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Effects of the CDM on Poverty Eradication and Global Climate Protection

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Summary

In an impure public good model we analyze the effects of CDM transfers on poverty as well as on the global climate protection level. We construct an analytical model of a developing and an industrialized region, both of which independently seek to maximize their utility – a function of private consumption, domestic air quality, and global climate protection. They do so by distributing their finite expenditures across (1) the aggregate consumption good, (2) end-of-pipe pollution control technologies, and (3) greenhouse gas abatement. Based on our analytical findings, we develop two sets of simulations for China in which we vary the rate of the CDM transfer. The simulations differ by the assumption of China's domestic air quality policy – the first assumes a technology-standards policy which fixes a level of end-of-pipe SO_2 control, whereas the second assumes a technology-neutral policy which simply fixes the level of total SO_2 emissions.

Keywords: Ancillary Benefits, CDM, Climate Policy, Impure Public Goods, Transfers, Abatement Technology

JEL Classification: Q54, H23,H41,O33

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1 Introduction

The Kyoto Protocol does not prescribe greenhouse gas (GHG) reductions to developing countries. This fact is employed by opponents to the Kyoto Protocol to stress its inefficiency, since GHG emission mitigation options can regularly be exploited more cheaply in the developing world. The US which refused to join the Protocol claims for participation of developing countries in international GHG emission reduction efforts. This claim is rejected by the developing world because of the economic burden which such efforts would imply. Furthermore, developing countries argue that the industrialized world is mainly responsible for the current dimension of the global warming threat. Therefore, it should mainly be the industrialized world's responsibility to combat global warming.

Yet, the Kyoto Protocol integrates a mechanism which addresses both opponent views. This mechanism, the Clean Development Mechanism (CDM), allows industrialized countries to fulfill their GHG abatement obligations partly by mitigating GHG emissions in developing countries, where mitigation options can be exploited in a cheaper way. The CDM-associated costs of climate protection are borne by the industrialized world.

"With the already huge and growing amount of greenhouse gas emissions and a great deal of low-cost abatement options available, China is widely expected as the world's number one host country of CDM projects" (Zhang 2006). According to Zhang (2000), about 60 percent of the total CDM flows in 2010 will go to China. Vennemo et al. (2006) review various studies assessing the total CDM potential in China and find that the highest CDM-potential estimate is 788 Mt CO_2 (based on the assessments by Zhang (1999, 2000)). Therefore, in our analysis we focus on the case where China is the host of CDM projects, which are initiated by the largest purchaser of CDM credits, i.e. Europe.

The CDM requires that corresponding GHG reductions in the developing world would not have occurred in the absence of respective emission mitigation policies, i.e. measures should be *additional*.

As Dutschke and Michaelowa (2003) point out, there are disputes about the interpretation of 'additionality'.[1] In our model, we consider additionality in the way that industrialized countries pay for an environmental protection technology shift which raises the level of climate protection. Only the funding of the shift is of interest, not the total funding of the applied technology, since only the shift is additional. Therefore, the CDM efforts are represented by subsidization of a climate-friendly technology which would not have been applied otherwise. More precisely, we consider the shift from technologies exclusively generating local/regional environmental benefits to technologies producing local/regional as well as global environmental benefits. In our analysis we consider climate policy to be an impure public good.

The analysis is organized as follows. In Section 2, we consider effects of transfers, i.e. income and price effects. The latter can only be induced by means of conditional transfers, like CDM transfers.

In Section 3, we explain in detail why climate policy is an impure public good. We describe the different groups of benefits generated by climate policy, i.e. primary and ancillary benefits. Primary benefits are derived from the pursuit of the primary aim targeted by climate policy, which is climate protection. Ancillary benefits in turn are received from joint effects which were not primarily intended. Such an effect would be the mitigation of local air pollution which is induced by the climate protection measure. Because primary benefits are global while ancillary benefits are local or regional, climate policy is an impure public good. Thereafter, we provide a survey of ancillary benefit studies in developing countries.

In Section 4, we develop an analytical model which indicates that there is scope for raising the global climate protection level by means of CDM transfers. The crucial prerequisites for such climate policy level increasing transfers are determined. There may also be a positive effect of CDM transfers on poverty reduction in the developing world, whose magnitude depends on the level of transfers received.

In Section 5, we present a simulation model in order to analyze the effect of the choice of the subsidy rate (or its level) on welfare and poverty (private good consumption) in the developing world. Here, the industrialized world is represented by Europe and the develop-

[1] Dutschke and Michaelowa (2003) stress that financial additionality requires that no public money that would have been spent anyway to climate-related action in the developing world is relabelled as CDM effort.

ing world by China. Furthermore, we analyze which effect the level of the subsidy rate has on the global climate protection level. In the simulation model, we distinguish two policy scenarios in China. One scenario depicts a flexible and incentive-compatible environmental policy in China, while the other considers a more rigid scheme where technology standards are set by the environmental policy. In this model, the rigidity of standards-based environmental regulations will have negative consequences for the Chinese private consumption level.

Section 6 concludes.

2 The Possible Impacts of Transfers on Climate Protection Levels

Climate policy is often simply regarded as a pure public good, since nobody can be excluded from the consumption of climate protection and this consumption exhibits non-rivalry. As Warr (1982, 1983) demonstrates for the case of pure public goods, unconditional transfers have no effect on the public good provision level, or more precisely, in an interior Nash equilibrium, redistribution of income among agents is *neutral*. Income transfers are called neutral if they do neither affect the total public good provision nor the individual agents' consumption of private goods. Prior to this, the neutrality result had already been noticed by Becker (1974).

