The Trouble With Voluntary Emissions Trading

Uncertainty and adverse selection in sectoral crediting programs¹

Adam Millard-Ball Environmental Studies Department University of California-Santa Cruz 1156 High St., Santa Cruz, CA 95064 United States

phone: (831) 459-1838 [to follow]

email: adammb@ucsc.edu [to follow]

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Abstract

Sectoral crediting has been proposed as a way to scale up project-level carbon offset programs, and provide sector-wide incentives for developing countries to reduce greenhouse gas emissions. However, simulations presented here suggest that information asymmetries and large uncertainties in predicting counterfactual business-as-usual (BAU) emissions are likely to render sectoral crediting an extremely unattractive mechanism in practice, at least for the transportation sector. The regulator faces a tradeoff between efficiency and transfers/environmental damage when setting the crediting baseline in relation to uncertain BAU emissions. A generous baseline promotes efficiency, as more developing countries participate and implement abatement measures. However, a generous baseline also produces large volumes of non-additional offsets, which lead to either increased global emissions, or transfers between developed and developing countries if developed country emission reduction targets are made more stringent in order to leave global emissions unchanged. I show that any crediting baseline that encourages a non-negligible number of countries to participate in a sectoral crediting mechanism results in environmental damage or transfers that are likely to be too high to be politically feasible.

Keywords: adverse selection; risk-sharing; carbon offsets; sectoral crediting; transportation

1 Introduction

The carbon market is the centerpiece of current efforts to fund low-cost measures to reduce greenhouse gas emissions in developing countries. In particular, the Clean Development Mechanism (CDM), an implementation mechanism of the Kyoto Protocol, allows developed countries to purchase carbon offsets from projects in developing countries as a partial alternative to domestic action. By equalizing marginal abatement costs across sectors and across countries, the CDM can in principle substantially reduce the cost of achieving a given abatement target (Anger et al. 2007).

The CDM, however, has come in for substantial criticism in recent years. There is evidence that many of the CDM offsets are not "additional;" i.e., the project would have been undertaken anyway in the absence of the CDM (Wara and Victor 2008; Haya 2009; Schneider 2009; Fujiwara 2010; He and Morse 2010). Other lines of criticism relate to problems with the methodologies used to quantify emission reductions (Millard-Ball and Ortolano 2010); the lack of broad sustainable development benefits from CDM projects (Sutter and Parreño 2007); and the inability of the CDM to promote innovation and incentivize long-term transformations in energy systems (Sterk 2008).

Sectoral no-lose targets and other sector-based crediting mechanisms have emerged prominently as a way to address these problems with project-level CDM (Bosi and Ellis 2005; Figueres 2006; Center for Clean Air Policy 2008; Ecofys 2008; Sterk 2008; Baron et al. 2009; IETA 2010). Developing countries would participate on a voluntary basis, and could generate tradable credits (offsets) by reducing emissions to below a sectoral "crediting baseline" (Figure 1). Emissions above the crediting baseline would not be penalized (hence the "no lose" designation).



Figure 1 Concept of Sectoral No-Lose Targets

There are four fundamental differences between sectoral no-lose targets and the existing CDM. First, the CDM operates at the project level, while sectoral no-lose targets consider aggregate sectoral emissions and do not seek to attribute reductions to any particular project. Second, CDM projects are typically proposed by private investors, while offsets from sectoral no-lose targets would accrue to national governments, who would in turn determine how to pass through incentives to private actors. Third, emission reductions under the CDM are calculated via a two-step process: a binary determination of additionality, followed by an estimate of emission reductions below a counterfactual baseline. In the case of sectoral no-lose targets, both additionality and baseline issues are implicit in determining the crediting baseline. Fourth, the baseline for CDM is typically business-as-usual (BAU).² In contrast, most discussions of sectoral no-lose targets assume that the crediting baseline would be set below BAU, as implied in Figure 1, bringing about a net reduction in global emissions. However, the crediting baseline could be set at any level, including at or above BAU.

² Some CDM methodologies do include a "conservativeness" factor or make conservative assumptions, meaning that the baseline can be slightly below BAU.

