quasi-fixed inputs' capacity restrictions on total factor productivity (TFP) growth, reflecting a temporary (short-run) equilibrium. Quasi-fixed inputs should then be evaluated at their shadow rather than their rental prices (i.e., the ex-post prices rather than the ex-ante prices) in order to derive accurate measures of TFP (Berndt and Fuss 1986). We assume the cost function to be linear homogenous in *EK* and *K*. Because output levels, capital stock and the factor price are expressed relative to India, the dummy variable takes on the value 0 for India (*I*) and 1 for Germany (*G*). The dummy variable catches country specific deviations from the joint cost function. It shifts the cost function inwards or outwards. The difference in cost between India and Germany at a given point in time is calculated as the total differential of the cost function (1). In form of logarithmic derivatives, we get:

$$\frac{d \ln C}{dD} = s_E \frac{d \ln PE}{dD} + \frac{\partial \ln C}{\partial \ln EK}\frac{d \ln EK}{dD} + \frac{\partial \ln C}{\partial \ln K}\frac{d \ln K}{dD} + \frac{\partial \ln C}{\partial D} \tag{2}$$

where $s_E = \frac{\partial \ln C}{\partial \ln PE} = \frac{PE \cdot E}{C}$ is the cost share of energy in this aggregate (Shephard's Lemma). In Equation (2) the partial derivatives of the variable cost function with respect to the capital stock *K* represents the savings in costs from a marginal increase in the stock. This savings in costs is the shadow price of the capital stock (PK_s). In logarithmic partial derivative with respect to *K*, it is the cost share (multiplied by –1), i.e.:

$$PK_s = -\frac{\partial C}{\partial K} \text{ and } s_K = \frac{PK_s \cdot K}{C} = -\frac{\partial \ln C}{\partial \ln K}.$$

Under the additional assumption of profit maximizing supply decisions, we have $PEK = \partial\, C/\partial\, EK$. The logarithmic partial derivative with respect to output then corresponds to the revenue cost-share. By rearranging (2), we get:

$$\frac{\partial \ln C}{\partial D} = \frac{d \ln C}{dD} - s_E \frac{d \ln PE}{dD} - \frac{PEK \cdot EK}{C}\frac{d \ln EK}{dD} + s_K \frac{d \ln K}{dD}. \tag{3}$$

Equation (3) shows the sectoral difference in costs between India and Germany if the costs were adjusted for the differences in the levels of production, capital stock, and factor prices at a given point in time. If there is a disadvantage in costs of an Indian sector, then $\partial \ln C/\partial D$ is negative. The left-hand side means that with given Indian energy price, output *EK* and capital stock *K* in the German industrial environment, cost would be lower. In the production function approach *EK* = *F*(*E, K, D*), the equivalent interpretation is that output would be higher by that percentage if Indian *EK* is produced with Indian *E* and *K* in Germany. Therefore, in Germany the resources are used more efficiently. The cost gap is calculated by adjusting the difference in costs by the weighted differences in *PE*, *EK* and *K*. Since under CRTS of in *EK* and *K* and under marginal cost pricing $PEK \cdot EK = C + PK_s \cdot K$, or

$$\frac{PEK \cdot EK}{C} - \frac{PK_s \cdot K}{C} = 1$$

we can cast (3) into the expression

$$\frac{\partial \ 1\text{n}\, C}{\partial D} = \frac{d \ 1\text{n}\, C}{dD} - s_E \frac{d \ 1\text{n}\, PE}{dD} - \frac{d \ 1\text{n}\, EK}{dD} - \frac{PK_s \cdot K}{C} \frac{d \ 1\text{n}\, (EK/K)}{dD}. \quad (3')$$

An increase in capital productivity *EK/K* in India would lower the positive term $\frac{d \ 1\text{n}\, (EK/K)}{dD}$ and would therefore reduce the Indian productivity gap.

As a discrete approximation of the Divisia Index (3), we use the Törnquist index. Then the cost gap s_D can be calculated as:

$$\begin{aligned} s_D &= 1\text{n}\, C(G) - 1\text{n}\, C(I) - \overline{s}_E(1\text{n}\, PE(G) - 1\text{n}\, PE(I)) \\ &\quad - \overline{s}_{EK}(1\text{n}\, EK(G) - 1\text{n}\, EK(I)) + \overline{s}_K(1\text{n}\, K(G) - 1\text{n}\, K(I)) \end{aligned} \quad (4)$$

with $\overline{s}_j = \frac{1}{2}\left(s_j(G) + s_j(I)\right)$ for *j* = *E, EK, K*.

Regional differences in the cost structure of two industries result from differences in the quantities of inputs which, in turn, are determined by the level of production, by factor prices, and by the capital stock. A descriptive analysis indicates which components are accountable for the differences in costs but does not determine their contribution in explaining the differences in factor demand. Therefore, the causes for the changes in the cost gaps have to be determined by employing an econometric model.

