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Reducing Carbon Dioxide Emissions through Joint Implementation of Projects

Will Martin

Most proposals for joint implementation of energy projects emphasize installing more technically efficient capital equipment to allow reduced energy use for any given mix of input and output. But increases in energy efficiency are likely to have second-round effects. Reducing energy demand, for example, will reduce the market price of energy and stimulate energy use, partially offsetting the initial reduction in demand. These effects are likely to be substantially larger in the long run, reducing the magnitude of these offsets.

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Summary findings

Efficient reduction of carbon dioxide emissions requires coordination of international efforts. Approaches proposed include carbon taxes, emission quotas, and jointly implemented energy projects.

To reduce emissions efficiently requires equalizing the marginal costs of reduction between countries. The apparently large differentials between the costs of reducing emissions in industrial and developing countries implies a great potential for lowering the costs of reducing emissions by focusing on projects in developing countries.

Most proposals for joint implementation of energy projects emphasize installing more technically efficient capital equipment, to allow reductions in energy use for any given mix of input and output. But such increases in efficiency are likely to have potentially important second-round impacts:

- Lowering the relative effective price of specific energy products.
- Lowering the price of energy relative to other inputs.
- Lowering the price of energy-intensive products relative to other products.

Martin explores the consequences of these second-round impacts and suggests ways to deal with them in practical joint-implementation projects.

For example, the direct impact of reducing the effective price of a fuel is to increase consumption of that fuel. Generally, substitution effects also reduce the use of other fuels, and the emissions generated from them.

If the fuel whose efficiency is being improved is already the least emission-intensive, the combined impact of these price effects is most likely to be favorable.

If the fuel whose efficiency is being improved is initially the most emission-intensive, the combined impact of these price changes is less likely to be favorable and may even increase emissions.

In the example Martin uses, increase in coal use efficiency was completely ineffective in reducing emissions because it resulted in emission-intensive coal being substituted for less polluting oil and gas.

This paper — a product of Trade, Development Research Group — is part of a larger effort in the group to understand key links between trade and the environment. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Lili Tabada, room MC3-333, telephone 202-473-6896, fax 202-522-1159, email address ltabada@worldbank.org. Policy Research Working Papers are also posted on the Web at www.worldbank.org/research/workingpapers. The author may be contacted at wmartin1@worldbank.org. June 2000. (26 pages)

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Reducing Carbon Dioxide Emissions through Joint Implementation of Projects

Sustainable reduction in global greenhouse gas emissions requires internationally coordinated policy action. Reaching such a position is difficult because of the different interests of sovereign states, and the incentives for free riding on the actions of others. The solution must lie in a set of policies that reduce costs by being efficient in achieving greenhouse gas emissions, and equitable in the burden that it imposes on individual countries. While there is great uncertainty about the burden likely to be involved in the required reductions in emissions, it is clear from SO_2 emissions trading in the United States that efficient policies can greatly reduce the costs of any given reduction[1].

Three broad policies have been proposed for achieving reductions in greenhouse gas emissions — quotas, taxes and joint implementation (JI) projects. Quota approaches have intuitive appeal in that they focus on achieving specific, tangible goals. However, except in extreme cases such as the ban on chlorofluorocarbons, national quotas are likely to be an inefficient approach to achieving any given reduction in global greenhouse gases. Fixed national quotas and emission reductions are likely to require reductions in some countries at much higher costs than in others. Approaches that move toward equalizing the marginal costs of reducing emissions across countries will lower the overall costs of achieving any given reduction in emissions and make it more likely that a sustainable agreement can be achieved.

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[1] The need to use the most efficient approach to emissions reduction will be particularly great if emissions are, as argued by Schmalensee, Stoker and Judson (1998), increasing at substantially higher rates than projected by the IPCC.

One approach to the problem with national quotas would be to define national quotas and to allow them to be traded between countries. Countries with high costs of emission reductions would find it worthwhile to purchase quotas from countries where the costs of reducing emissions were lower. In the long run, the marginal costs of emission reduction would fall in the quota-purchasing countries and rise in the quota-selling countries. A problem with this approach is that it is likely to lead to very large international transfers of quota rents — perhaps more than could be sustained or enforced between sovereign countries.

McKibbin and Wilcoxen (1997) have proposed an interesting alternative policy involving an initial national quota supplemented by additional units of quota sold at an internationally agreed price. This would reduce the distributional problems associated with international transfers of quota rents[2], and ensure that the marginal costs of emissions were equalized worldwide. At the margin, this policy would have essentially the same impacts as an internationally agreed tax on energy use.