Kemp (1984) extends Warr's 'neutrality theorem' to the case of more than one public good. Boadway, Pestieau and Wildasin (1989) point out that transfers may be neutral even when there are distortions in the shape of taxes and subsidies on private goods or factors, strictly local public goods, or on goods that are public to all. Varian (1994) finds that neutrality may also occur for Stackelberg equilibria. These results suggest that unconditional income transfers would only cause a redistribution of climate protection activities among countries while leaving the global abatement level, as well as the individual countries' welfare, unchanged. Therefore, incentives for development aid in the shape of unconditional transfers would not exist.

Yet, neutrality may break, if we consider that there exist cost differentials in the production of public goods (Buchholz and Konrad 1995: 496) like climate policy, corner solutions (Bergstrom, Blume and Varian 1986), non-zero conjectures (Sandler and Posnett 1991) and impure publicness (Andreoni 1986, 1989, 1990). However, the positive impact of unconditional transfers channeled towards developing countries, i.e. of alleviating poverty in the developing world, on the provision level of the global public good ‘climate policy’ tends to be quite weak (Rübbelke 2002).

Therefore, conditional transfers, i.e. payments not only inducing an income effect, tend to be more attractive. Transfers which are provided conditionally on climate policy efforts in the transfer receptor countries additionally generate a price effect by reducing the effective price of climate policy from the transfer-receiving countries’ point of view. Due to the effective price reduction, the production of climate policy becomes more attractive in these countries. This kind of transfers is in the focus of our paper and is represented by CDM transfers channeled to the developing world.

Yet, in contrast to many other studies analyzing conditional transfers, our starting point (before transfers are paid) is a corner solution. By means of conditional transfers, the climate-protecting countries intend to convince the free-riding nations to participate in the international climate protection efforts. Hence, we have a starting point similar to the current Kyoto-situation, where most industrialized countries commit to climate protection, while developing countries are not at all obligated to control their greenhouse gas (GHG) emissions.

3 Climate Policy Considered as an Impure Public Good

CDM transfers (if chosen sufficiently high) may induce an increase in private consumption in the receptor country and they simultaneously initiate climate protection measures conducted by the recipient (see Figure 1). Climate protection measures in turn, provide pure public as well as private (from an individual country’s point of view) characteristics. Consequently, they can be considered as impure public goods. In the subsequent sections, individual countries’ decisions on climate policy production will be analyzed in an impure public good model.

3.1 Characteristics of Climate Policy

The *pure public characteristic* subsumes the climate-change mitigating effects or the climate protection generated by climate policy. The benefits derived from these effects can be enjoyed globally, irrespective of which country abates greenhouse gas emissions. No country can be excluded from the consumption of climate protection and non-rivalry in consumption prevails. The benefits resulting from climate protection are called primary benefits of climate policy.

Climate policy also provides some *private characteristic* with purely local/regional influence that can be exclusively enjoyed by countries/regions generating climate policy. So, the reduction of combustion processes also causes a decline in the emissions of local/regional air pollutants like particulates, NO_X and SO_2. This decline represents a domestic public good for the inhabitants of the considered country. From the point of view of the country or region as a whole, the characteristic is private, since the associated benefits are exclusively enjoyed in this country or region. The benefits which countries enjoy from consuming the domestic public characteristic are the ancillary or secondary benefits.

Yet, we have to take account of the fact that the ancillary benefits can also be generated independently of climate policy. Desulphurization installations, for example, reduce the emission of SO_2 independently of climate policy. So, the higher the level of such installations, the lower will be the (marginal) ancillary benefits of climate policy.

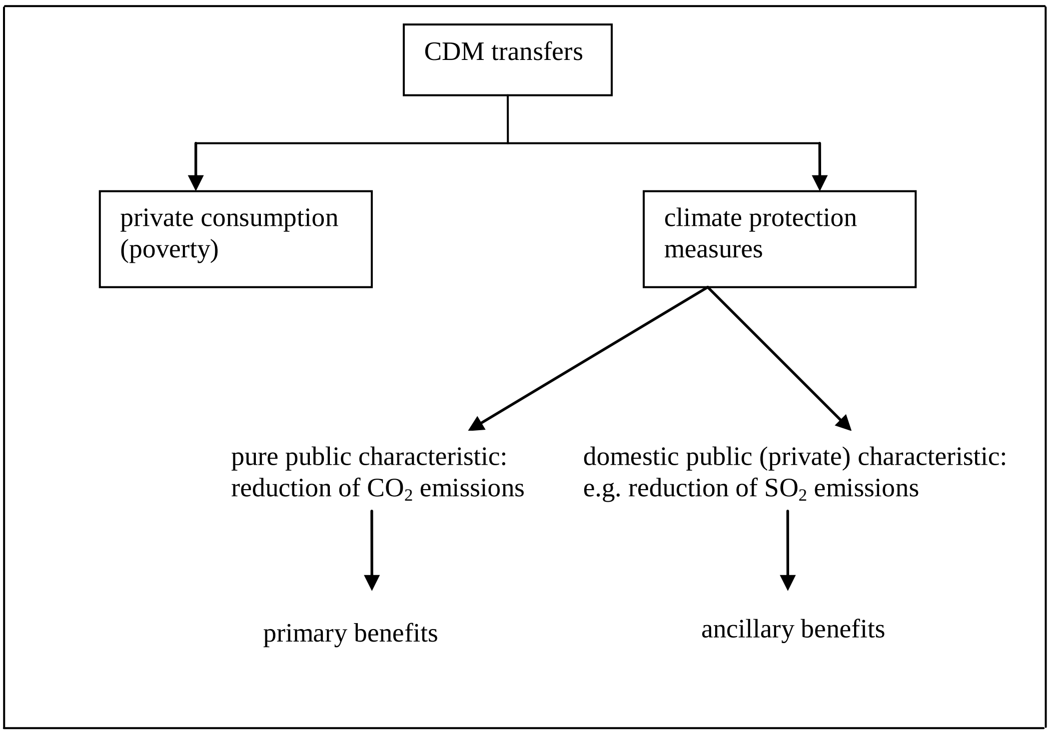

Figure 1: Characteristics of Climate Policy.