For our CGE analysis, we use a CES specification of the restricted cost function:

$$\begin{aligned} C \ &= \ PE \cdot \left[(EK \cdot \exp(-a_0 - a_D \cdot D))^{-\rho} - (d_K + d_{K,D} \cdot D) \cdot K^{-\rho}\right]^{-\frac{1}{\rho}} \\ &\quad \cdot (d_E + d_{E,D} \cdot D)^{\frac{1}{\rho}} \end{aligned} \quad (5)$$

where $\sigma = \frac{1}{1+\rho}$ is the elasticity of substitution. The cost shares s_E, s_{EK}, s_K and the gap $s_D = \frac{\partial \ 1\text{n}\, C}{\partial D}$ can be derived by differentiating the cost function with respect to *PE*, *EK*, *K* and *D*.[6] It is

$$s_D = \frac{\partial 1\text{n}\, C}{\partial D} = \frac{-a_D + \frac{d_{K,D}}{\rho}\left(\frac{EK}{K}\right)^{\rho} \exp(-a_o \cdot \rho)}{1 - \left(\frac{EK}{K}\right)^{\rho} \exp(-a_0 \cdot \rho) \cdot d_k} + \frac{d_{E,D}}{\rho \cdot d_E} \quad (6)$$

and $\frac{\partial s_D}{\partial(\frac{EK}{K})} > 0$ gives the impact of $\frac{EK}{K}$ on the difference in costs. The positive sign means that the difference in costs ($s_D < 0$) will be reduced if capital productivity can be raised in India.

The following figure (Figure 2) presents the situation. We assume that output is the same in both countries and that the relative price of energy with respect to capital is normalized to be one in both countries in a long run equilibrium situation. Given capital shortage in India, the shadow price of capital, PK_s, in India is higher than in Germany, implying the less steep slope of the iso-cost line for India in its temporary equilibrium. Since capital is quasi-fixed, India does not produce at its minimal cost combination B. It has to produce at A with $\overline{K} = 3$, $E = 12.5$. If India would produce $EK = 10$ with 4.5 units of capital instead of its 3 units, it would save 3 units of energy (9.5 instead of 12.5). If it would use only 4 units of energy, it would require about 3 times as much capital than Germany. Since the Indian electricity industry is in a short-run equilibrium (*A*), investment in capital through joint implementation would help to reach the long-run equilibrium in *B*.

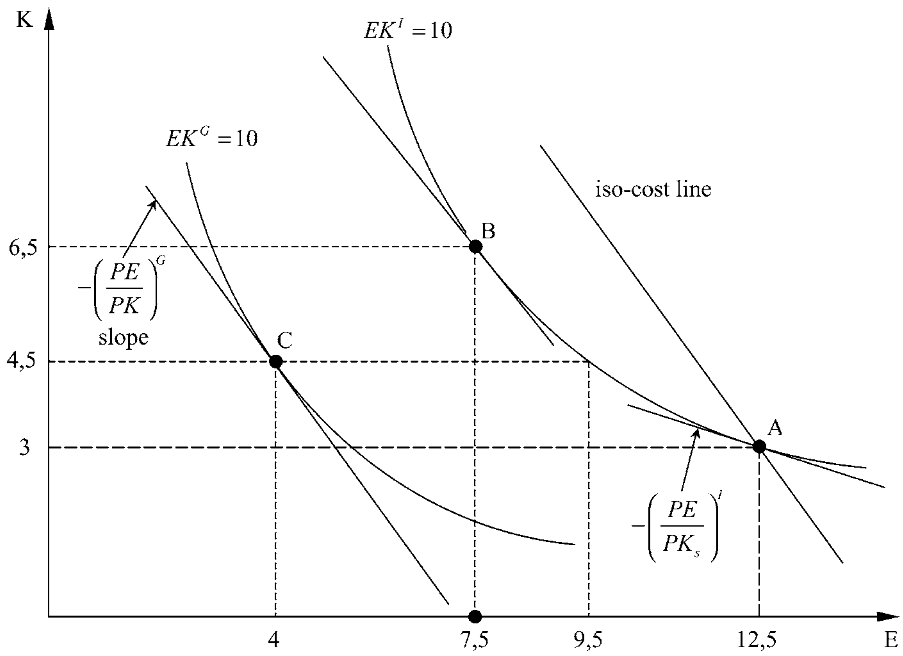

Figure 2. Productivity gaps in the electricity sector.

Since energy and capital are internationally traded goods, we assume that the slope of the iso-cost line in *B* and *C* is the same for India's and Germany's electricity sector. Since costs are lower in *B* compared to *A*, the cost gap will be reduced by becoming less negative. From the production side, the saving in costs can be used to buy more inputs and the increase in the resulting output will reduce the productivity gap. In the cost gap calculation (4) 1n $C(I)$ declines, the new s_D^{JI} will be less negative. Therefore the parameter a_0 in the Equation (6) for s_D has to be revised.[7] Its new value enters into the variable cost function and thereby into the price determination of *PEK*. Since for electricity the demand side determines the size of the aggregate *EK* (electricity can not be stored), only a CGE calculation can say whether capital productivity *EK/K* has changed. In a partial equilibrium framework, *EK/K* will not change if *K* changes because *EK* then changes by the same magnitude, due to constant returns to scale.

2.4. PARAMETERIZATION

Benchmark data are used to calibrate parameters of the functional forms from a given set of quantities, prices and elasticities. Data from two different sources are combined to yield a consistent benchmark data set for 1995:

- *GTAP4* (McDougall, Elbehri and Truong 1998). GTAP includes detailed input-output tables for 50 sectors and 45 regions with bilateral trade flows for 1995.
- *IEA energy balances and energy prices/taxes* (IEA 1996). IEA provides statistics on physical energy flows and energy prices for industrial and household demands.

We accommodate a consistent representation of energy markets in physical units by replacing GTAP's aggregate input-output monetary values for energy supply and demand with physical energy flows and energy prices as given in IEA's energy statistics. This "bottom-up" calibration of energy demands and supplies yields sector-specific and energy-specific CO_2 coefficients. The advantage is that marginal abatement cost curves, and hence the cost evaluation of emission constraints, are based on actual energy flows rather than on aggregate monetary data, which strengthens the credibility of the quantitative results. The magnitude of efficiency gains from JI depend crucially on the emission structure in the Indian and German economy.

