Carbon Taxes and Joint Implementation

An applied general equilibrium analysis for Germany and India

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Non-technical summary

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 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* 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 general equilibrium model for Germany and India where Germany may undertake joint implementation with the Indian electricity sector. Our main finding is that joint implementation offsets 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.

JEL classification: D 24, D58, F20, Q25

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

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 inefficiences 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

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[1] For a survey on the double-dividend literature see Goulder (1995) and Bovenberg (1997).

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 model for Germany and India where Germany may undertake joint implementation with the Indian electricity sector. Our main finding is that joint implementation offsets 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 provides small welfare and 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.

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.

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[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).

2. Analytical Framework

2.1 Basic Model

This section presents the main characteristics of a comparative-static multi-sector model for the German and Indian economies (see Appendix A for the algebraic model formulation). The choice of production sectors 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 intersectorally mobile within each region, but cannot move between regions. Capital is sector specific and internationally immobile. Capital stocks are assumed to be not in the long-run equilibrium. The model captures only short-run adjustment. 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 1 summarizes the sectors, countries and primary factors incorporated in the model.

Table 1

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				

Production

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

In the production of commodities other than primary fossil fuels and electricity, intermediate non-energy goods and crude oil 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, crude oil and refined oil products 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.

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 exogenously given price elasticities of fossil fuel supplies.

Privat 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.

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.

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).

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. To 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.

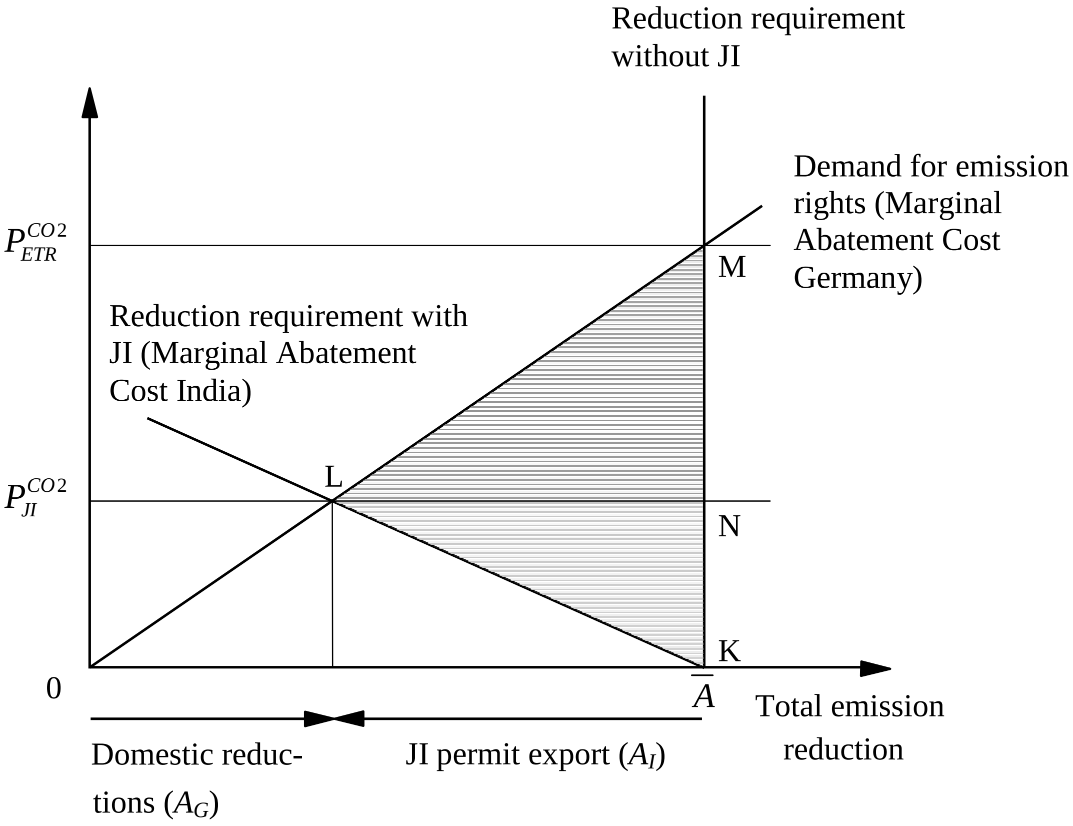

Figure 1: Joint Implementation Mechanism

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

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[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.

manufacturing industries. Additional revenues from permits reduce the electricity price in India.