Stiglitz (1997) reviews the approaches for reducing global carbon emissions, and emphasizes the need for developing countries to participate in reductions in greenhouse gas emissions. For one of the main greenhouse gases, carbon dioxide, he points out that developing countries already emit as much carbon from industrial processes as do developed countries. By the middle of the next century, carbon dioxide emissions from developing countries are likely to be twice those from the current OECD countries. This

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[2] However, it would still not seem to deal with the international transfers between net energy exporters and importers that would follow from declining world prices of carbon-intensive energy products. Clearly, this distributional concern could potentially be dealt with by levying part of any agreed tax on the production side and part on the consumption side.

implies that the task of reducing emissions in developing countries will be enormous and increases the importance of sound policy design.

In the long run, some form of internationally agreed carbon tax or set price at which emission permits can be sold seems likely to be the most efficient solution to this problem. However, we are a long way from reaching the international consensus for such policies that would be required for their effective implementation. The recently agreed Kyoto Protocol provides for quotas on emissions in the industrial countries only, with the developing countries pointing out that the current stock of emissions is primarily the result of past and present emissions from today's industrial countries.

The Kyoto Protocol provides for some potential mitigation of the costs of a system of national quotas through provisions for a clean development mechanism (UNFCCC 1997). This could increase the efficiency with which reductions in greenhouse gas emissions are made by allowing countries to substitute lower-cost reductions overseas for higher-cost reductions at home[3]. Engineering evidence suggests that the costs of achieving given reductions in energy use are frequently lower in developing countries even without quotas in the industrial countries. These differentials are likely to become considerably larger if binding quotas are enforced in the industrial countries. As developed countries use up their lowest-cost abatement options, the marginal costs of achieving larger reductions will rise.

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[3] The Kyoto Convention uses the term joint implementation to refer to activities between the industrial countries whose emissions are subject to agreed quotas (Article 6). Joint activities between industrial and developing countries are covered by the clean development mechanism (Article 12). The focus of this paper is cn joint activities between industrial and developing countries and the term joint implementation is used to refer to these activities.

A difficulty faced by joint implementation approaches of the type envisaged by the Kyoto Protocol is the measurement of the reductions in greenhouse gas emissions. While quotas and taxes focus on the emissions of greenhouse gases, a project-based approach such as the clean development mechanism must focus on the somewhat more speculative concept of "reductions in emissions that are additional to any that would occur in the absence of the certified project activity" (UNFCCC, p12).

A key step in estimating the impact of a joint implementation project on emissions is to take into account the direct impact of the project on the output of greenhouse gases per unit of output. The approach taken in this paper is that this input-output approach is necessary, but not sufficient for assessing the total impact of the project on emissions. The central point of this paper is that it is highly likely that the technical changes created by joint implementation will affect emissions indirectly by induced changes in the level and mix of energy and other inputs into production — and that these indirect effects may be large. The changes in technique brought about by joint implementation will also have impacts on consumer prices of some goods, and the consequent changes in the pattern of consumption may also need to be taken into account.

Once the impact of the technical change induced by a joint implementation project on the demand for carbon fuels has been identified, one further step is needed before the results can be compared with *ex post* reductions in emissions of the type achieved using emissions quotas. This step involves the price responsiveness of the supply of the different types of energy. If the price elasticities of supply for these energy sources are low, much of the impact of a reduction in demand may fall on the price of that fuel, rather than on the level of its use.

The next section of the paper deals with the nature of joint implementation projects, and the likely impacts of these projects on energy use patterns. The third section considers the elasticities and CO_2 intensities that are needed as a basis for evaluating the impacts of the joint implementation projects. The fourth section presents some simple numerical estimates designed both to provide an order of magnitude indication of the likely importance of the phenomenon under consideration for particular types of project. In the fifth section, the supply side of the energy market is considered. The final section presents some conclusions and suggestions on approaches for evaluation of joint implementation projects.

Joint Implementation and Technical Change

The joint implementation projects envisaged under the Kyoto Protocol have two stated goals: to assist developing countries in achieving sustainable development, and to assist the industrial countries by allowing them to use certified emission reductions against their reduction commitments. To achieve these objectives, the projects clearly must change the production processes used in the developing countries. One way in which they might do this is by substituting a less-polluting technology for the one currently in use, without necessarily improving the overall efficiency of production. Another way would be to introduce technology that is superior to that previously in operation in the country. Changes in technique of the first type would contribute to the carbon emission goal, but not necessarily to the development goal, while changes of the second type seem more likely to contribute to both goals.

A general framework for categorizing the various types of technical change that might be used in joint implementation is provided in Alston and Martin (1994). Using the producer profit function[4], they categorize technical changes into three broad types: (a) those represented by direct incorporation of technical change variables in the profit function (Binswanger 1974; Kohli 1991); (b) those represented through a distinction between actual and effective quantities and prices (eg Dixon, Parmenter, Sutton and Vincent 1982); and (c) those represented through changes in the parameters of profit or production functions (eg Fulginiti and Perrin 1993).