The regulator, such as the UN or other multilateral body, faces a key tradeoff when setting the crediting baseline in the presence of uncertainty over BAU. Set the crediting baseline too stringently, and developing countries may not participate – a rational decision if the costs of reducing emissions to the crediting baseline exceed the revenues from the sale of offsets from further emission reductions. Thus, a stringent baseline risks foregoing low-cost abatement opportunities in countries that do not participate. Set the crediting baseline too generously, and it risks being above counterfactual BAU and enabling developing countries to sell non-additional offsets. These non-additional offsets either represent an environmental cost if global emissions increase, or else a transfer cost from developed to developing countries if targets in developed countries are made more stringent to leave global emissions unchanged. The essential tradeoff faced by the regulator is between efficiency on the one hand, and environmental or transfer costs on the other hand, and the ex-ante optimal baseline depends on their relative importance.

One underlying cause of this tradeoff can be overall uncertainty about BAU emissions – i.e., uncertainty that is common to the regulator and the developing country. In this case, the impacts of uncertainty on efficiency, environmental costs, and distributional outcomes will partly depend on how risk is allocated between offset purchasers and the developing country offset suppliers. Another cause can be adverse selection, which arises from information asymmetries between the regulator and individual developing countries. Since a country has more information on its own counterfactual BAU emissions than does the regulator, it can decide to participate if it is granted (by virtue of the regulator's uncertainty) a favorable baseline.

Indeed, adverse selection is an issue with any voluntary emissions trading program, including domestic cap-and-trade systems that allow firms to decide whether or not to participate. In the case of the U.S. Acid Rain Program, generating units with a "generous" baseline (one set above their

counterfactual BAU emissions) were more likely to participate, resulting in increased SO₂ emissions and a net social loss after considering abatement cost savings (Montero 1999, 2000). Adverse selection problems have also been raised in the contexts of crediting rules under project-based CDM (Fischer 2005) and under opt-in programs for agriculture and forestry (Kerr and Sweet 2008; van Benthem and Kerr 2010). With one main exception (Montero 1999), however, the impacts of adverse selection in emissions trading have not been estimated empirically.

This paper offers three main contributions. First, I numerically simulate the tradeoff between environmental or transfer costs and efficiency. In contrast to Montero, who provides econometric estimates using historical emissions data, my simulations allow me to explore the impacts of a wide range of regulatory decisions over crediting baselines – not just the baseline that happened to have been implemented by the regulator. As discussed in Section 2, analytic results are ambiguous, necessitating the use of simulations. Moreover, I consider the case where uncertainty is common to the regulator and the developing country, as well as the asymmetric information case with adverse selection.

Second, I offer the first case study of implementing sectoral crediting in the transportation sector. Transportation is important because of the sheer size of the sector – it accounted for 23% of global energy-related CO_2 emissions in 2009 (International Energy Agency 2012). Moreover, its underrepresentation in the CDM, accounting for less than 1% of emission reductions, suggests the gains from moving to a sectoral approach may be large (Bradley et al. 2007; Ellermann 2009; Schneider and Cames 2009; Wittneben et al. 2009).

Third, I contribute to the policy literature on sectoral crediting and other market-based mechanisms to engage developing countries in greenhouse gas abatement. There is a considerable literature advocating sectoral crediting as a policy solution, but it has focused on conceptual design issues with

little detailed analysis of how to set the crediting baseline. This paper is the first to quantify the costs that uncertainty and adverse selection may impose on such a mechanism.

The conclusions of this paper stand in contrast to the excitement over sectoral no-lose targets evident in the policy literature, as well as the theoretical attraction of using voluntary market mechanisms to equalize marginal abatement costs across the globe. I show that the tradeoff between efficiency and environmental or transfer costs is likely to be stark and unappealing in practice, at least for the transportation sector. Any crediting baseline that encourages a non-negligible number of countries to participate is too generous from the standpoint of additionality – more than 75% of offsets under most scenarios are non-additional, leading to major increases in global emissions or transfers that can exceed \$10 billion per year. At root, this result is due to the imprecision with which the regulator can predict counterfactual BAU emissions in developing countries that are rapidly growing. Thus, while the efficient outcome³ is attainable, the necessary transfers from developed to developing countries are likely to be too high to be politically feasible. These transfers are assumed to be made through adopting more stringent emissions targets in developed countries, in order to maintain global emissions at the optimum level. If targets are not adjusted, then there may be no efficiency gain at all due to increased environmental damage.