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:*

$$C = C(PE, EK, K, D) \qquad (1)$$

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

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[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).

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:

$$(2) \qquad \frac{d \ln C}{d\,D} = s_E \frac{d \ln PE}{d\,D} + \frac{\partial \ln C}{\partial \ln EK}\frac{d \ln EK}{d\,D} + \frac{\partial \ln C}{\partial \ln K}\frac{d \ln K}{d\,D} + \frac{\partial \ln C}{\partial\,D}$$

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.:

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

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:

$$(3) \qquad \frac{\partial \ln C}{\partial\,D} = \frac{d \ln C}{d\,D} - s_E \frac{d \ln PE}{d\,D} - \frac{PEK \cdot EK}{C}\frac{d \ln EK}{d\,D} + s_K \frac{d \ln K}{d\,D}\,.$$

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 $C(\cdot)$ 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

$$\text{(3')} \qquad \frac{\partial \ln C}{\partial D} = \frac{d \ln C}{d D} - s_E \frac{d \ln PE}{d D} - \frac{d \ln EK}{d D} - \frac{PK_s \cdot K}{C} \frac{d \ln (EK/K)}{d D}.$$

An increase in capital productivity EK/K in India would lower the positive term $\frac{d \ln (EK/K)}{d D}$ 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:

$$\text{(4)} \qquad \begin{aligned} s_D = {} & \ln C(G) - \ln C(I) - \overline{s}_E \left(\ln PE(G) - \ln PE(I)\right) \\ & - \overline{s}_{EK} \left(\ln EK(G) - \ln EK(I)\right) + \overline{s}_K \left(\ln K(G) - \ln K(I)\right) \end{aligned}$$

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:

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

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

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

and $\frac{\partial s_D}{\partial \left(\frac{EK}{K} \right)} > 0$ 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 $\bar{K}$ = 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*. 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*,

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[6] See Appendix C for the calibration of the parameters under a temporary equilibrium and a cost gap.

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) $\ln C(I)$ 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. 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.[7] 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.