For technical changes that affect variable inputs, these three different types of technical change may be represented as:

(a) $\pi = g(p, v, \tau \mid \alpha)$

(b) $\pi = g(p(\tau), v \mid \alpha)$

(c) $\pi = g(p, v \mid \alpha(\tau))$

where π is the producer profit from the activity under consideration; p is the vector of input and output prices facing producers in the country; v is a vector of fixed inputs (and perhaps outputs); α is the vector of parameters of the profit function; and τ a vector of parameters representing the technical changes under consideration.

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[4] This profit function may be a simple, partial equilibrium profit function for a single industry able to purchase all of its inputs at fixed prices (see Binswanger 1974 for this general type of application), or an economy-wide profit function representing the technology for production of total GDP in the

The profit function approach to the specification of changes in techniques of production is particularly desirable when the objective of the analysis is to consider the welfare impacts of the technical change, and hence the contribution of the project to development. As shown by Martin and Alston (1997), the welfare consequences of particular types of technical change may be substantially greater than would be suggested by the producer surplus techniques that have typically been used to measure these benefits. For a cost-reducing technical change in a commodity supplied with an elasticity of 0.5, for example, the producer surplus methodology understates the welfare benefits by just over half.

The profit function approach outlined above is also a useful organizing framework for considering the impacts of different types of JI-induced technical changes on greenhouse gas emissions. For the evaluation of these projects, it seems likely that the most relevant form of technical change will be type (b), although some projects may perhaps usefully be categorized by type (c). Type (a) is typically used in relatively stylized representations of technical change, where the specific form of technical change is either not known, or cannot be specified with precision. Almost by definition, the nature of the change in technique is well known and understood when a JI project is undertaken.

Most practical applications of Type (b) technical change involve a distinction between physical and effective quantities of a particular good (ie input or output). The relationship between the physical and the effective units of an input (or output) can be

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economy given predetermined endowments of aggregate factors such as labor and capital (see Kohli 1991 for this type of application).

represented by $q_i^* = q_i.\tau_i$ where q_i^* is the effective quantity of the good; q_i is the actual quantity of the good; and τ_i is the level of input-augmenting technology[5]. A good example of such a technical change would be one that increased the efficiency with which a particular fuel could be converted into usable energy, for example, the use of improved combustion techniques that raised the energy efficiency of coal used in electricity generation from 25 to 35 percent. Using the definition above, this improvement raises the number of effective units in any given physical quantity of coal by 40 percent.

Clearly, increases in the number of effective units associated with a given physical quantity of fuel allow reductions in the quantity of fuel, and hence CO_2 emitted, in achieving any given outcome. The effects of this change in the input-output coefficients appears to be the main thing currently considered in evaluating the impacts of projects on greenhouse gas emissions (World Bank forthcoming).

Associated with the increase in the effective quantity of good i is a change in its effective price. The relationship between actual and effective prices is given by $p_i^* = p_i / \tau_i$ where p_i^* is the effective price of the good. Clearly, the impact of the improvement in efficiency considered above is to reduce the effective price of this type of energy. In most cases, however, it is not enough to consider the impact of the technical change on the input-output coefficients. Typically, the sponsor of a project has the ability to influence these coefficients, but not to fully control the operation of the project, or the industry of which it is a part, in the host country. Industrial managers can be expected to respond to the changes in the effective prices resulting from the technical change. Depending upon

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[5] For expositional ease, technical change has been specified so that an increase in τ_i represents an improvement in technology.

the relevant elasticities, this may substantially change the impact of the project on total carbon emissions.

From the above discussion, it is clear that changes in technology that change the effective prices of particular types of energy in a particular application have both output and substitution effects. The nature of these effects is very readily seen using a demand function for a particular energy input, such as the following linear demand curve resulting from differentiation with respect to effective prices of a normalized quadratic profit function specified in effective quantities and prices.

$$(1) \qquad q_i^* = \alpha_i + \Sigma_j \beta_{ij} p_j^* + \Sigma_k \theta_{ik} v_k$$