The paper proceeds as follows. In Section 2, I present a theoretical model that specifies participation and abatement decisions by developing countries, and the baseline-setting decision by the regulator. Section 3 describes the empirical approach to estimating abatement cost functions and business-asusual emissions. In Section 4, I present the results of the simulations. Section 5 concludes with implications for the design of policy instruments to fund abatement in developing countries.

³ Throughout this paper, I ignore potential inefficiencies from the raising of public funds.

2 A Model of a Voluntary Trading Program

2.1 Participation and Abatement Decisions by Developing Countries

The model presented here is similar in spirit to that of van Benthem and Kerr (2010), who develop a model in the forestry context. There are entities i = 1...N that may choose to participate in a trading program. The entities are non-Annex I countries (primarily developing nations) that do not face binding emission targets under an international agreement. I refer to them simply as "countries" or "developing countries" in the following sections. (Annex I countries do not enter into the model, except as an exogenous source of demand for offsets.) For simplicity, I develop a model with a single compliance period. Provided abatement costs and decisions are independent over different compliance periods, the model generalizes in a straightforward way to multiple compliance periods.

Each country has BAU emissions z_i^0 . If it does not participate, its emissions remain z_i^0 and its abatement cost is zero. Otherwise, it chooses abatement $q_i > 0$, incurs an abatement cost $c_i(q_i)$ and has emissions $z_i = z_i^0 - q_i$. Each country is assigned a crediting baseline b_i for the compliance period by the regulator. Reductions below b_i can be sold as offsets at an exogenous price p if a country opts in. Note the important distinction between participation (undertaking nonzero abatement) and opt in (formally taking part in the mechanism, and being eligible to sell offsets).⁴

⁴ The distinction arises because the participation decision is private information. A country can easily claim that it is undertaking abatement (or at least attempted to do so), given the difficulty for observers in disentangling abatement efforts from policies and projects that would have happened anyway under BAU. Given the "no lose" provision, every country will opt in – since a country never needs to buy offsets, there is no reason not to do so. However, some will not participate and will claim that BAU policies and projects represent their abatement efforts.

However, each country estimates its BAU emissions z_i^0 with error, i.e. $\tilde{z}_i^0 = z_i^0 + \delta_i$. Assuming risk neutrality, a country will participate in the compliance period if and only if:

I assume that countries know the carbon price p and the cost function $c_i(q_i)$ with certainty.⁵

$$\max_{q_i} \left[p \left(q_i - \left(\tilde{z}_i^0 - b_i \right) \right) - c_i \left(q_i \right) \right] \ge 0$$
⁽¹⁾

Assuming that countries are profit-maximizing and do not care about aggregate emissions, each country receives the following payoff:

$$\pi_{i} = p(b_{i} - z_{i}) - c_{i}(q_{i}) \qquad \text{if } b_{i} \ge z_{i} \text{ and } q_{i} > 0$$

$$\pi_{i} = -c_{i}(q_{i}) \qquad \text{if } b_{i} < z_{i} \text{ and } q_{i} > 0$$

$$\pi_{i} = p(b_{i} - z_{i}) = p(b_{i} - z_{i}^{0}) \qquad \text{if } b_{i} > z_{i} \text{ and } q_{i} = 0$$

$$\pi_{i} = 0 \qquad \text{otherwise}$$

$$(2)$$

In the first case, the country participates and sells offsets. The profit may be negative if the country underestimates BAU emissions, and thus is unable to sell as many offsets as expected. In the second case, the country also participates but is unable to sell any offsets, due to an underestimate of BAU. (Note that the "no lose" provision means that a country never needs to buy offsets, even if emissions are above the crediting baseline.) In the third case, the country does not participate and emissions remain at BAU, but it is able to sell offsets due to a generous baseline or an unexpected drop in emissions. In the fourth case, the country neither participates nor sells offsets.

Given the usual conditions on the shape of the cost function, a country that participates will choose abatement q_i^* , defined as the point at which price equals marginal abatement costs. Thus, a developing country's emissions z_i^* are as follows:

⁵ The first assumption can easily hold through the purchase of options to sell offsets at a predetermined price, the forward sale of emission reductions, or the use of similar financial instruments.