3. Scenarios and Results

Within the EU burden sharing agreement under the Kyoto Protocol, Germany is obligated to reduce its greenhouse gas emissions by 21% during the period 2008–2012 as compared to its 1990 emission level (EC 1999). Independent of this international commitment, the German government adopted a much more ambitious national climate policy plan which foresees a reduction of domestic carbon emissions by 25% in 2005 vis-à-vis the emission level in 1990. In our simulations, we refer to the 25% reduction target and apply it to our benchmark situation for 1995.[8]

We distinguish two alternative policy scenarios how Germany can meet its reduction target. The first scenario ETR refers to an environmental tax reform in

Table II. Welfare, unemployment, marginal abatement cost, emission reductions

	ETR	JI
Welfare in Germany[a]	–0.47	–0.26
Welfare in India[a]	–	2.49
Unemployment in Germany[a]	0.22	–0.49
Marginal Abatement Cost[b]	61	33
Emission reduction in Germany[c]	242	154
Emission reduction in Indian electricity sector[c]	–	88

[a]percentage change.
[b]in USD_{95} per ton of CO_2.
[c]in mio. tons CO_2.

Germany where carbon taxes are levied in order to meet the domestic emission constraint. Carbon taxes are recycled in a revenue-neutral way to lower labor costs. The second scenario JI allows for joint implementation with the Indian electricity sector. Germany's reduction target can be met by domestic abatement as well as emission reduction undertaken in the Indian power sector. Table II summarizes the implications of the two different abatement scenarios for inframarginal welfare (measured in terms of Hicksian-equivalent variation), unemployment and marginal abatement costs.

3.1. WELFARE

An environmental tax reform *stand-alone* is far more costly for Germany than carbon taxes supplemented with joint implementation. Under ETR a carbon tax of roughly 60 USD is required to cut down Germany's carbon emissions by 25 per cent. With JI the carbon tax can be reduced to about 30 USD while ensuring the same overall environmental effectiveness. Lower domestic abatement efforts reduce costly reallocation of resources towards less carbon-intensive production (see Table III for the sectoral effects on production).[9] Except for direct efficiency gains from joint abatement under JI, Germany benefits from demand for energy-efficient power plants which triggers additional income. Whereas ETR induces welfare costs of roughly 0.5 per cent, JI offsets largely these adverse effects of carbon emission constraints. As expected, India is not affected by ETR undertaken in Germany. With JI, however, India experiences a large increase in welfare (almost 2.5 per cent). The latter stems from the substantial productivity increase in electricity production due to the capital stock augmentation through JI.

3.2. UNEMPLOYMENT

Our simulations indicate that higher carbon taxes as necessary under ETR are not likely to yield an employment double dividend given the initial tax distortions and

Table III. Sectoral effects on production and employment (percentage change)

	GER		IND
	ETR	JI	JI
Production			
COL	–32.31	–20.96	–2.32
GAS	–4.22	–3.21	1.83
OIL	–4.76	–2.58	0.33
ELE	–4.95	–2.76	18.24
EIS	–3.11	–1.69	6.38
TRN	–0.06	–0.03	3.03
OME	0.69	0.50	2.65
CNS	–0.11	0.07	0.52
Y	–0.44	–0.18	1.22
Employment			
COL	–52.90	–38.67	–26.02
GAS	–6.98	–5.33	13.62
OIL	–6.66	–3.67	3.16
ELE	–0.43	–0.19	9.63
EIS	–1.86	–0.99	1.61
TRN	0.20	0.11	–0.87
OME	0.87	0.62	0.21
CNS	–0.03	0.12	–2.20
Y	–0.05	0.05	0.13

labor market imperfections in Germany. Carbon tax revenues under ETR amount to nearly 45 bill. USD which accommodates a reduction in labor costs of about 5 per cent. The implied positive substitution effects get, however, more than offset by negative output effects due to higher energy prices. JI reduces the negative impact of carbon abatement on employment in Germany. With JI, carbon taxes are reduced and carbon tax revenues fall to 27 billion USD. As a consequence, labor costs can be lowered by only 3 percent which weakens the substitution effect in favor of labor. On the other hand, the negative output effect is reduced as well – with positive implications for labor demand. In addition, there are direct positive effects on output demand and employment associated with investment under JI.

3.3. EMISSIONS

Under ETR Germany must cut down emissions from 972 mio. tons CO_2 to 730 mio. tons CO_2. Entering JI with India, Germany's emissions rise to 818 mio. tons

CO_2. In other words, India takes over carbon abatement of 88 mio. tons CO_2 as emissions in the Indian electricity sector decline from 353 mio. tons to 265 mio. tons CO_2. Germany then only fulfills 64 per cent of its national reduction target domestically – the remaining 36 percent is delivered by abatement measures in the Indian power sector. It should be noted, that JI only considers emission abatement in the Indian power sector, i.e., indirect (general equilibrium) effects on emissions by other sectors of the Indian economy are not taken into account. In fact, there is intersectoral carbon leakage for India since increased overall economic activity triggered by JI leads to a rise in carbon emissions of the non-electric production sectors. The "intersectoral" leakage rate, which can be measured as the ratio between the emission increase in the non-electric sectors over emission reduction in power generation, amounts to 56%. From the point of view of global environmental effectiveness, these non-negligible leakage effects of JI should be taken into account although – in political practice – severe problems with respect to the proper determination of the macro-baseline might occur.