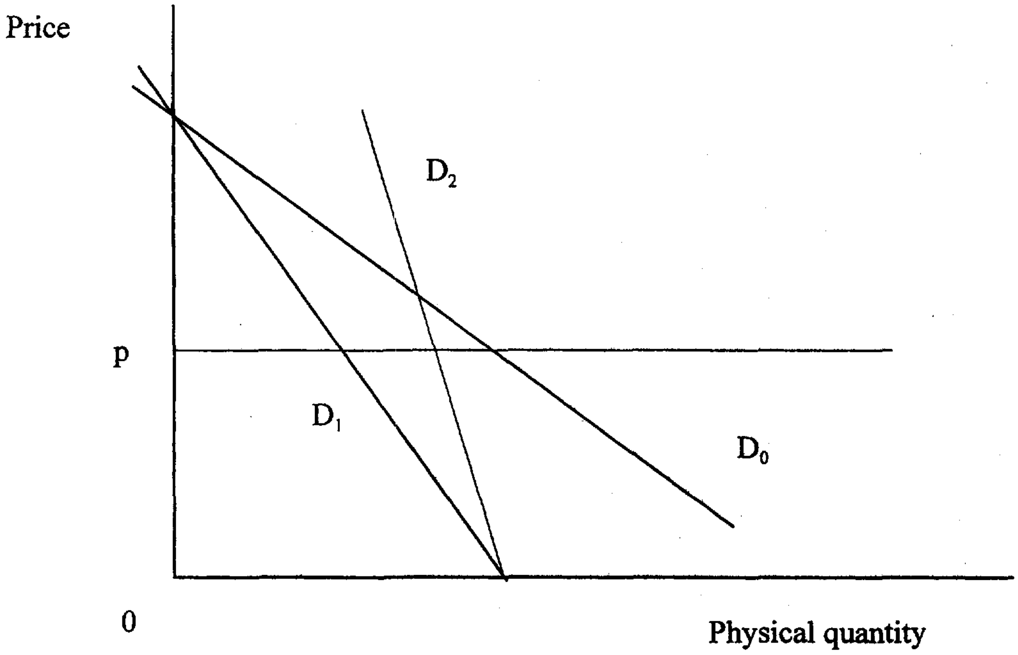
Since the physical quantity of the fuel consumed, rather than the effective quantity, typically determines the quantity of greenhouse gas emissions, we need to rewrite this equation in terms of actual prices and quantities, rather than effective prices and quantities.

$$(2) \qquad q_i = 1/\tau_i (\alpha_i + \Sigma_j \beta_{ij} p_j^* + \Sigma_k \theta_{ik} v_k) = 1/\tau_i (\alpha_i + \Sigma_j \beta_{ij} p_j /\tau_j + \Sigma_k \theta_{ik} v_k)$$

a formulation which highlights the input-saving consequences of the technical change.

Since p_i^* is equal to p_i/τ_i the lowering of the effective price has an effect that depends upon the slope of the demand curve. The contribution of the two effects to demand for the physical product is shown in Figure 1. The shift from Demand Curve D_0 to D_1 corresponds to the impact of the $1/\tau_1$ term at the front of the right hand side of equation (2). It causes the demand curve to rotate about the vertical axis. The impact of the effective price change is represented by the rotation of curve D_1 around the horizontal axis. The decline in the effective price of the input stimulates demand to an extent that depends on the slope of the demand curve and on the price level. This effect is represented by the rotation of the demand curve from D_1 to D_2. In the diagram, the input-saving effect of the technical change dominates and demand at price p is lower with the final demand curve D_2 than with the original demand curve. However, this would not have been the case at higher price levels, or with a more elastic demand curve.

Figure 1. Impacts of augmenting technical change on the demand for an input



While the impact of an input-augmenting technical change on the demand for any particular energy source is ambiguous in general, the elasticity of demand for the good gives a local approximation to the impact. If, for instance, the elasticity of demand for the good is less (greater) than one, the compensated[6] demand for the input will decline (increase) following an input-augmenting technical advance.

The ambiguous impact of the change in effective prices on own demand is not the end of the story because the change in the effective price of the good will also change the demand for other production inputs through substitution effects. In this case, at least, the direction of the impact is clear as long as the goods are substitutes — a reduction in the effective price of one fuel will reduce the demand for any substitute fuel. Even if the demand for a fuel rises following the technical change, this effect may offset the impact on aggregate carbon emissions. If the demand for an alternative fuel has fallen, then this substitution effect will augment the reduction in fuel use and carbon emissions. Whether the substitution effects will outweigh the own price impacts will depend a great deal on the carbon intensity of the fuels; if the fuel whose use is expanding is more carbon intensive than its substitutes, then overall emissions may rise as a consequence of the project.

While input-augmenting technical change seems likely to be the most relevant for most cases considered under joint implementation, type (c) technical change might be important in some applications. Changes in technology of this type are very difficult to implement in the flexible functional forms so widely used in modern applied studies because of the restrictions imposed by economic theory, including homogeneity of degree one in prices; symmetry of cross price effects; and the adding up restrictions. However, this approach has sometimes been used for broad technical changes such as the very large

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[6] That is, output-constant.

shift in demand towards more skilled labor in the industrial countries (Tyers and Yang 1997). For most applications likely to be encountered in joint implementation projects, the input-augmenting technical change approach appears likely to be the most useful.