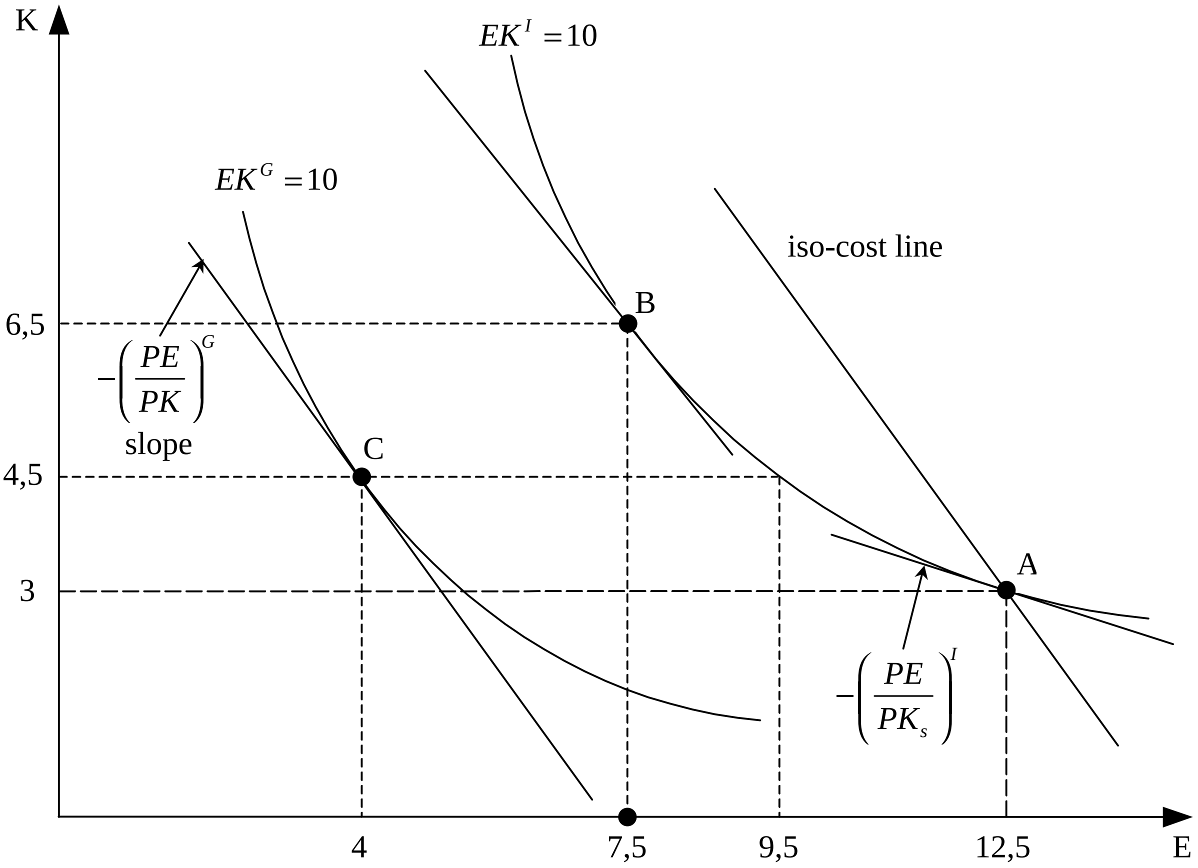

Figure 2: Productivity gaps in the electricity sector

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[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.

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

In our simulations we distinguish two scenarios. Our first scenario ETR refers to an environmental tax reform in Germany where carbon taxes are levied in order to meet a 25 percent reduction of domestic emissions as compared to 1990 emission levels. 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 1 summarizes the implications of the two different abatement scenarios for infra-marginal welfare (measured in terms of Hicksian-equivalent variation), unemployment and marginal abatement costs.

Table 1

Welfare, unemployment, marginal abatement cost, emission reductions (percentage change)

	ETR	JI
Welfare in Germany	-0.47	0.03
Welfare in India	-	3.16
Unemployment in Germany	0.22	-0.37
Marginal Abatement Cost*	61.36	17.82
Emission reduction in Germany**	242	129
Emission reduction in India**	-	113

* in USD_{95} per ton of CO_2

** in mio. tons CO_2

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 less than 20 USD while ensuring the same overall environmental effectiveness. Lower domestic abatement efforts reduces costly reallocation of resources towards less carbon-intensive production (see Table 2 for the sectoral effects on production). 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 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 (more than 3 per cent). The latter stems from the substantial productivity increase in electricity production due to the capital stock augmentation through JI.

Table 2

Sectoral effects on production and employment (percentage change)

	GER		IND
	ETR	JI	JI
Production			
COL	-32.31	-16.87	-2.87
GAS	-4.22	-5.90	-0.78
OIL	-4.76	-1.22	0.33
ELE	-4.95	1.79	22.94
EIS	-3.11	-0.29	8.54
TRN	-0.06	0.18	3.73
OME	0.69	0.19	3.27
CNS	-0.11	0.14	0.66
Y	-0.44	0.13	1.52
Employment			
COL	-52.90	-32.64	-30.41
GAS	-6.98	-9.67	-5.06
OIL	-6.66	-1.74	3.19
ELE	-0.43	-0.24	3.00
EIS	-1.86	-0.14	2.18
TRN	0.20	0.18	-0.99
OME	0.87	0.22	0.33
CNS	-0.03	0.16	-2.59
Y	-0.05	0.20	0.24

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 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 15 billion USD. As a consequence, labor costs can be lowered by only 2 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.

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 843 mio. tons CO_2. In other words, India takes over carbon abatement of 113 mio. tons CO_2 as emissions in the Indian electricity sector decline from 353 mio. tons to 240 mio. tons CO_2. Germany then only fulfills 53 per cent of its national reduction target domestically - the remaining 47 percent is delivered by abatement measures in the Indian power sector.

Cost gap reduction

Through joint implementation the capital stock in the Indian electricity sector increases by 15 percent. The reduction in costs due to the movement of the temporary equilibrium towards the long-run equilibrium (which is characterised 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:

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

The costs of abating CO_2 $\left(AC\left(A^I\right)\right)$ 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 Fig. 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 3), the price index of electricity in India declines significantly from 1 to 0.67. 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 0.24 for India and from 0.33 to 0.22 for Germany. Capital intensity increases from 1.26 to 1.35 for India and from 1.33 to 1.40 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 = -0.46 is reduced to s_D^{JI} = -0.19 with JI.