Furthermore, as Rypdal et al. (2005) point out, there are greenhouse gases which are not included in the Kyoto Protocol, that generate more regionally confined climate effects. Hence, the abatement of these gases cannot fully be regarded as a global pure public good.

On the other hand there exist ancillary benefits that are global. The abatement of the greenhouse gases CFCs generates an important ancillary benefit by protecting the ozone layer (Rübbelke 2002: 23). However, throughout we will suppose primary benefits to be global, while ancillary benefits are local or regional.

3.2 Ancillary Benefits in Developing Countries

While in the 1990s the focus of studies investigating ancillary benefits was on those occurring in industrialized countries, meanwhile a large strand of literature exists that deals with ancillary benefits in developing countries.[2] This subsection provides a short survey of this literature on ancillary benefits in the developing world.

As can be observed from Table 1, the geographical foci of these studies are heterogeneous although most of them address co-benefits in China. Yet, even the studies for China have different regional perspectives with diverging results. The analysis by Gielen and Chen (2001) considers Shanghai and it shows that the relevance of no-regret options - due to ancillary benefits derived from NO_X and SO_2 emission reductions - is limited because of significant energy efficiency improvements in Shanghai in recent years. However, the authors admit that Shanghai seems not to be representative for the whole of China and that main GHG emission mitigation potential may be located in the rural areas of China. Nevertheless, in their assessment of ancillary benefits associated with a reduced PM_{10} emission level, Kan et al. (2004) find results for Shanghai which illustrate that an effective energy and environmental policy will play an active role in the reduction of air pollution and the promotion of public health. Aunan et al. (2004) focus on co-benefits in Shanxi and assess that CO_2-reducing abatement options entail large co-benefits and are highly profitable in a socio-economic sense. Aunan et al. (2007: 472) argue that a climate protection commitment would provide significant

[2] Still the literature on the qualitative implications of ancillary benefits (in contrast to the literature only assessing those benefits' size) is small. Among the few exceptions are Lutter and Shogren (2002) who analyze how these benefits affect emissions permit trading.

ancillary benefits to China, since climate protection efforts will not only cause a reduction in GHG emissions but also reductions in particles- and NO_X-emissions. These (and other) non-GHG-emission reductions – in turn – will not only improve public health but will additionally increase agricultural yields. Van Vuuren et al. (2003) also assess that large co-benefits of climate protection by means of energy efficiency improvement prevail in China.

Study	**Country**	**Pollutants** (local/regional)	**Model/Approach**
Aunan et al. (2003)	China	PM, SO_2, TSP	comparison of studies that comprise a bottom-up study, a semi-bottom-up study and a top down study using a CGE model
Aunan et al. (2004)	China	SO_2, Particles	analysis and comparison of six different CO_2-abating options
Aunan et al. (2007)	China	NO_X, TSP	CGE model
Bussolo, O'Connor (2001)	India	NO_X, Particulates, SO_2	CGE model
Cao (2004)	China	SO_2, TSP	technology assessment, sensitivity to discount rate
Cao, Ho, Jorgenson (2008)	China	NO_X, Particulates, SO_2	integrated modelling approach combining a top-down recursive dynamic CGE model with a bottom-up electricity sector model
Chen et al. (2007)	China		comparison of partial and general equilibrium MARKAL models
Cifuentes et al. (2000)	Chile	CO, PM, NO_X, SO_2	no economic modelling
Cifuentes et al. (2001)	Brazil, Chile, Mexico	Ozone, Particulates	development of scenarios that estimate the cumulative public health impacts of reducing GHG emissions
Dadi et al. (2000)	China	SO_2	linear programming model
Dessus, O'Connor (2003)	Chile	CO, Lead, NO_2, Ozone, PM, SO_2	CGE model
Dhakal (2003)	Nepal	CO, HC, NO_X, SO_2, Particles, Lead	analysis of long-range energy system scenarios
Eskeland, Xie (1998)	Chile, Mexico	NO_X, Particulates, SO_2, VOCs	technology and cost-curve assessment
Garbaccio et al. (2000)	China	PM, SO_2	CGE model

Gielen, Chen (2001)	China	NO_X, SO_2	MARKAL, technology assessment and alternative policy scenarios
Ho, Nielsen (2007)	China	SO_2, TSP	CGE model
Kan et al. (2004)	China	Particulates	Shanghai MARKAL model
Larson et al. (2003)	China	SO_2	MARKAL of energy sector; base vs. advanced technology scenarios for controlling CO_2 and SO_2
Li (2006)	Thailand	Particulates	dynamic recursive CGE model
McKinley et al. (2005)	Mexico	CO, HC, NO_X, Particulates, SO_2	analysis of five pollution control options in Mexico City
Mestl et al. (2005)	China	PM, SO_2	project-by-project analysis
Morgenstern, Krupnick, Zhang (2004)	China	SO_2	survey of recent banning of coal burning in small boilers in downtown area of Taiyuan
O'Connor et al. (2003)	China	NO_X, SO_2, TSP	CGE model
Peng (2000)	China	Particulates, SO_2	RAINS-Asia for local, and GTAP for economy-wide effects
Shrestha, Malla, Liyanage (2007)	Thailand	NO_X, SO_2	four scenarios, use of end-use based Asia-Pacific Integrated Assessment Model (AIM/Enduse)
Smith, Haigler (2008)	China		sample calculations regarding interventions in the household energy sector
Van Vuuren et al. (2003)	China	SO_2	simulation model
Vennemo et al. (2006)	China	SO_2, TSP	synthesis of a significant body of research on co-benefits of climate policy in China
Wang, Smith (1999a,b)	China	Particulates, SO_2	no economic modelling
West et al. (2004)	Mexico	CO, HC, NO_X, Particulates, SO_2	linear programming model

Table 1: Ancillary Benefit Studies Regarding Developing Countries.