Relevant elasticities of demand for energy and emissions intensities

The practical importance of the changes in effective prices induced by the technical changes caused by joint implementation will depend a great deal on the magnitudes of the relevant elasticities of demand for energy inputs, and for energy-intensive final products. Where these elasticities are small, the induced impacts of changes in effective prices will almost always be small.

Three groups of elasticities need to be considered. The first is the elasticities of demand for particular energy sources. The second is the demand for energy as a whole. The third is the elasticity of demand for energy-intensive products.

As Atkinson and Manning (1995) observe, the literature on the elasticities of demand for energy is not in very satisfactory, with the range of estimates for different parameters being particularly wide, especially for the cross-price effects that are of importance in this analysis. Further, the full implications of recent developments in econometric techniques being only partially reflected in the stock of elasticity estimates. Despite this, some regularities do seem to emerge fairly strongly.

The own and cross price elasticities of demand for individual energy sources do generally seem to be larger than the elasticity of demand for energy as a whole. From the range of estimates presented by Atkinson and Manning (1995), it seems likely that the own-price elasticity of demand for energy as a whole is in the order of -0.2. The elasticities of demand for particular energy-intensive goods also seem likely to be relatively low. Further, the impact of a change in the effective price of a particular fuel has only an indirect impact on the price of the good in which it is embodied. Assuming the good is nontraded, and produced according to constant returns to scale, the maximum price impact will be given by the share of the fuel in the total cost of producing the good. Thus, except for goods such as aluminium or home-produced goods such as electric lighting, which are particularly energy intensive, it seems likely that the impacts of technical changes on consumption of final goods will be relatively minor. In a small country, such changes will be unobservable for traded goods because the price of the good will not be affected by changes in the domestic technology alone.

The elasticities of demand for individual fuels, such as gas, oil and coal generally appear to be much larger, with values above 1.0, and even above 2.0, in absolute value frequently appearing in the literature. Where the own price elasticities are large, the cross price elasticities typically are also large, making evaluation of the substitution effects considerably more important.

It seems likely that, with such large elasticities, both the own-price effects induced by input-augmenting technical change, and the substitution effects from this source, will be important. A simple numerical example is used to explore the potential sensitivity of the effects of projects that improve the efficiency with which particular types of energy are used.

To explore the effects of projects on overall energy use requires knowledge of the price elasticities of demand, and the CO_2 intensity of each fuel. The price elasticities need to be derived from comprehensive, system-based approaches because of the importance of the cross-price impacts that tend to be poorly estimated when traditional, single commodity estimation approaches are used. There are many levels at which an exploratory analysis might be undertaken. However, the area in which the best estimates of demand elasticities appear to be available is use in the industrial sector. Jones (1996) provides a comprehensive set of elasticity estimates for the G-7 countries utilizing a modern system-based econometric estimator, the linear-logit estimator applied to aggregate data. Pindyck (1979) provides a similar set of estimates obtained by applying the Translog estimator to national data for a group of OECD countries. Woodland (1993) provides estimates based on a panel of establishment-level data for New South Wales industrial firms over an eight-year period. Another set of estimates underlies the simulation modeling undertaken by McKibbin and Wilcoxen (1995a) using the G–Cubed model.

The elasticities estimated by Jones (1996) are based on inter-fuel substitution in the industrial sector. He allows for substitution between coal, oil, natural gas and electricity. Thus his results provide estimates of the direct usage of coal, oil and natural gas in the industrial sector, which should be comparable with the data on energy use and CO_2 emissions by sector provided by the International Energy Agency. He provides both short run and long run estimates. The long run elasticities are used here because of the long run focus of the global warming problem. The matrix of own and cross price elasticities of demand for direct use of coal, oil, and gas is provided in Table 1.

Table 1. Long run elasticities of demand in the industrial sector of the G-7

	Coal	Oil	Gas
Coal	-1.55	0.72	0.15
Oil	0.63	-2.23	0.78
Gas	0.13	0.79	-0.86

The elasticities presented in Table 1 are higher than many in the literature. However, they do not appear unreasonable as estimates of the long run values of elasticities allowing for inter-fuel substitution. Pindyck's comparable estimates of the own-price elasticity of demand for individual OECD countries were in the same range for coal, generally lower for oil, and generally higher for natural gas. Woodland's estimates based on data at the establishment level are generally somewhat lower for coal and substantially higher for natural gas. Jones' estimates are, however, considerably above the comparable estimates utilized by McKibbin and Wilcoxen, who apply an energy elasticity of substitution of 0.80 in the durable manufacturing sector and 1.0 in the non-durable sub-sector.

Unfortunately, there appears to be a dearth of recent system-based estimates of the elasticities of demand for fuels in developing countries. If the underlying parameters of the system are the same, it would be possible to utilize the estimates provided by Jones, together with information on the shares of each fuel in total energy use, to estimate elasticities for particular developing countries. However, it would be very desirable to have estimates actually obtained using data from developing countries. If joint implementation becomes an important feature of the implementation of global strategies for greenhouse gas mitigation, it will be particularly important to have such estimates.