Table 3

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	0,39	0,53
PE	1	1	1.38	1.22
EK (in bill. USD)	1,84	3,18	2,27	3,33
PEK	1.46	1	1.09	0.90
PELE	1	1	0.67	0.96

4. Conclusions

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

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.

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Appendix

A. Algebraic Model Summary

This appendix provides an algebraic summary of the equilibrium conditions for 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. Tables A1 and A2 explain the notations for variables and parameters. Key elasticities are summarized in Table A3. 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.

Production of goods except fossil fuels and electricity:

$$\text{(A1)} \quad \Pi_i^Y = CET\left(PX_i, P_i\right) - LT\left[PA_j^Y, PA_{CRU}^Y, CES\left(PL, CES\left(PK_i, PE_i\right)\right)\right] = 0 \qquad i, j \notin EG$$

Production of fossil fuels:

$$\text{(A2)} \quad \Pi_i^Y = CET\left(PX_i, P_i\right) - CES\left[PR_i, CES\left(PE_i, PA_i^Y, PK_i, PL\right)\right] = 0 \qquad i \in FF,\ j \notin EG$$

Production of electricity:

(A3) $$\Pi_i^Y = CET\left(PX_i, P_i\right) - LT\left[PA_j^Y, PA_{CRU}^Y, PA_{OIL}^Y, CES\left(PL, C\left(PE_i, K_i, EK_i, D\right)\right)\right] = 0 \qquad i \in ELE,\ j \notin EG$$

Sector-specific energy aggregate:

(A4) $$\Pi_i^E = PE_i - CES\left[PA_{ELE}^Y, CES\left(PA_{COL}^Y, CES\left(PA_{GAS}^Y, PA_{OIL}^Y\right)\right)\right] = 0 \qquad i \notin EG$$

$$\Pi_i^E = PE_i - LT\left(PA_j^Y\right) = 0 \qquad i \in FF,\ j \in EG$$

$$\Pi_i^E = PE_i - CES\left(PA_{GAS}^Y, PA_{COL}^Y\right) = 0 \qquad i \in ELE$$

Armington aggregate:

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

Aggregate imports across import regions:

(A6) $$\Pi_i^{M,I} = PM_i^I - CES\left(P_i^G, PX_i\right) = 0$$

$$\Pi_i^{M,G} = PM_i^G - CES\left(P_i^I, PX_i\right) = 0$$

Investment:

(A7) $$\Pi^{INV} = PINV - LT\left(PA_i^{INV}\right)$$

Public demand:

(A8) $$\Pi^Z = PZ - CD\left(PA_i^Z, CES\left(PA_j^Z\right)\right) = 0 \qquad i \notin EG,\ j \in EG$$

Household consumption demand:

(A9) $$\Pi^C = PC - CES\left(CD\left(PA_i^C\right), CD\left(PA_j^C\right)\right) = 0 \qquad i \notin EG,\ j \in EG$$

Utility production:

(A10) $$\Pi^U = PU - CES\left(PC, PL\right) = 0$$

Market Clearance Conditions

Labor:

$$\text{(A11)} \quad \bar{L} = \sum_i Y_i \frac{\partial \Pi_i^Y}{\partial PL}$$

Capital:

$$\text{(A12)} \quad \bar{K}_i = Y_i \frac{\partial \Pi_i^Y}{\partial PK_i}$$

Natural resources:

$$\text{(A13)} \quad \bar{Q}_i = Y_i \frac{\partial \Pi_i^Y}{\partial PR_i} \qquad i \in FF$$

Domestic output:

$$\text{(A14)} \quad Y_i \frac{\partial \Pi_i^Y}{\partial P_i} = \sum_j \sum_d A_i^d \frac{\partial \Pi_{dj}^A}{\partial P_j}$$

Sector specific energy aggregate:

$$\text{(A15)} \quad E_i = Y_i \frac{\partial \Pi_i^Y}{\partial PE_i}$$

Import aggregate:

$$\text{(A16)} \quad M_i = \sum_d A_i^d \frac{\partial \Pi_{di}^A}{\partial PM_i}$$

Armington aggregate:

$$\text{(A17)} \quad A_i^d = \sum_j Y_j \frac{\partial \Pi_j^Y}{\partial PA_i^Y} + C \frac{\partial \Pi^C}{\partial PA_i^C} + INV \frac{\partial \Pi^{INV}}{\partial PA_i^{INV}} + Z \frac{\partial \Pi^Z}{\partial PA_i^Z}$$