3.4. COST GAP REDUCTION

Through joint implementation the capital stock in the Indian electricity sector increases by about 14 percent. The reduction in costs due to the movement of the temporary equilibrium towards the long-run equilibrium (which is characterized by less energy and more capital input) results in a significant decline of the electricity price in India. The zero profit condition for the Indian electricity sector states:

$$PELE \cdot ELE = C(ELE; PE, PK, PL) + AC(A^I) - A^I \cdot P^{CO2}.$$

The costs of abating CO_2 ($AC(A_I)$) are added to the cost of production and the revenues from selling permits at the permit price P^{CO2} are subtracted. Since the revenue is higher than the cost of abatement, the resulting profit (see the area *LNK* in Figure 1) can be used to lower the price *PELE* of electricity. Although the price *PE* of fossil fuel increases by the price of a permit (see Table IV), the price index of electricity in India declines significantly from 1 to 0.72. As the fossil fuel mix of India has higher CO_2 emission coefficients, the price *PE* in India is higher than this price in Germany. Energy intensity *E/K* drops from 0.40 to 0.27 for India and from 0.33 to 0.26 for Germany. Capital productivity *EK/K* increases from 1.19 to 1.22 for India and decrease from 1.33 to 1.25 for Germany. Overall, *JI* improves the performance of the Indian economy and narrows the productivity gap in the Indian electricity sector with respect to the German sector. The initial gap s_D = –0.67 is reduced to s_D^{JI} = –0.11 with JI.

4. Conclusions

Carbon taxes which are sufficiently high to achieve substantial domestic emission reductions would have non-negligible adverse impacts on welfare and employment

Table IV. Effects of JI on the electricity sector

	Benchmark		JI	
	IND	GER	IND	GER
K (in bill. USD)	1,46	2,39	1,68	2,39
PK	1.44	1	1.15	0.99
E (in bill. USD)	0,58	0,79	0,45	0,63
PE	1	1	2.15	1.58
EK (in bill. USD)	1,73	3,18	2,05	2,99
PEK	1.55	1	1.41	1.12
PELE	1	1	0.72	1.05

in Germany. JI can help to reduce these negative effects through the associated cost savings and additional investment demand from JI host countries. There are, however, some important remarks on the representation of JI in our analytical framework: Planning and implementation of JI projects in a developing country like India typically involve considerable control and transaction costs. These costs may reduce the attractiveness of JI. In our analysis we have neglected this aspect, mainly because of a lack in accurate data. We also did not consider the problem that JI between Annex I and non-Annex I countries provides an incentive for the parties to overstate baseline emission levels in order to generate additional emission rights. Furthermore, our analysis is restricted to carbon emission constraints for *one* industrialized country, Germany, that can be met through purely domestic action or via joint implementation with *one* developing country, India. A broader setting, which allows for the incorporation of emission constraints on several industrialized countries as well as joint implementation with all developing countries (as foreseen under the Kyoto Protocol) may affect our quantitative results: For example, a larger reduction of global fossil fuel demand by the industrialized world will depress international fossil fuel prices which provides substantial terms-of-trade gains for fuel importers and terms-of-trade losses for fuel exporters (see Böhringer and Rutherford 2002). Likewise, the demand and supply schedule for joint implementation projects will be affected by the increased number of participating countries. However, the key mechanisms of JI elaborated in our paper apply independently of such a more general setting.

The implications of our results for ongoing negotiations may be important. Many developing countries have reservations about joint implementation which might be considered as a pre-stage of binding international emission reduction objectives for the developing world. Moreover, some developing countries regard compensation projects as a cheap buy-out option for the industrialized world from their historic obligation to reduce greenhouse gas emissions. However, JI may be the only possibility for developing countries like India to equip its electricity industry with scarce capital goods yielding large welfare gains through more efficient power production and lower electricity prices. As to future research, an intertemporal analysis of the process of capital accumulation in developing countries towards the long-run equilibrium would be desirable in order to shed more light on the dynamic aspects of joint implementation.

Acknowledgement

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Notes

1. For a survey on the double-dividend literature see Goulder (1995) and Bovenberg (1997).
2. Under Articel 6, countries with emission reduction targets (Annex I countries) may fund joint implementation projects in other Annex I countries in return for "emission reduction units", which may be supplemental to domestic actions for the purpose of meeting the commitments. Articel 12 defines the Clean Development Mechanism (CDM) as joint implementation between Annex I and non-Annex I countries. In the following, we only refer to joint implementation as the general concept.
3. For detailed information on joint implementation see Kuik et al. (1994), Jackson (1995) and Jepma (1995).
4. We assume that JI abatement is fully credible towards domestic abatement requirements and that there is no minimum share for domestic abatement. For other specifications see Cansier and Krumm (1996), p. 165.
5. India's electricity sector is largely in the responsibility of State Electricity Boards (SEBs). Almost all SEBs are making losses and are nearly bankrupt. Therefore the electricity sector in India has been suffering a severe shortfall in investment resources. See Bose and Shukla (1999).
6. See Appendix C for the calibration of the parameters under a temporary equilibrium and a cost gap.
7. If policy instruments are to be considered to close the gap, then instruments like research and development or infrastructure have to be introduced as arguments into the cost function.
8. To avoid speculation on the future economic development and baseline emissions for Germany (see e.g., Böhringer, Jensen and Rutherford 2000), we abstain from the forward-calibration of the 1995 economy to 2005.
9. Coal production in India only decreases by 2.3% even though coal inputs into power generation under JI decline by 28% to accommodate the substantial cutback in carbon emissions in this sector. The reason is that the reduced coal demand in the electricity sector leads to a substantial fall in the output price of coal which, in turn, increases coal demand in other sectors. This also explains the "sectoral leakage" effect described below. In addition, the large decrease in the market price of coal by about 40% exerts a strong cost pressure which results in the dismissal of 26% of the labor force in coal production.