However, not only the geographical foci of studies differ but also the considered non-CO_2 pollutants and the employed methodologies. Many studies assess co-benefits associated with the mitigation of SO_2 and particles reductions. Also, NO_X is frequently included in the analyses. Yet, in their CGE study for Chile, Dessus and O'Connor (2003) gather a larger basket of pollutants, which includes CO, Lead, NO_2, Ozone, PM, SO_2. In strong contrast, in their study regarding China, Larson et al. (2003) only investigate ancillary benefits of SO_2 mitigation. However, they provide an integrated analysis and not just a co-benefit assessment. In their analyses dealing with ancillary effects in the transport sectors in Mexico City and Santiago de Chile, Eskeland and Xie (1998) provide technology and cost-curve assessments. Cifuentes et al. (2000) do not apply an economic model, but conduct an aggregate analysis to estimate potential ancillary benefits in Chile. A CGE model is used by Bussolo and O'Connor (2001) in order to investigate ancillary benefits in India. Their study estimates the magnitude of spillovers from limiting growth of greenhouse gas emissions to local air quality and the health of the urban population.

O'Connor (2000) provides another comparison of different ancillary benefit studies for developing countries. Ancillary benefits may however be different to those associated with the mitigation of air pollution. As Sagar (2005) points out climate policy may contribute immense social-economic benefits to the world's poor, while Campbell-Lendrum and Corvalán (2007) stress the implications of climate policy for both, environmental health and equity.

4 Analytical Model

4.1 Countries' Consumption of Goods

In our model we distinguish between the industrialized and the developing world. The individual countries belonging to the industrialized or developing world may consume commodities which have a private good character from each country's individual point of view, as well as a commodity which also provides benefits to all the other countries, i.e., the global public good 'climate policy'. It is supposed that climate policy's private or domestic public characteristic can also be generated independently of the public characteristic. Countries can consume the following commodities:

Private commodity: Each country group produces an amount y of a marketed goods bundle whose characteristic is private to each of them (first private characteristic). Each unit of this marketed *private good* provides one unit of the good's characteristic, so that y denotes the amount of the private commodity as well as the amount of the private characteristic generated by this commodity.

Domestic public commodity: Furthermore, each country generates an amount *a* of a second commodity (e.g., desulphurisation installation) that is a domestic public good, i.e., a good whose characteristic (e.g., local air quality improvements) is private to the consuming country (second private characteristic). Each unit of this *domestic public good* provides one unit of its 'private' or domestic public characteristic.

Impure public commodity: The third commodity is an *impure public good* (climate policy) providing the private characteristic (e.g., local air quality improvements) which is also produced by the second commodity. It is consumed up to an amount q and each unit of the public good generates α units of the private characteristic. Therefore, the total amount of the private characteristic is $z = a + \alpha q$, where αq is the ancillary effect - such as the reduction in conventional air pollution - associated with climate policy. Furthermore, the impure public good provides a characteristic (climate protection) which is public to all countries. Each unit of the public good generates β units of the public characteristic. The total amount X of the public characteristic is equal to the sum of the developing (x_d) and the industrialized (x_i) country groups' provision.

	Industrialized Country	Developing Country	Unit Costs
Private good 1	y_i	y_d	$p^y{}_i$ or $p^y{}_d$
Private good 2 or local (domestic) public good	a_i	a_d	p_i^a or p_d^a
Impure (global) public good	q_i	q_d	p_i^q or p_d^q
Total domestic public good (env) benefit	$z_i = a_i + \alpha_i q_i$	$z_d = a_d + \alpha_d q_d$	
Climate benefit	$x_i = ß_i q_i$	$x_d = ß_d q_d$	
Aggregate (global) climate benefit $X = x_i + x_d$			
α = private benefit produced per unit of the impure public good, q, produced			
β = (global) public benefit produced per unit of impure public good, q, produced			
s = subsidy rate, the rate at which the industrialized country subsidizes the production of the impure public good in the developing country			

Table 2: Notations.

For simplicity, we aggregate the individual countries by assigning them to one of the country groups, i.e. the developing or industrialized country group. The private commodity has the unit price p^y. The domestic public good has the unit costs of $p^a(a)$ and the impure public good has unit costs of $p^q(q)$, both of which are functions of their respective abatement levels. The characteristics are assumed to behave like normal goods. The parameters which differ in size among countries get an index, where the index *d* stands for 'developing world' and *i* indicates the 'industrialized world'. For simplicity, we apply $ß_i = ß_d = 1$.

4.2 The Developing World's Maximization Problem

The welfare in both country groups is assumed to depend on the consumption of the private and public characteristics. Yet, we assume that a corner solution in international climate protection prevails, where the developing world does not contribute to climate policy, i.e., $X = x_i$. This results from a climate policy level in the industrialized world which provides climate protection in excess of the level demanded by the poorer developing countries. As Gielen and Chen (2001: 258) stress the order of issues on the political agenda in developing countries like China is: "First the apparent local air pollution problems are tackled; next the more distant GHG problem is considered. Therefore, it is more relevant to study the impact of local air pollution abatement on GHG emission reduction than vice versa."