Foreign closure:

$$\text{(A18)} \quad \sum_i \left(PX_i \cdot \frac{\partial \Pi_i^{Y,I}}{\partial PX_i} \cdot Y_i^I + PX_i \cdot \frac{\partial \Pi_i^{Y,G}}{\partial PX_i} \cdot Y_i^G \right)$$

$$= \sum_i \left(PX_i \cdot \frac{\partial \Pi_i^{M,I}}{\partial PX_i} \cdot M_i^I + PX_i \cdot \frac{\partial \Pi_i^{M,G}}{\partial PX_i} \cdot M_i^G \right) + \bar{B}^I + \bar{B}^G$$

Household consumption:

$$\text{(A19)}\quad C \cdot PC = PL \cdot \overline{L} + \sum\nolimits_i PK_i \cdot \overline{K}_i + \sum\nolimits_{j\in FF} PQ_j \cdot \overline{Q}_j - PINV \cdot \overline{INV} - PC \cdot \overline{B}^I \qquad \text{for I}$$

$$C \cdot PC + (\overline{L} - L) \cdot PL = PL \cdot \overline{L} + \sum\nolimits_i PK_i \cdot \overline{K_i} + \sum\nolimits_{j\in FF} PQ_j \cdot \overline{Q_j} - PINV \cdot \overline{INV} - PC \cdot \overline{B}^G \quad \text{for G}$$

Government consumption:

$$\text{(A20)}\quad Z \cdot PZ = P^{CO2} \cdot \overline{CO2} + other\ taxes$$

Government output:

$$\text{(A21)}\quad \overline{Z} = Z$$

Investment:

$$\text{(A22)}\quad \overline{INV} = INV$$

German carbon emissions:

$$\text{(A23)}\quad \overline{CO2} = \sum_d \sum_i A_i^d \frac{\partial \Pi_{di}^A}{\partial PA_i^d} \cdot a_{di}^{CO2}$$

Representation of Joint Implementation

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

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

German's carbon emissions constraint:

$$\text{(A23')}\quad \overline{CO2} + EXP = \sum_d \sum_i A_i^d \frac{\partial \Pi_{di}^A}{\partial PA_i^d} \cdot a_{di}^{CO2}$$

India's carbon emission constraint in the electricity sector:

$$\text{(A24')}\quad \overline{CO2}_{ELE} - EXP = \sum_d \sum_i A_i^d \frac{\partial \Pi_{di}^A}{\partial PA_i^d} \cdot a_{di}^{CO2}$$

Table A1

Representation of Joint Implementation

EXP	JI permit export from India to Germany
$\overline{CO2}_{ELE}$	Endowment of carbon emission rights in the Indian electricity sector
b_i	Share of JI investment demand directed to sector *i*

Table A2

Sets, activity and price variables, endowments

Sets:

i	Sectors and goods (aliased with j)
r	Regions (aliased with s): G = Germany, I = India
EG	All energy goods: Coal, crude oil, refined oil, gas and electricity
FF	Primary fossil fuels: Coal, crude oil and gas
d	Demand categories: Y = intermediate, C = hh., Z = gov., INV = investment

Activity variables:

Y_i	Production in sector i
E_i	Aggregate energy input in sector i
M_i	Aggregate imports of good i
A_i^d	Armington aggregate for demand category d of good i
INV	Aggregate investment
Z	Aggregate public output
C	Aggregate household consumption

Price variables:

P_i	Output price of good i produced in region r for domestic market
PE_i	Price of aggregate energy in sector i
PX_i	ROW prices of exports and imports in sector i
PM_i	Import price aggregate for good i
PA_i^d	Price of Armington aggregate for demand category d of good i
$PINV$	Price of investment demand
PZ	Price of government demand
PC	Price of aggregate household consumption
PU	Utility price index
PL	Wage rate
PK_i	Price of sector specific capital services in sector i
PQ_i	Rent to natural resources (i $\in$ FF)
P^{CO2}	Price of CO$_2$ permit

Endowments:

$\overline{L}$	Aggregate labor endowment
$\overline{K}_i$	Aggregate capital endowment
$\overline{Q}_i$	Endowment of natural resource i (i$\in$FF)
$\overline{Z}$	Aggregate government demand
$\overline{INV}$	Aggregate investment demand
$\overline{B}$	Balance of payment surplus
$\overline{CO2}$	Endowment of carbon emission rights