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Appendix A (Algebraic Model Summary)

This appendix provides an algebraic summary of the equilibrium conditions for the generic comparative-static model without unemployment. Two classes of conditions characterize the competitive equilibrium: zero profit conditions and market clearance conditions. The former class determines activity levels and the latter determine price levels. In our algebraic exposition, the notation Π_i^z is used to denote the profit function of sector i where z is the name assigned to the associated production activity. Differentiating the profit function with respect to input and output prices provides compensated demand and supply coefficients (Shephard's lemma), which appear subsequently in the market clearance conditions. Table V explains the notations for variables and parameters. Key elasticities are summarized in Table VI For the sake of transparency, we do not write down the explicit functional forms but instead use the acronyms CET (constant elasticity of transformation), CES (constant elasticity of substitution), CD (Cobb-Douglas) and LT (Leontief) to indicate the class of functional form in place.

ZERO PROFIT CONDITIONS

Competitive producers operating a constant return to scale technology earn zero profit in equilibrium. Profit maximization under constant returns to scale thus implies that the output price equals the unit cost functions. The value of output to the firms equals the value of sales in the domestic and the export markets. Costs of production include factor inputs and intermediate inputs.

Table V. Sets, activity and price variables, endowments

Sets:	
I, i, j	Sectors and goods
E, e	Energy goods (COL, OIL, GAS and ELE)
N, n	Non energy goods
F, f	Fossil fuels (COL, CRU, GAS)
V, v	Non fossil fuels and electricity
r, s	Regions: GER = Germany, IND = India
d	Demand categories: Y = intermediate, C = hh., Z = gov., INV = investment
Activity variables:	
Y_i	Aggregate production
E_i	Aggregate energy input
M_i	Aggregate imports
A_i^d	Armington aggregate for demand category d
U	Household utility
C	Private consumption
Z	Government consumption
EXP	JI permit export from India to Germany
Price variables:	
P_i	Output price
PE_i	Price of aggregate energy
PA_i^d	Price of Armington aggregate
PM_i	Price of import aggregate
PU	Utility price index
PC	Price of aggregate household consumption
PZ	Price of government consumption
PL	Wage rate
PK_i	Price of capital services
PQ_f	Rent from natural resource
$PINV$	Price of investment demand
PFX	ROW export and import price
P^{CO2}	Price of carbon permit
Endowments:	
$\overline{L}$	Aggregate labor endowment
$\overline{K}_i$	Aggregate capital endowment
$\overline{Q}_f$	Endowment of natural resource
$\overline{INV}$	Aggregate investment demand
$\overline{B}^r$	Balance of payment surplus
$\overline{CO2}$	Endowment of carbon emission rights (Germany)
$\overline{CO2}_{ELE}$	Endowment of carbon emission rights in the Indian electricity sector
Other parameters	
a_{di}^{CO2}	Carbon coefficient
b_i	Share of JI investment demand directed to sector *i*

Table VI. Selected elasticities

Substitution elasticities in non-fossil fuel production (except electricity)	
Capital-labor-energy vs. intermediates	0
Capital-energy vs. labor	0.3
Capital vs. energy	0.5
Electricity vs. primary energy inputs	0.25
Gas-oil vs. coal	0.5
Gas vs. oil	0.9
Substitution elasticities in electricity production	
Capital-energy vs. labor	0.5
Gas vs. coal	4
Substituion elasticities in final demand	
Energy goods vs. non-energy goods	0.5
Non-energy goods vs. non-energy goods	1
Energy goods vs. energy goods	1
Substitution elasticities in government demand	
Fossil fuels vs. non-fossil fuels	1
Fossil fuels vs. fossil fuels	0.3
Elasticities in international trade (Armington)	
Substitution elasticity imports vs. domestic inputs	2
Substitution elasticity imports vs. domestic inputs for GAS and ELE	0.75
Substitution elasticity imports vs. imports	4
Substitution elasticity imports vs. imports for GAS and ELE	1.5
Transformation elasticity domestic vs. export2	
Supply elasticities	
CRU and GAS production	1
COA production	0.5

Production of goods except fossil fuels and electricity:

$$\begin{aligned}\Pi_i^Y &= CET(PEX_i, P_i)\\ &-LT\left[PA^Y_{n,n\in N}, PA^Y_{CRU}, CES(PL, CES(PK_i, PE_i))\right] = 0 \qquad \forall\, i \in V \qquad \text{(A1)}\end{aligned}$$

Production of fossil fuels:

$$\Pi_i^Y = CET(PEX_i, P_i) - CES\left[PR_i, LT(PA^Y_{j,j\in I}, PK_i, PL)\right] = 0 \quad \forall\, i \in F \quad \text{(A2)}$$

Production of electricity:

$$\begin{aligned}\Pi_{ELE}^Y &= CET(PFX_{ELE}, P_{ELE})\\ &-LT\left[PA^Y_{n,n\in N}, PA^Y_{OIL}, CES(PL, C(PE_{ELE}, K_{ELE}, EK_{ELE}, D))\right] = 0 \quad \text{(A3)}\end{aligned}$$