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$$z_{i}^{*} = \begin{cases} z_{i}^{0} - q_{i}^{*} & \text{if } p\left(q_{i}^{*} - \left(\tilde{z}_{i}^{0} - b_{i}\right)\right) \ge c_{i}\left(q_{i}^{*}\right), \text{ where } q_{i}^{*} \text{ satisfies } p = \frac{\partial c_{i}}{\partial q_{i}^{*}} \\ z_{i}^{0} & \text{otherwise} \end{cases}$$
(3)

Graphically, this is shown in Figure 2. If, in expectation, the cost of reducing emissions from BAU to the crediting baseline b (area A) is less than the rents earned on emission reductions that can be sold as offsets (area D), then a country participates (*left panel*). A country also participates if b is greater than BAU emissions z^{0} in which case area A is negative. If area A is greater than area D, which occurs if the crediting baseline is changed to b', a country does not participate, as in the right panel.

Figure 2 Abatement Decisions By Developing Countries



A < D --> country participates

A > D --> country does not participate

2.2 BAU Estimating and Baseline Setting by the Regulator

I assume that the regulator knows the carbon price p (which depends on the crediting baseline in equilibrium) and country-specific cost function $c_i(q_i)$ with certainty.⁶ However, it estimates BAU emissions with error as $\hat{z}_i^0 = z_i^0 + \varepsilon_i$. These BAU estimates, in turn, serve as the basis for setting the crediting baseline b_i . Most likely, the crediting baseline would be set as a percentage of estimated BAU. I assume that this percentage r is the same for each country, and thus $b_i = r\hat{z}_i^0$.

While both the country and regulator estimate BAU with error, I assume that the regulator's error is larger, i.e. $|\epsilon_i| > |\delta_i| \quad \forall_i$. This asymmetry in information regarding BAU emissions between countries and the regulator is the source of the adverse selection. It might arise as the regulator does not know the nature of the infrastructure investments, taxation changes and regulatory measures a country planned to undertake under BAU. In addition, while the regulator makes a one-shot estimate of BAU, the country has the opportunity to update its emissions estimate over time. Moreover, while the regulator can condition a dynamic estimate of BAU on observables such as GDP (i.e., predicted BAU \hat{z}_i^0 in year *t* can be a function of variables in year *t*, *t-1*, *t-2*...), it cannot condition the estimate on variables that may be the target of transportation policy measures. For example, suppose that a crediting baseline is set as a percentage of BAU, which in turn is estimated as a function of contemporaneous fuel prices and public transportation provision. Then, there is no incentive for a country to reduce fuel subsidies, increase fuel taxes or improve rail service as an emission reduction measure. Such actions would simply be cancelled out by a more stringent crediting baseline.

⁶ While the regulator may not have perfect information regarding abatement costs, information asymmetries are less pronounced than with BAU emissions. Abatement cost estimates are often provided by multinational agencies or consultants, with the results being freely available. This assumption also makes the analysis in this paper more conservative; i.e., putting sectoral crediting mechanisms in a more favorable light. To the extent that information asymmetries do exist regarding costs, the regulator's decision is complicated further.

I posit three alternative objective functions that the regulator may seek to maximize or minimize when setting the vector of crediting baselines **b**:

1. Maximize average offset quality. A non-additional offset is one that is generated by virtue of the crediting baseline being set above BAU. A country needs to take no action and incurs no abatement costs to generate non-additional offsets. I thus define an average offset quality objective as one that minimizes the global proportion of non-additional offsets. Formally, the regulator sets:

$$\mathbf{b}_{QUALITY}^{*} = \underset{\mathbf{b}}{\arg\min} E\left\{\frac{\sum_{i=1}^{N} \max(b_{i} - z_{i}^{0}, 0)}{\sum_{i=1}^{N} \max(b_{i} - z_{i}^{*}, 0)}\right\}$$
(4)

The numerator is the volume of non-additional offsets. The denominator is the total volume of offsets generated. In the absence of the private information held by each country about their true baseline, the regulator could ensure that all offsets are additional by setting $b_i \le z_i^0$. However, since z_i^0 is estimated with error, this may not be possible for all countries.