Table A3

Selected elasticities

Elasticity of transformation between production for the domestic market and production for export	2
Elasticity of substitution between the capital and energy aggregate and labor in production (except fossil fuels and electricity)	0.3
Elasticity of substitution between capital and energy in production (except fossil fuels and electricity)	0.5
Elasticity of substitution between electricity and non-electricity energy goods in production (except fossil fuels and electricity)	0.25
Elasticity of substitution between coal and non-coal fossil fuels in production (except fossil fuels and electricity)	0.5
Elasticity of substitution between gas and oil in production (except fossil fuels and electricity)	0.9
Elasticity of supply in COA production	0.5
Elasticity of supply in CRU and GAS production	1
Elasticity of substitution between labor and the capital-energy aggregate in electricity production	0.5
Elasticity of substitution between gas and coal in electricity production	4
Elasticity of substitution between energy and non energy composite in final demand	0.5
Elasticity of substitution between energy goods and between non-energy goods in final demand	1
Elasticity of substitution between fossil fuels and non-fossil fuels in government demand	1
Elasticity of substitution between fossil fuels in government demand	0.3
Elasticity of substitution between imports from different regions	2
Elasticity of substitution between imports from different regions for GAS and ELE	1.5
Elasticity of substitution between imported and domestic inputs	4
Elasticity of substitution between imported and domestic inputs for GAS and ELE	0.75

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 B1). 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-) 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.

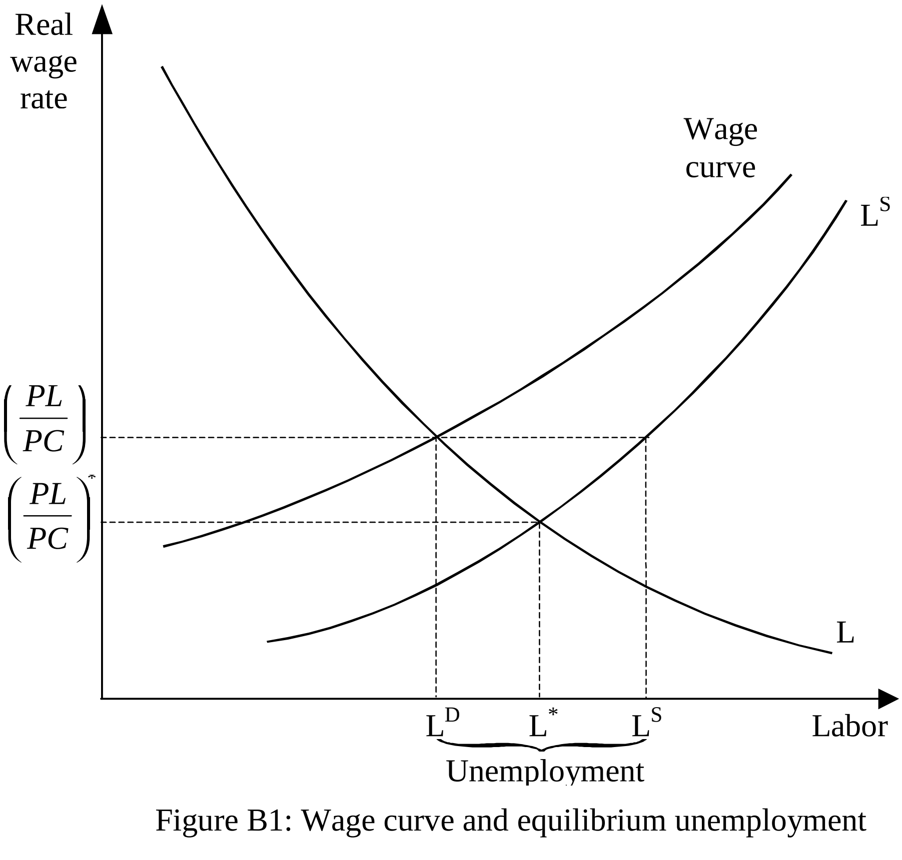

Figure B1: Wage curve and equilibrium unemployment

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.

The joint CES production function is:

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

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

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

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

where $(a_0 + a_D) = 0$.