In the maximization of the country groups' welfare, we apply the Nash assumption that each group considers the other group's public good/characteristic provision as being given.

Furthermore, it is supposed that $\frac{p_d^q(q_d)}{\alpha_d} > p_d^a(a_d)$. This assumption is in line with the findings by Gielen and Chen (2001: 267). In their conclusions they point out concerning the options of GHG abatement measures with local air pollution co-effects on the one hand side and local air pollution mitigation measures (without or with limited GHG benefits) on the other hand side: "The results suggest that dedicated emission abatement technology (without or with limited GHG benefits) is a more cost-effective way to reduce local air pollution. Examples are 3-way catalysts for cars and IGCC for electricity production. Such technologies should be considered if secondary benefits are valued".

From this starting point, we then assume that the industrialized world offers the developing world a conditional transfer, i.e. it offers to subsidize the developing world's production of the impure public good.

Consequently, the developing world's welfare maximization problem becomes:[3]

$$\begin{aligned}
&\max_{y_d, a_d, q_d} U_d(y_d, z_d) \\
&s.t. \\
&\bar{I}_d = \overline{p_d^y} \cdot y_d + p_d^a \cdot a_d + (1-\bar{s}) \cdot p_d^q \cdot q_d \\
&z_d = a_d + \alpha_d q_d \\
&a_d, q_d \geq 0
\end{aligned} \quad (1)$$

I_d represents the developing country's national income. The bars above I and p^y indicate that they are fixed in our model. The rate s is calibrated on initial levels of p^q, p^a, q, and a, and is also fixed.

This is associated with the following Kuhn-Tucker conditions:

$$\bar{I}_d = \overline{p_d^y} \cdot y_d + p_d^a \cdot a_d + (1-\bar{s}) \cdot p_d^q \cdot q_d \quad (2)$$

$$\frac{\partial U_d}{\partial y_d} = \lambda_d \cdot \overline{p_d^y} \quad (3)$$

$$\frac{\partial U_d}{\partial a_d} \leq \lambda_d \cdot \frac{\partial(p_d^a \cdot a_d)}{\partial a_d}, a_d \geq 0, a_d \left[\frac{\partial U_d}{\partial a_d} - \lambda_d \cdot \frac{\partial(p_d^a \cdot a_d)}{\partial a_d} \right] = 0 \quad (4)$$

$$\frac{\partial U_d}{\partial q_d} \leq \lambda_d \cdot (1-\bar{s}) \cdot \frac{\partial(p_d^q \cdot q_d)}{\partial q_d}, q_d \geq 0, q_d \left[\frac{\partial U_d}{\partial q_d} - \lambda_d (1-\bar{s}) \frac{\partial(p_d^q \cdot q_d)}{\partial q_d} \right] = 0 \quad (5)$$

The variable λ can be interpreted as the shadow price of the income constraint.

4.3 The Industrialized World's Maximization Problem

The industrialized country faces no public characteristic provision in excess of its demand. The maximization problem of the industrialized world is given by:

[3] We suppose that the developing world disregards the public characteristic in its reasoning. This is due to the assumptions that the industrialized world provides – throughout – this characteristics in excess of the developing world's demand and that the developing world takes x_i as given. See Rübbelke (2006) for a similar approach.

$$\max_{y_i, a_i, q_i, q_d} U_i(y_i, z_i, X)$$
$$s.t.$$
$$\bar{I}_i = \overline{p_i^y} \cdot y_i + p_i^a \cdot a_i + p_i^q \cdot q_i + \bar{s} \cdot p_d^q \cdot q_d \tag{6}$$
$$X = q_i + q_d$$
$$z_i = a_i + \alpha_i q_i$$
$$a_i, q_i, q_d \geq 0$$

The optimization problem yields the following Kuhn-Tucker conditions for the industrialized region:

$$\bar{I}_i = \overline{p_i^y} \cdot y_i + p_i^a \cdot a_i + p_i^q \cdot q_i + \bar{s} \cdot p_d^q \cdot q_d \tag{7}$$

$$\frac{\partial U_i}{\partial y_i} = \lambda_i \cdot \overline{p_i^y} \tag{8}$$

$$\frac{\partial U_i}{\partial a_i} \leq \lambda_i \cdot \frac{\partial(p_i^a \cdot a_i)}{\partial a_i}, a_i \geq 0, a_i \left[\frac{\partial U_i}{\partial a_i} - \lambda_i \cdot \frac{\partial(p_i^a \cdot a_i)}{\partial a_i} \right] = 0 \tag{9}$$

$$\frac{\partial U_i}{\partial q_i} \leq \lambda_i \cdot \frac{\partial(p_i^q \cdot q_i)}{\partial q_i}, q_i \geq 0, q_i \left[\frac{\partial U_i}{\partial q_i} - \lambda_i \cdot \frac{\partial(p_i^q \cdot q_i)}{\partial q_i} \right] = 0 \tag{10}$$

$$\frac{\partial U_i}{\partial q_d} \leq \lambda_i \cdot \bar{s} \cdot \frac{\partial(p_d^q \cdot q_d)}{\partial q_d}, q_d \geq 0, q_d \left[\frac{\partial U_i}{\partial q_d} - \lambda_i \cdot \bar{s} \cdot \frac{\partial(p_d^q \cdot q_d)}{\partial q_d} \right] = 0 \tag{11}$$

4.4 Conditions for the Acceptance of Transfers

Each region has its own demands regarding the acceptability of CDM activity; this can be seen in equations (5) and (11). The industrial region will accept the CDM as long as the following condition is satisfied:

$$\frac{\partial U_i}{\partial q_d} \geq \lambda_i \cdot \bar{s} \cdot \frac{\partial(p_d^q \cdot q_d)}{\partial q_d} \tag{12}$$

The developing region will accept the region as long as:

$$\frac{\partial U_d}{\partial q_d} \geq \lambda_d \cdot (1 - \bar{s}) \cdot \frac{\partial(p_d^q \cdot q_d)}{\partial q_d} \tag{13}$$

In equilibrium, only one of the Kuhn-Tucker conditions related to q_d shall be binding, and the lowest acceptable level of s will prevail. This is generally associated with the developing region's condition. As such, we drop the industrialized region's Kuhn-Tucker condition related to q_d (equation (11)), and replace it with equation (12). The combination of equations (5) and (12) ensures that both regions are satisfied with the CDM subsidy arrangement.