The other information needed to investigate the impact of any given improvement in energy use efficiency is the importance of each fuel as a source both of energy and of emissions in the industrial sector. These data were obtained from the International Energy Agency (1997, 1991) and are presented in Table 2. The first column shows estimated CO_2 emissions from direct use of each fuel in the industrial sector and the second the corresponding shares. The third column shows the delivered fuel emission factors, taking into account both the inherent carbon intensity of each fuel and the efficiency with which it used to provide usable energy. The final column shows the implied shares of each fuel in total usable energy availability from these fuels in the industrial sector.

Table 2. IEA estimates of energy and emissions data for the industrial sector of Annex I Parties

	CO_2 emissions Million Mt CO_2	Emission shares %	Emission factors Mt C/Mtoe	Energy shares %
Coal	945.5	40	1.14	32
Oil	677.3	29	0.89	29
Gas	734	31	0.73	39
Total	2356.8	100		100

This short survey of relevant elasticities and emission intensities points to some likely implications of different types of joint implementation that results in different types of improvements in fuel use efficiency. The much higher elasticities of demand for individual fuels, than for energy as a whole, implies that substitution between fuels is likely to be important for its effects on quantities of fuel used. The very different emissions intensities mean that changes in the mix of fuels used will have major impacts on fuel emissions. Projects that increase the efficiency of a fuel that is carbon intensive may induce greater use of that fuel relative to less emission-intensive fuels. Conversely, increases in the efficiency of a less carbon intensive fuel will shift energy usage towards that fuel, with potentially important second-round savings in carbon emissions. The importance of substitution between fuels means, however, that technical changes that increase efficiency for all fuels will create smaller induced substitution impacts.

Some stylized experiments

The experiments undertaken to highlight some of the important features of the problem were increases in energy use efficiency sufficient, with no other adjustments, to reduce total CO_2 emissions by ten percent. This target required improvements of 25 percent, 35 percent and 32 percent for coal, oil and gas respectively. The results of this direct energy-saving effect on total emissions are shown in column 1 of Table 3.

Because of the reduction in the effective price of each energy source resulting from the improvement in technology, there are impacts on the consumption both of the fuel itself and other fuels. The impact of the reduction in the effective price of each fuel on emissions directly from that fuel is shown in Column 2 of the table. The total effective price induced impact is shown in Column 3. These estimates differ from those in Column 2 by taking into account the substitution effects on usage of, and emissions from, other fuels.

The total impact of the change in efficiency is shown in Column 4 of the table. These estimates include both the direct impact on emissions, and that induced by the changes in effective price.

Table 3. Impacts of improvements in fuel use efficiency on total CO_2 emissions, percent

	Direct impact	Own effective price impacts	All effective Price impacts	Total impact
	%	%	%	%
Coal efficiency	-10	15.5	10.0	0.0
Oil efficiency	-10	22.3	3.7	-6.3
Gas efficiency	-10	8.6	-0.5	-10.5
All fuels	-30	46.4	13.2	-16.8

The improvement in coal use efficiency shown in the first row of the table would directly reduce total emissions by ten percent if there were no changes in the input or output mix. However, the own price effect of the reduction in the effective price of coal increases total emissions by over 15 percent as emission-intensive coal is substituted for oil and gas. This adverse effect is offset by the reductions in carbon emissions resulting from the induced reductions in oil and gas usage. The net impact of all the price-induced changes in the fuel mix on direct consumption of fossil fuels is an increase of ten percent. This increase of ten percent exactly offsets the direct reduction in consumption resulting from the increase in efficiency, leaving this increase in energy use efficiency completely ineffective in reducing CO_2 emissions.

The improvement in oil use efficiency has, by construction, the same impact on emissions as the efficiency improvement in coal. Because the elasticity of demand for oil is so high, this change in the effective price of oil has a larger impact on direct consumption of oil than was the case with coal. When only the own-price impact is taken into account, the effect on emissions is more strongly adverse than for coal, with a 22 percent increase in total emissions. However, the substitution effects are more strongly favorable both because of the elasticities, and because of the higher emission intensity of coal. With these substitution effects included, the total price-induced impact is an increase in emissions of 3.7 percent. Thus, in this case, the price-induced impact only partially offsets the direct energy-saving impact of the technical change.