Sector-specific energy aggregate:

$$\Pi_i^E = PE_i - CES\left[PA_{ELE}^Y, CES(PA_{COL}^Y, CES(PA_{GAS}^Y, PA_{OIL}^Y))\right] = 0 \quad \forall\, i \in V$$

$$\Pi_{ELE}^E = PE_{ELE} - CES(PA_{GAS}^Y, PA_{COL}^Y) = 0 \tag{A4}$$

Armington aggregate:

$$\Pi_{di}^A = PA_i^d - CES(P_i, PM_i) - P^{CO2} a_{di}^{CO2} = 0 \tag{A5}$$

Aggregate imports across import regions:

$$\Pi_i^{M,r} = PM_i^r - CES(P_i^s, PEX) = 0 \tag{A6}$$

Investment:

$$\Pi^{INV} = PINV - LT(PA_{i,i \in I}^{INV}) \tag{A7}$$

Public demand:

$$\Pi^Z = PZ - CD(PA_{n,n \in N}^Z, CES(PA_{e,e \in E}^Z)) = 0 \tag{A8}$$

Household consumption demand:

$$\Pi^C = PC - CES(CD(PA_{n,n \in N}^C), CD(PA_{e,e \in E}^C)) = 0 \tag{A9}$$

Utility production:

$$\Pi^U = PU - CES(PC, PL) = 0 \tag{A10}$$

MARKET CLEARANCE CONDITIONS

Labor:

$$\overline{L} = \sum_i Y_i \frac{\partial \Pi_i^Y}{\partial PL} + U \frac{\partial \Pi^U}{\partial PL} \tag{A11}$$

Capital:

$$\overline{K}_i = Y_i \frac{\partial \Pi_i^Y}{\partial PK_i} \tag{A12}$$

Natural resources:

$$\overline{Q}_f = Y_f \frac{\partial \Pi_f^Y}{\partial PR_f} \tag{A13}$$

Domestic output:

$$Y_i \frac{\partial \Pi_i^Y}{\partial P_i} = \sum_d A_i^d \frac{\partial \Pi_{di}^A}{\partial P_i} \tag{A14}$$

Sector specific energy aggregate:

$$E_i = Y_i \frac{\partial \Pi_i^Y}{\partial PE_i} \tag{A15}$$

Import aggregate:

$$M_i = \sum_d A_i^d \frac{\partial \Pi_{di}^A}{\partial PM_i} \tag{A16}$$

Armington aggregate:

$$A_i^Y = \sum_j Y_j \frac{\partial \Pi_j^Y}{\partial PA_i^Y} + INV \frac{\partial \Pi^{INV}}{\partial PA_i^{INV}}, A_i^C = C \frac{\partial \Pi^C}{\partial PA_i^C}, A_i^Z = Z \frac{\partial \Pi^Z}{\partial PA_i^Z} \tag{A17}$$

Foreign closure:

$$\sum_r \sum_i PFX \frac{\partial \Pi_i^{Y,r}}{\partial PFX} \cdot Y_i^r = \sum_r \sum_i PFX \frac{\partial \Pi_i^{M,r}}{\partial PFX} M_i^r + \sum_r \overline{B}^r \tag{A18}$$

Household consumption:

$$\begin{aligned} C \cdot PC = {} & PL \cdot \overline{L} + \sum_i PK_i \cdot \overline{K}_i + \sum_f PQ_f \cdot \overline{Q}_f \\ & - PINV \cdot \overline{INV} - PC \cdot \overline{B}^r \qquad\qquad r = IND \end{aligned}$$

$$\begin{aligned} C \cdot PC + (\overline{L} - L) \cdot PL = {} & PL \cdot \overline{L} + \sum_i PK_i \cdot \overline{K}_i + \sum_f PQ_f \cdot \overline{Q}_f \\ & - PINV \cdot \overline{INV} - PC \cdot \overline{B}^r \qquad\qquad r = GER \end{aligned} \tag{A19}$$

Government consumption:

$$Z \cdot PZ = P^{CO2} \cdot \overline{CO2} + other\ taxes \tag{A20}$$

Government output:

$$\overline{Z} = Z \tag{A21}$$

Investment:

$$\overline{INV} = INV \tag{A22}$$

Carbon emissions:

$$\overline{CO2} = \sum_d \sum_i A_i^d a_{di}^{CO2} \tag{A23}$$

REPRESENTATION OF JOINT IMPLEMENTATION

Market clearance for Armington aggregate with additional investment demand through JI:

$$A_i^Y = \sum_j Y_j \frac{\partial \Pi_j^Y}{\partial PA_i^Y} + INV \frac{\partial \Pi^{INV}}{\partial PA_i^{INV}} + b_i \cdot EXP \cdot P^{CO2} \qquad (A17')$$

(Sectoral) carbon emissions constraints:

$$\overline{CO2} + EXP = \sum_d \sum_i A_i^d a_{di}^{CO2} \qquad r = GER \qquad (A23')$$

$$\overline{CO2}_{ELE} + EXP = \sum_d A_{ELE}^d a_{d,ELE}^{CO2} \qquad r = IND \qquad \text{(A24)}$$

Appendix B (Labor Market Specification)

Unemployment in Germany is generated by the existence of a "wage curve", which postulates a negative relationship between the real wage rate and the rate of unemployment:

$$\frac{PL}{PC} = g(ur), \quad g' < 0,$$

with PC the consumer goods price index and ur ≡ (L^S – L^D)/L^S, the unemployment rate. The wage curve replaces the labor supply curve (Figure 3). Consequently, the equilibrium wage rate *(PL/PC)* lies above the market clearing wage rate *(PL/PC)** leading to benchmark unemployment (L^S–L^D). We use a simple specification of the wage curve as a log-linear equation

$$\log\left(\frac{PL}{PC}\right) = \gamma_0 + \gamma_1 \log(ur) - \log\theta,$$

with γ_0 a positive scale parameter, $\gamma_1 < 0$ the elasticity of the real wage in relation to the unemployment rate and $(1 - \theta)$ the tax wedge between the employers' gross wage costs and the employees' net wages with $\theta \equiv \frac{1-\tau_w}{1+\tau_L}$. If the household is rationed on the labor market, the budget restriction changes in so far as the actual net wage income is by determined $PL \cdot (1 - \tau_w) \cdot L^D$. Welfare effects are also based on enforced leisure consumption.