5 Simulation Model

Conditional transfers may improve the outcome: developing countries may enjoy a higher regional environmental quality and both, industrialized and developing countries may enjoy a mitigation of the global warming threat. The effect on poverty reduction, i.e. increase in private consumption, in the developing world crucially depends on the level of transfers received. Part of these transfers may not be conditionally employed and could be used by the developing world for additional consumption of the private good y_D. In order to analyze the effect of the level of the subsidy rate on poverty or private good consumption in the developing world, we conduct a simulation study. We also analyze the effects of changing transfer rates on global climate protection and local/regional air quality levels.

5.1 European Funds Transferred to China

We apply the theoretical framework to a simulation model based around empirical data. For this illustrative example, we focus on CDM transfers between Europe[4] (the largest purchaser of CDM credits) and China (the largest provider of CDM credits), and the impact on SO_2 emissions in both regions in 2010. Europe and China take the roles as developed and developing regions respectively, although we also account for CO_2-reducing measures in the rest of the world.

Functional Forms

It is assumed that our regions have utility functions of the form:

$$U_i = \gamma_{1i} \ln y_i + \gamma_{2i} \ln z_i + \gamma_{3i} \ln X \tag{14}$$

[4] European Union plus Norway, Iceland, Liechtenstein, and Switzerland.

$$U_d = \gamma_{1d} \ln y_d + \gamma_{2d} \ln z_d \tag{15}$$

In addition, the average price functions are assumed to take the following form (using p_d^a as an example):

$$p_d^a(a_d) = Aa_d^2 + Ba_d + C \tag{16}$$

The coefficients are determined for each price function using region-specific data described below.

Empirical Data

We assemble appropriate consumption and abatement data in order to obtain initial values and to calibrate our model. A key source is the CICERO GRACE model (Aaheim and Rive 2005), which is aggregated to include China, Europe, and the Rest of World. The business as usual (BAU) GRACE scenario broadly follows the SRES B2 (IPCC 2000) scenario to 2010.

The initial budget constraint (*I*) is taken from the BAU GRACE scenario.

Region	**Budget 2010 (Trillion $)**
Europe	20
China	6.36

Table 3: Budgets.

The GRACE model is also used to obtain the marginal abatement cost (MAC) curve for CO_2 abatement in Europe. This marginal abatement curve is obtained by calculating the permit price and abatement quantities for increasingly stringent CO_2 reduction targets, as is done by Ellerman and Decaux (1998), within the current group of EU-ETS (emissions trading scheme) sectors.[5]

The marginal abatement cost curve for China is not calculated in the GRACE model, as the model does not reflect the transaction and uncertainty costs involved with CDM-type projects. As such, a simplistic linear MAC curve is assumed for the CDM transfers between China and Europe, using the \$7-14/tCO_2 range of CER prices in recent years.

The marginal abatement costs for SO_2 abatement are calculated from separate models,

[5] The sectors are: power plants, cement, paper and pulp, iron and steel, and oil refining.

as GRACE does not feature treatment for emissions control technologies. MAC curves for SO_2 abatement in Europe and China are calculated using the RAINS-Online (Amann et al. 2004) and GAINS-Asia (Klaassen et al. 2006) models respectively. The MAC curves are for the year 2010, for 'current legislation' (CLE) assumptions about pollution control and moderate economic growth.

These four MAC curves are converted into average abatement cost curves, characterized by the coefficients as per equation (16). The coefficients for each curve are shown in Table 4 below, with the average prices given in $/t$SO_2$ or $/t$CO_2$ abated, under abatement levels denominated in MtSO_2 or MtCO_2.

Curve/Coefficient	**A**	**B**	**C**
Europe CO_2	0	0.0467	1.06
Europe SO_2	57.4	-450	1140
China CO_2	0	0.0989	7.0
China SO_2	0.268	-27.4	765

Table 4: Coefficients.

Calibrating the model for European and Chinese CO_2 and SO_2 abatement, of course, depends on assumptions about climate policy (i.e. the Kyoto Protocol), air quality policy, and how Europe's CO_2 reductions are distributed between domestic and CDM abatement. Initial SO_2 abatement levels in Europe and China are taken from the CLE abatement levels in the RAINS-Online and GAINS-Asia, using the 'no control' levels as a starting point. In order to meet its Kyoto target, Europe must reduce its CO_2 emissions from the GRACE BAU 2010 level by 8.5% or 326 MtCO_2.[6] If we assume that all domestic abatement will be undertaken within the EU-ETS sectors, and future allocations will keep the domestic permit price to 20 $/t$CO_2$, the GRACE MAC curve suggests that only 203 MtCO_2 of this will be abated at home. This leaves a shortfall of 123 MtCO_2 that must come from CDM credits. At face value, this appears to be a reasonable assumption given that the UNEP CDM Pipeline database predicts 300 MtCO_2 of CDM credits will be available in 2010 (Fenhann 2008).