The efficiency improvement in the use of natural gas presented in the third row of Table 3 causes an induced increase in natural gas usage. However, the increase in emissions resulting from this is more than offset by the induced reductions in the use of coal and oil, so that the total price-induced impact is -0.5 percent, reinforcing the direct reduction in the energy use. Had the own and cross-price elasticities been larger, as they were in Woodland's (1993) study, it is likely that the total price-induced impact would have been a substantially larger negative value, augmenting the direct impact to a much greater degree. The result from this experiment supports the general principle that, other things equal, an improvement in efficiency in what is already the most energy-efficient technology will have a more favorable impact on emissions than an improvement in a less efficient technology.

When simultaneous increases in efficiency in all fuels are considered, the direct reduction in emissions is 30 percent. The increase in emissions resulting from own-price induced increases in fuel usage is 46.4 percent, but this figure falls to only 13.2 percent once substitution effects are taken into account. Thus, the overall reduction in emissions resulting from this experiment is 16.8 percent. This experiment supports the general principle that substitution effects are less a concern for a broad-based improvement that increases efficiency for all fuels than for improvements concentrated only in emission-intensive fuels.

The numerical examples provided in this section are deliberately simplified and stylized. They represent only the impacts on direct use of fuels in industry, ignoring indirect consumption in the form of electricity (unless this is generated from nonpolluting or renewable sources). Further, they ignore the indirect impacts on energy consumption and emissions that arise from induced changes in demand for energy in total, and from induced effects on the prices of particular commodities. Their purpose is purely to highlight the potentially important, and frequently ignored, impacts of changes in effective prices on fuel consumption and on emission levels.

Supply side considerations

All of the analysis to this point has focused on the demand side of the market for energy. However, the impact of a reduction in the demand for fuel on its consumption will clearly also depend upon the price responsiveness of fuel supply. If the fuels are not in perfectly elastic supply, reductions in demand will not be translated directly into reductions in the quantity of fuel used. As demand declines, the price will fall, thus stimulating fuel use and partially offsetting the effects of the original decline in demand. This introduces another factor that may need to be taken into account when comparing joint implementation outcomes with those from outcome-based measures such as tradeable quotas.

On the supply side, the cross-price impacts are probably much smaller than on the demand side simply because of the diversity of the natural resource bases involved in the production of major fuels such as coal, oil and gas. While all produced goods are general equilibrium substitutes (or complements) in production simply through their demands for resources, it seems likely that these cross-price impacts are relatively small, and that attention can focus primarily on the own-price elasticities.

As long as the elasticity of fuel supply lies between zero and infinity, the impact of any technology-induced reduction in demand will fall partly on the price of the fuel, and partly on fuel usage. The reduction in price will to some degree offset the original reduction in demand, introducing an additional offset to the effectiveness of joint implementation that is quite different from the one discussed on the demand side. The magnitude of the reduction in price, for any given horizontal shift in the demand curve, will depend upon the sum of the elasticities of supply and demand. The exact impact of the shift on the demand for fuel depends, however, on the individual elasticities and on the nature of the shift in the demand curve. For example, for any given horizontal shift in the demand curve, the reduction in demand is greater, the higher is the absolute value of the supply elasticity. Similarly, the reduction in demand will be less, the larger is the absolute elasticity of demand.

In the short run, the elasticity of supply of the major fuels is probably fairly inelastic because of the quasi-fixed nature of investments in resource extraction. Over time, these elasticities tend to rise as it becomes possible to invest in new capital, and to invest in the discovery and proving of new reserves. Since the supply of capital and exploration services to these industries is highly elastic, it seems likely that the long run elasticities of supply for the major energy sources are quite elastic, substantially reducing the need to account for supply-side offsetting impacts of joint implementation projects.

The supply side effects considered in this section and the demand side impacts considered in the remainder of this paper can be integrated using computable general equilibrium models such as the GTAP model (Hertel 1997) or the G-Cubed model (McKibbin and Wilcoxen 1995b). These models include both the demand and supply side linkages. In any such analysis, it is particularly important to focus attention on the specification of the change in demand for energy, and on the effects of shifts in demand on energy supply.

Conclusions and policy implications

Much of the literature on evaluating the impacts of joint implementation projects appears to assume that an improvement in efficiency that reduces the amount of fuel required to achieve a particular objective by 10 percent will reduce the quantity of emissions by the same 10 percent. The main purpose of this paper is to point out that technological advances of the most common kind have two impacts—one through their direct energy-saving impact, and one through their impact on the effective price of the fuel in the use(s) under consideration. Unfortunately, this channel of effect appears to have been ignored in much of the recent literature on evaluation of jointly implemented projects or demand side management.

The direct impact of the reduction in the effective price of a fuel is an increase in the consumption of that fuel. In addition, there are substitution effects that will generally reduce the use of other fuels, and the emissions generated from that source. If the fuel whose efficiency is being improved is already the least emission-intensive, the combined impact of these price impacts is most likely to be favorable. If the fuel whose efficiency is being improved is initially the most emission-intensive, the combined impact of these price changes is less likely to be favorable, and may even result in an increase in emissions. In the numerical example considered in this paper, an increase in coal use efficiency was completely ineffective in reducing emissions because it resulted in emission-intensive coal being substituted for less polluting oil and gas.