Appendix C (Calibration of Parameters under a Temporary Equilibrium and a Cost Gap)

In this section the calibration of a joint production function for the electricity producing industry is described, where the Indian sector is in a temporary equilibrium including a productivity gap.

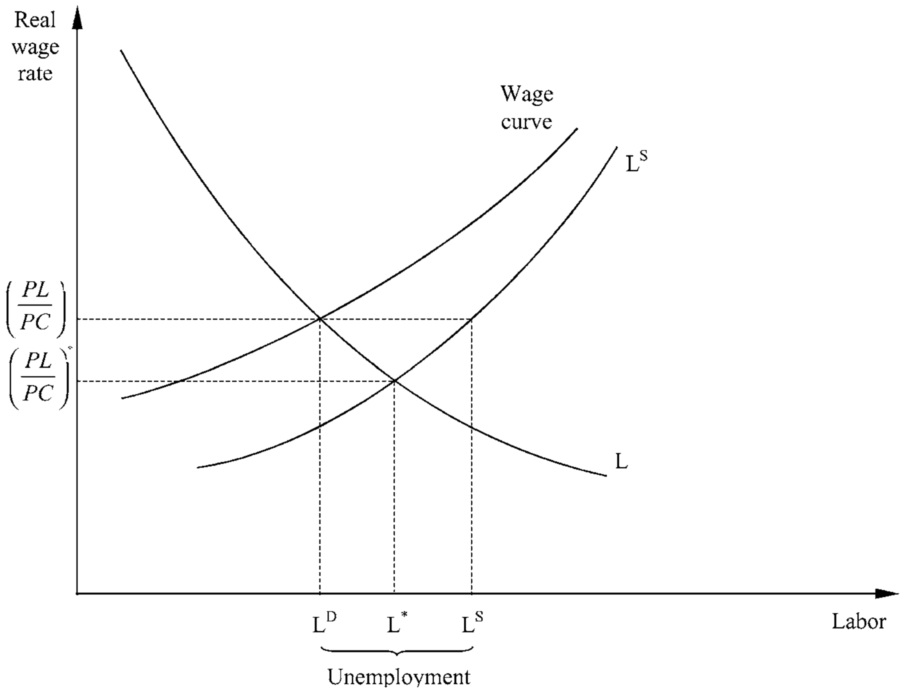

Figure 3. Wage curve and equilibrium unemployment.

The joint CES production function is:

$$EK = \exp(a_0 + a_D \cdot D) \cdot \left[(d_E + d_{E,D} \cdot D) \cdot E^{-\rho} + (d_K + d_{K,D} \cdot D) \cdot K^{-\rho}\right]^{-1/\rho} \tag{C1}$$

where $\sigma = \frac{1}{1+\rho}$ is the elasticity of substitution. The cost-minimizing input coefficients are

$$\frac{E}{EK} = (d_E + d_{E,D} \cdot D)^{\sigma} \left(\frac{PEK}{PE}\right)^{\sigma} \cdot \exp[(a_0 + a_D \cdot D) \cdot (-\rho \cdot \sigma)] \tag{C2}$$

$$\frac{K}{EK} = (d_K + d_{K,D} \cdot D)^{\sigma} \left(\frac{PEK}{PE}\right)^{\sigma} \cdot \exp[(a_0 + a_D \cdot D) \cdot (-\rho \cdot \sigma)] \tag{C3}$$

where $(a_0 + a_D) = 0$.

We start from benchmark data for Germany *(D = 1)* (Table VII) and assume $\sigma = 0.5$, i.e., $\rho = 1$. We obtain from (C2) and (C3):

$$d_E + d_{E,D} = 0.062, \quad d_K + d_{K,D} = 0.563. \tag{C4}$$

Energy input for India is $E^I = 0.582$. In order to construct a figure for the capital stock, we assume that energy efficiency is lower by 20 percent in India. Since $(E/K)^G$ is 0.333 in Germany, we assume that $(E/K)^I = 0.333 \cdot 1.20 = 0.399$ (see Figure 4).

Table VII. Benchmark data for the German electricity sector

K^G (in bill. USD)	2,386
PK^G	1
E^G (in bill. USD)	0,794
PE^G	1
EK^G (in bill. USD)	3,180
PEK^G	1