Yet China and Europe are involved in numerous CDM transactions, and not all of them are of particular interest here. In this paper, we are primarily interested in CDM transactions between the two regions related to combustion-based CO_2 emissions.

[6] Assuming all Eastern European hot air is allowed.

However, Europe will likely purchase credits from F-gas and N_2O projects in China, and it will also likely buy credits from other regions at the same time. In addition, China will likely be selling credits to other regions. Of course, it is impossible to predict the distribution of project types in Europe's and China's transactions. As such, we simply assume that it simply follows the broad distribution of projects already featured in the CDM projects that are registered and under validation. We take these additional transaction expenditures into account by adding them as fixed parameters into Europe's and China's budget constraints (equations (2) and (7) above).

Finally, we must account for climate policy in the other Annex B countries having ratified the Kyoto Protocol such as Canada, New Zealand, Australia, Russia, and Japan. These countries will also reduce their emissions via a mix of domestic and CDM/JI abatement measures. Their abatement is included in the model as a fixed parameter contributing to the total CO_2 abatement level *X*.

These parameters are presented below in Table 5.

Initial Abatement (2010)	**MtSO_2 or MtCO_2**
SO_2 Targets	
Europe	7.3
China	100
Kyoto Targets	
Europe	326
Other Annex B	380
Europe CER Purchases	
Combustion CDM from China	36
All other CERs	87
China CER Sales	
Combustion CDM to Europe	36
All other CERs	120

Table 5: Fixed Parameters.

The initial marginal costs of abatement are presented below in Table 6.

Parameter [units]	**Europe**	**China**
p^a [\$/tSO_2]	3750	3300
p^q [\$/tCO_2]	20	14

Table 6: Marginal Abatement Costs.

The alpha (α) variable in the model represents the rate at which SO_2 is reduced jointly with CO_2 reduction. The European value is taken from a previous paper by Löschel and Rübbelke (2009), whereas the China value is taken from unpublished calculations undertaken by the authors.

Alpha (α)	$kgSO_2/tCO_2$ abated
EU-17	1
China	3

Table 7: Values for α.

The final step of the calibration is to calculate the initial consumption (*y*) levels, and the subsidy rate for CDM expenditures. These are shown below in Table 8.

Parameter	Initial Value
Europe Consumption (Trillion $)	20
China Consumption (Trillion $)	6.29
Subsidy rate (*s*)	0.29

Table 8: Initial Consumption Levels and the Subsidy Rate.

5.2 Simulation Results

By our model, we assess the impact of the subsidy rate (*s*) paid by Europe for combustion CO_2-based CDM projects in China on utility, consumption, emissions control, and prices. We undertake two sets of simulations, within both of which we incrementally vary the level of *s*. Each set differs, however, in how China is assumed to achieve its domestic SO_2 goals. The first simulation set is assumed to be *technology-specific*, keeping the use of end-of-pipe technologies (*a*) fixed. The second set, however, is *technology-neutral*, and merely keeps the total level of SO_2 emissions (*z*) constant. Our interest is how these approaches may impact our results. The results are presented in Figures 2 and 3 below. It is seen that, as expected, the level of global CO_2 abatement (*X)* increases with an increased subsidy under both simulations.

Under both simulations, the level of utility in China rises with increasing subsidy rates. The sign of the impact of rising subsidy rates on *consumption* depends acutely on the policy approach assumed for air quality in China. Under a standards-driven policy, where end-of-pipe abatement technology usage is fixed, consumption actually falls under increased CDM subsidy rates. The opposite is the case for the technology-neutral policy.

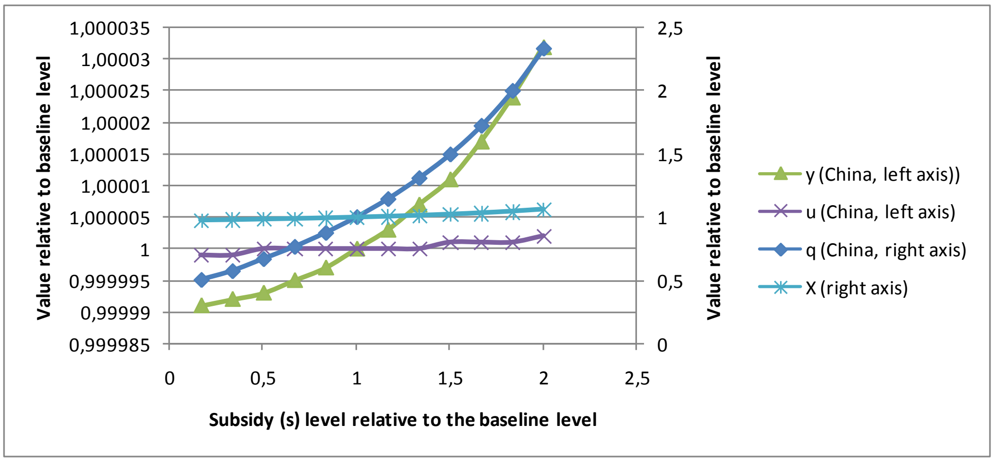

Figure 2: Change in global CO_2 reduction (x), and consumption (y), utility (u), and CO_2 emissions abatement in China (q) under changes to the CDM subsidy level. Technology-neutral domestic air quality policy assumed with a fixed SO_2 emissions level.