The final impact of the demand shifts on fuel consumption and energy emissions will also depend on supply side responses in energy markets. As long as energy supply is less than perfectly elastic, reductions in energy demand resulting from joint implementation will reduce the market price of energy and stimulate energy use, partially offsetting the initial reduction in demand. These effects are likely to be substantially larger in the long run, reducing the magnitude of these offsets.

Many analysts have advocated ignoring the offsetting effects that are the focus of this paper on the grounds of lack of information. While the need to form some assessment of the magnitude of the relevant demand elasticities is a serious difficulty given the paucity of estimates of elasticities for developing countries, it need not be insuperable. Further, the general principles following from the analysis provide a (potentially rebuttable) case for favoring particular types of projects. Projects that improve the efficiency of the fuel that is already the least emission-intensive are likely to be more effective than projects focusing on more emission-intensive fuels. Projects that improve the efficiency of all fuels are unlikely to be offset by adverse substitution effects. By contrast, projects that improve the efficiency of an emission-intensive process may be completely ineffective in reducing carbon emissions.

References

Alston, J. and Martin, W. (1994), 'A dual approach to evaluating research benefits in the presence of trade distortions' *American Journal of Agricultural Economics* 76:26-35.

Atkinson, J. and Manning, N. (1995), 'A survey of international energy elasticities' in Barker, T., Ekins, P. and Johnstone, N. eds. *Global Warming and Energy Demand*, Routledge, London.

Binswanger, H. (1974), 'A cost function approach to the measurement of elasticities of factor demand and elasticities of substitution' *American Journal of Agricultural Economics* 56:377-86.

Dixon, P., Parmenter, B., Sutton, J. and Vincent, D. (1982), *ORANI: A Multisectoral Model of the Australian Economy,* North-Holland, Amsterdam.

Fulginiti, L. and Perrin, R. (1993), 'Prices and productivity in agriculture' *Review of Economics and Statistics* 75:471-82.

Hertel, T. ed. (1997), *Global Trade Analysis: Modeling and Applications,* Cambridge University Press, New York.

International Energy Agency (1997), *CO_2 Emissions From Fuel Combustion: a New Basis for Comparing Emissions of a Major Greenhouse Gas,* OECD, Paris.

International Energy Agency (1991), *Energy Efficiency and the Environment,* OECD, Paris.

Jones, C.T. (1993), 'A pooled dynamic analysis of interfuel substitution in industrial energy demand by the G-7 countries' *Applied Economics* 28:815-21.

Kohli, U. (1991), *Technology, Duality and Foreign Trade,* University of Michigan Press, Ann Arbor.

McKibbin, W. and Wilcoxen, P. (1995a), 'Environmental policy and international trade' Brooking Discussion Paper in International Economics No. 117, The Brookings Institution, Washington DC.

McKibbin, W. and Wilcoxen, P. (1995b), 'The theoretical and empirical structure of the G-Cubed model' Brookings Discussion Paper in International Economics No 118, The Brookings Institution, Washington DC.

McKibbin, W. and Wilcoxen, P. (1997), 'A better way to slow global climate change' Brookings Policy Brief No. 17, The Brookings Institution, Washington DC. (available at www.brookings.edu).

Martin, W. and Alston, J. (1997), 'Producer surplus without apology? Evaluating investments in R&D' *Economic Record* 73(221):146-58.

Pindyck, R. (1979), 'Interfuel substitution and the industrial demand for energy: an international comparison' *Review of Economics and Statistics* 61:169-79.

Schmalensee, R., Stoker, T. and Judson, R. (1998), 'World carbon dioxide emissions: 1950-2050' *Review of Economics and Statistics* LXXX(1):15-27.

Stiglitz, J. (1997), 'Stepping toward balance: addressing global climate change' Paper presented to World Bank Conference on Environmentally and Socially Sustainable Development, Washington DC, October 6.

Tyers, R. and Yang, Y. (1997), 'Trade with Asia and skill upgrading: effects on factor markets in older industrial countries' *Weltwirtschaftliches Archiv* 133(3):383-417.

UNFCCC (1997), 'Kyoto protocol to the United Nations framework convention on climate change', United Nations Framework Convention on Climate Change, United Nations. (www.unfccc.de).

Woodland, A. (1993), 'A micro-econometric analysis of industrial demand for energy in NSW' *The Energy Journal* 14(2):57-89.

World Bank (forthcoming), *Greenhouse Gas Assessment Handbook: A Practical Guidance Document for the Assessment of Project-Level Greenhouse Gas Emissions,* Environment Department, World Bank.

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