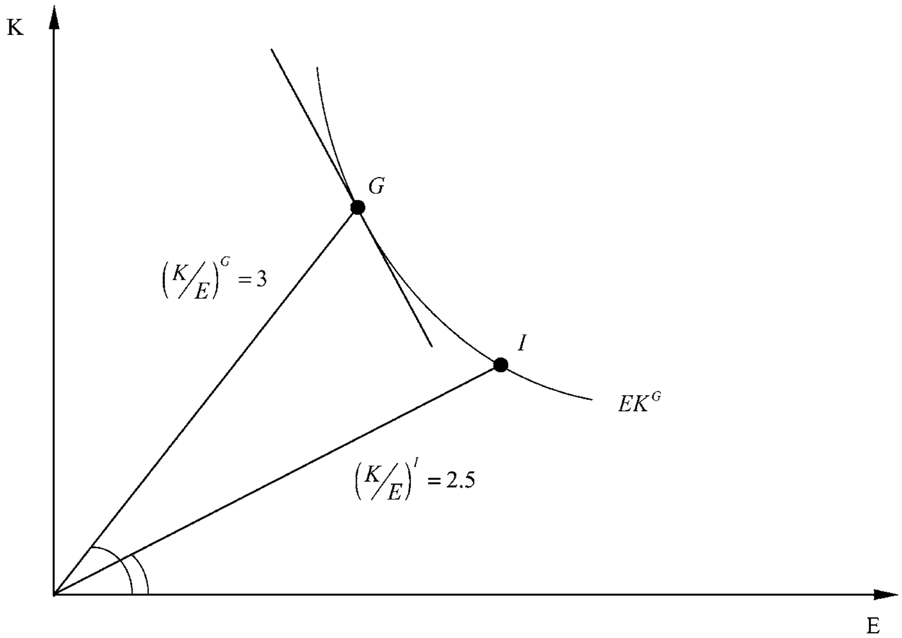

Figure 4. Energy efficiency in Germany and India.

We assume $PE^I = 1$ which implies a shadow price of capital for India larger than one. For calculating this shadow price *PK* for India we assume that India is in *I* on the isoquante in a temporary equilibrium. From *MRS* = $(PE/PK)^I$ we determine PK^I:

$$MRS = \frac{d_E + d_{E,D}}{d_K + d_{K,D}} \left(\frac{K}{E}\right)^{I_{\rho+1}} = \left(\frac{PE}{PK}\right)^I \tag{C5}$$

Since $(E/K)^I$ = 0.399 and E^I = 0,582 we obtain K^I = 1,457 and from (5) PK^I = 1.44. We finally assume an efficiency gap of 15 percent, i.e., $EK^I = 0.85(K^I + E^I)$ = 1,733. The efficiency term in (C1) becomes therefore exp(–0.163 + 0.163 · *D*), i.e., a_0 = –0.163,

Table VIII. Calibrated benchmark data for the Indian electricity sector

K^I (in bill. USD)	1,457
PK^I	1.440
E^I (in bill. USD)	0,582
PE^I	1
EK^I (in bill. USD)	1,733
PEK^I	1.547

a_D = 0.163. The productivity gap will be higher than 15 percent because of the temporary equilibrium situation. The price *PEK* comes from the zero profit condition

$$PEK^I \cdot EK^I = PK^I \cdot K^I + PE^I \cdot E^I = 2.681$$

that is, PEK^I = 1.547. The data for India are summarized in Table VIII.

Using these data we can determine d_E and d_K from (C2) and (C3):
$d_E = 0.062, d_K = 0.560$
and from (4):
$d_{E,D} = 0.0004, d_{K,D} = 0.003$.

We can then calculate the productivity gap in terms of the dual cost gaps according to (4):

$$\begin{aligned} s_D &= 1\mathrm{n}\frac{0.794}{0.582} - \frac{1}{2} \cdot \left(\frac{2.681}{0.582} + \frac{3.180}{0.794}\right) \cdot 1\mathrm{n}\frac{3.180}{1.733} \\ &\quad + \frac{1}{2} \cdot \left(\frac{2.098}{0.582} + \frac{2.386}{0.794}\right) \cdot 1\mathrm{n}\frac{2.386}{1.457} = -0.672 \end{aligned}$$

In order to derive the variable or restricted cost function *C(PE, EK, K, D)* we insert *E*, derived from (C1), into $C = PE \cdot E$ and obtain:

$$\begin{aligned} C &= PE \cdot \left[(EK \cdot \exp(-a_0 - a_D \cdot D))^{-\rho} - (d_K + d_{K,D} \cdot D) \cdot K^{-\rho}\right]^{-1/\rho} \\ &\quad \cdot (d_E + d_{E,D} \cdot D)^{1/\rho} \end{aligned}$$

It is

$$PK^I = -\frac{\partial C}{\partial K} = 1.44$$

and

$$s_D = \frac{\partial 1\mathrm{n}\, C}{\partial D} = -\frac{EK^{-\rho} \cdot a_D \exp(a_0 \cdot \rho) - \frac{K^{-\rho} \cdot d_{K,D}}{\rho}}{EK^{-\rho} \cdot \exp(a_0 \cdot \rho) - K^{-\rho} \cdot d_K} + \frac{d_{E,D}}{\rho \cdot d_E}. \tag{C6}$$

If $|s_D|$ gets smaller, a_0 in (C6) captures this effect and *PEK* from

$$PEK = \frac{C(\cdot)}{EK} + \frac{PK \cdot K}{EK}$$

will decline. If a new gap s_D has been calculated according to the residual method (4), then a_0 follows from (C6) by solving it for a_0, with $a_D = -a_0$, since Germany's efficiency is not affected by joint implementation ($a_0 + a_D \cdot D = 0$ for $D = 1$). With joint implementation the gap decreases to $s_D^{JI} = -0.109$ and a_0 becomes $a_0 = -0.038$.
Finally, from profit maximization it is $PEK = \frac{\partial C}{\partial EK}$, or, in a revenue share:

$$\frac{PEK \cdot EK}{C} = \frac{EK^{-\rho} \cdot \exp((a_0 + a_D \cdot D) \cdot \rho)}{EK^{-\rho} \cdot \exp((a_0 + a_D \cdot D) \cdot \rho) - (d_K + d_{K,D} \cdot D) \cdot K^{-\rho}}.$$

With German or Indian data, given the calibration, this condition is satisfied. Solved for *EK* it is the supply function which we do not need because demand in the CGE framework will in any case be supplied.