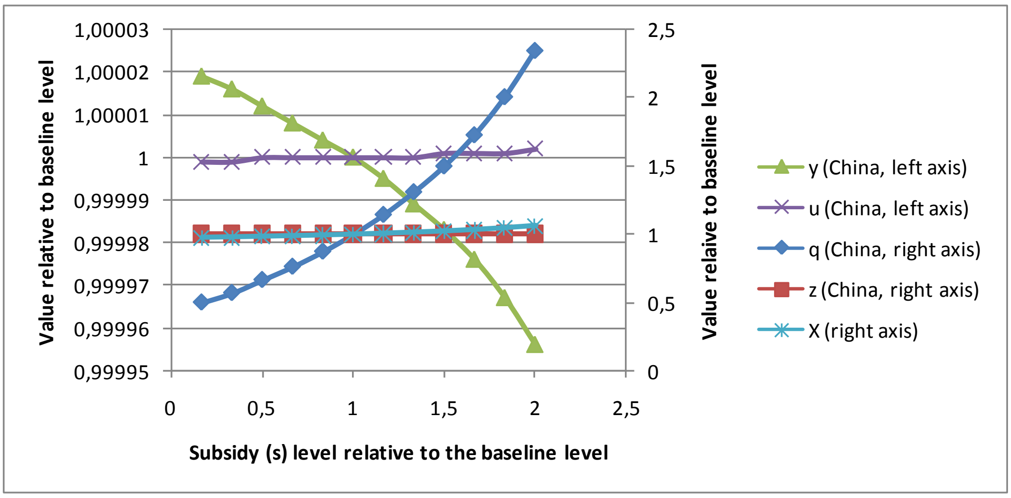

Figure 3: Change in global CO_2 reduction (x), and consumption (y), utility (u), and CO_2 (q) and SO_2 (z) emission abatement in China under changes to the CDM subsidy level. Technology-standards-driven domestic air quality policy assumed.

The reason for this is that under the standards-driven policy, China does not have the flexibility to take advantage of the air quality co-benefits of the CDM and substitute between end-of-pipe and CDM contributions to SO_2 reductions. Under the technology-neutral policy (where only the *level* of SO_2 emissions is mandated) and higher CDM subsidies, China can reduce its expenditures on end-of-pipe technologies – affording it higher levels of consumption. This result is in line with much of the market-based environmental policy literature in the recent decades. To take maximal advantage of the co-benefits of CDM, a flexible technology-neutral air quality policy (such as emissions trading or taxes) is thus advisable.

6 Concluding Remarks

The importance of environmental sustainability for poverty mitigation is frequently stressed. The seventh UN Millennium Development Goal, for example, calls for the integration of the principles of sustainable development into country policies and programmes and to reverse the loss of environmental resources. Such a strategy of linking two policy issues, i.e. environmental protection and poverty eradication, is considered in this paper. However, we not only consider the impact of an improved environment on the welfare of poor countries, but also the effects of international environmental measures on private consumption in developing countries. Increases in welfare and private consumption levels can both be regarded as a mitigation of poverty.

The international protection measures analyzed here are CDM transfers channeled from the industrialized to the developing world. More precisely, we investigated the influence of transfers from Europe, which is currently the largest purchaser of CDM credits, towards China, which is the largest provider of CDM credits, on changing the technology application in China. We observed the effects on poverty (welfare and private consumption levels) in China as well as on China's and the whole world's climate protection levels.

The results show how industrialized countries can positively influence the consumption level by raising the transfers to the developing world. There may be a range of transfer levels which is profitable for both parties. In the example we have considered, with CO_2 and SO_2 emissions, we find that a rise in the transfer level within this range will have different impacts, depending on the kind of SO_2 regulation in China.

Our results suggest that this type of development aid will be more effective at increasing private consumption in the receptor country if its domestic environmental policy is implemented in a flexible and incentive compatible way. In our example, this is the case when China stipulates the abatement target (z), but not the level (a) of end-of-pipe technology application for SO_2 control. CDM transfers towards developing countries that base their environmental regulations mainly on command-and-control instruments like the implementation of technological standards will likely have a lower poverty-mitigating impact (in the sense of raising private consumption). As highlighted in the previous section, this advantage is a result of the flexibility afforded by a technology-neutral policy; developing countries will take advantage of the co-benefits of the CDM by paring down their application of end-of-pipe technologies, which in turn will allow for more private consumption. This is in line with the preference in the literature for market-based environmental policy (such as taxes or permits) over a technology-driven approach.

When it comes to the impact of the transfer level on global climate protection, our results suggest that the higher the level of the subsidy rate the higher the global climate protection level under both options for domestic environmental policy. Climate protection appears to increase slightly more under the flexible regulation option, albeit with only a 1.5% advantage.

Both environmental regulation scenarios offer positive welfare (*u*) responses to increasing CDM transfer rates in our model. Yet, the CDM transfers actually caused a decline in private consumption if China applied a technology-specific policy.

At first sight, the consumption and climate protection results may appear to contradict the assumption that positive environmental protection and poverty mitigation (via increased consumption) always go hand in hand. We find that the most advantageous outcome from a consumption perspective may not be the same as the one from a climate perspective.

We must, however, note that the negative consumption impact in our technology-specific scenario occurs within a model where SO_2 emission reductions are the only co-benefit of climate policy. If we were to expand the co-benefits into additional pollutants (NO_x, PM) and effects (such as energy cost savings and energy security) it might be the case that both technology-specific and technology-neutral scenarios will feature positive consumption impacts of increased subsidies. Energy savings, for example, will allow for more consumption on other goods and services. In such a case, environmental protection and consumption would increase simultaneously. However, what our model effectively demonstrates is the importance of co-benefits in environmental policy analysis and design.

In future extensions of this work, it would be interesting to add complexity to the model by including additional pollutants and ancillary effects, and by linking consumption levels to pollution. Another important extension of the analysis would be the investigation of distributional effects within China, e.g. of the question whether the change in private consumption would mainly improve the well-being of the poor or of the rich in China.

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