Table C1

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

We start from benchmark data for Germany *(D=1)* (Table C1) and assume $\sigma = 0.5$, i.e. $\rho = 1$. We obtain from (C2) and (C3):

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

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 $\left(E/K \right)^G$ is 0.333 in Germany, we assume that $\left(E/K \right)^I = 0.333 \cdot 1.20 = 0.399$ (see Figure C1).

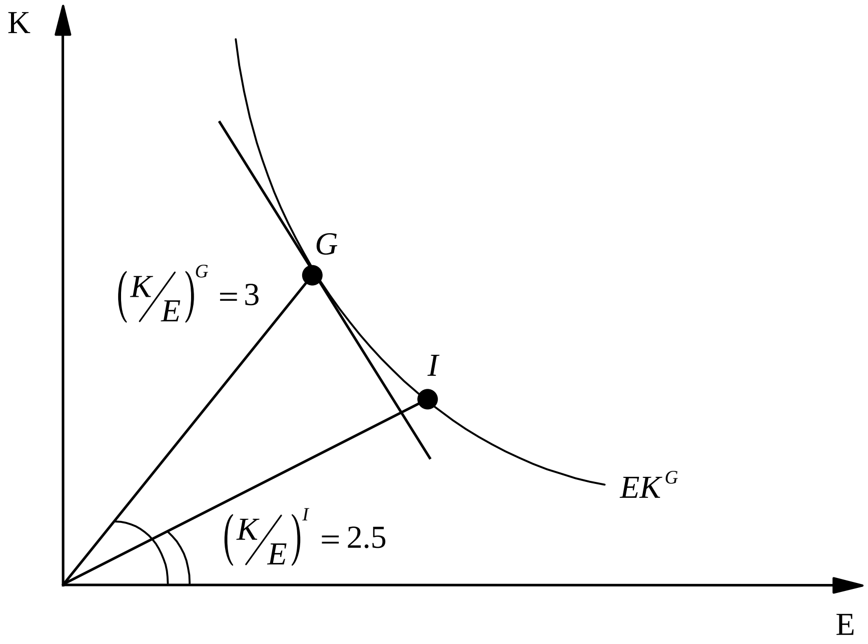

Figure C1: Energy efficiency in Germany and India

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 $MRS = \left(PE/PK\right)^I$ we determine PK^I:

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

Since $\left(E/K\right)^I = 0.399$ 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 10 percent, i.e. $EK^I = 0.9\left(K^I + E^I\right) = 1,835$. The efficiency term in (C1) becomes therefore $\exp(-0.105 + 0.105 \cdot D)$, i.e. $a_0 = -0.105$, $a_D = 0.105$. The productivity gap will be higher than 10 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, $PEK^I = 1.461$. The data for India are summarized in Table C2.

Table C2

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)	1,835
PEK^I	1.461

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):

$$s_D = \ln\frac{0.794}{0.582} - \frac{1}{2}\cdot\left(\frac{1.835}{0.582}+\frac{3.180}{0.794}\right)\cdot\ln\frac{3.180}{1.835} + \frac{1}{2}\cdot\left(\frac{1.457}{0.582}+\frac{2.386}{0.794}\right)\cdot\ln\frac{2.386}{1.343} = -0.426$$

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:

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

It is

$$PK^I = -\frac{\partial C}{\partial K} = 1.69$$

and

$$\text{(C6)}\qquad s_D = \frac{\partial \ln C}{\partial D} = -\frac{EK^{-\rho}\cdot a_D\exp(a_0\cdot\rho) - \dfrac{K^{-\rho}\cdot d_{K,D}}{\rho}}{EK^{-\rho}\cdot\exp(a_0\cdot\rho) - K^{-\rho}\cdot d_K} + \frac{d_{E,D}}{\rho\cdot d_E}.$$

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 for $\exp(-a_0 \cdot \rho)$:

$$\exp(-a_0 \cdot \rho) = \frac{s_D - \frac{d_{E,D}}{\rho \cdot d_E} + a_D}{\left(\frac{EK}{K}\right)^{\rho} \left[\frac{d_{K,D}}{\rho} + \left(s_D - \frac{d_{E,D}}{\rho \cdot d_E} \right) d_K \right]} .$$

With joint implementation the gap decreases to $s_D^{JI} = 0.187$ and a_0 becomes $a_0 = 0.479$.

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.