2. Minimize global emissions. This objective has an environmental motivation. It is most applicable in a world where emission reductions targets in Annex I countries do not adjust to the expected supply of non-additional offsets. Offsets allow Annex I countries to increase their emissions. Therefore, to minimize global emissions, the regulator sets the crediting baseline to minimize the sum of developing country emissions (the first term inside the summand in Eq. 5) and offsets generated (the second term). The regulator wishes to set the crediting baseline stringently enough that a country is indifferent as to whether to participate (and then, by assumption, does so).

$$\mathbf{b}_{MIN_EMISSIONS}^{*} = \arg\min_{\mathbf{b}} E\left\{\sum_{i=1}^{N} \left[z_{i}^{*} + \max\left(b_{i} - z_{i}^{*}, 0\right) \right] \right\}$$
(5)

3. Maximize efficiency. Under this objective, the regulator maximizes the number of countries that participate, weighted by abatement potential. In a world where targets in Annex I countries adjust to

the expected supply of non-additional offsets from developing countries, this can be interpreted as an efficiency objective, in that the regulator takes advantage of all developing world abatement opportunities with a marginal cost less than the carbon price. This objective is also equivalent to minimizing emissions in developing countries. The baseline that maximizes efficiency may not be uniquely defined (if all countries participate, then increasing the baseline further will yield the same result); if this is the case, the regulator chooses the smallest from the set of efficient baselines.

$$\mathbf{b}_{EFF}^{*} = \min_{\mathbf{b}} \left\{ \arg\min_{\mathbf{b}} E\left\{ \sum_{i=1}^{N} z_{i}^{*} \right\} \right\}$$
(6)

2.3 Implications of Alternative Baselines

The probability of participation is decreasing in abatement cost $c_i(q_i)$, and increasing in the carbon price p and the crediting baseline b_i , as can be seen from (3). The probability also depends on the distribution of actual BAU emissions around the estimates of the country and the regulator, i.e. the distributions of δ_i and ε_i . However, the crediting baseline is the only variable that can be controlled by the regulator. Conditional on participation, the crediting baseline also affects the distribution of the surplus and the level of transfers between Annex I and developing countries. One can think of b_i^r as a "rent extraction" point in that it is the most stringent baseline that ensures participation.

$$p\left(q_i^* - \left(\tilde{z}_i^0 - b_i^r\right)\right) = c_i\left(q_i^*\right) \Longrightarrow b_i^r = \frac{c_i\left(q_i^*\right)}{p} + \tilde{z}_i^0 - q_i^*$$

$$\tag{7}$$

As demonstrated by Montero (2000), the choice of crediting baseline trades off efficiency for transfer costs. The number of countries participating and the transfer costs (payment for non-additional offsets) are both increasing in the crediting baseline. Figure 3 illustrates the fundamental tradeoff faced by the regulator in the presence of uncertainty. Intuitively, there is a "window" between the rent extraction point and BAU emissions under which a country will participate and all offsets will be

additional. The regulator can satisfy at least two objectives (maximize offset quality and efficiency) if the prediction error for BAU can be contained within this window. If the prediction error is larger than the window, then the trade off exists.





The regulator estimates BAU emissions z^0 and the rent extraction point b' (the most stringent baseline at which a country will participate) with error. Note that the two error distributions (shaded) are not independent; indeed, they are likely to be perfectly correlated. If a country participates, it reduces emissions to $z^0 - q$. In the left panel, the regulator can set a crediting baseline *b* that with certainty lies both above the true rent extraction point b' (ensuring participation) and below true BAU emissions z^0 (ensuring 100% additionality). In the right panel, the regulator faces greater uncertainty. With crediting baseline *b*, Area A represents Pr $[z^0 < b]$, i.e. the probability that a country generates non-additional offsets. Area C represents Pr [b' > b], i.e. the probability that a country does not participate. Through setting *b*, the regulator must trade off transfer costs (reducing the size of Area A) against efficiency losses (reducing the size of Area C). Note that this simplified set up does not consider a country's own prediction errors (i.e., it assumes $\delta=0$).

The solution to the "maximize efficiency" objective is straightforward – set a crediting baseline sufficiently generous that all countries participate. However, this implies very high transfer costs. In contrast, it is far from clear how the regulator should set **b** to optimize against the other objectives – maximizing average offset quality, or minimizing global emissions. There is no general analytic solution. In the case of offset quality, both the numerator and denominator of (4) are increasing in **b**; hence, the effect of changing the baseline on the proportion of additional offsets is ambiguous. Over

the range of **b**, the proportion of non-additional offsets is increasing in \mathbf{b} ,⁷ but this result does not hold locally (as clearly demonstrated in Section 4).

A similar ambiguity applies to the "minimize global emissions" objective in (5). Global emissions are the sum of developing country emissions z_i^* , which are decreasing in b_i , and offsets $\max(b_i - z_i^*, 0)$, which are increasing in b_i . For both (4) and (5), a formal demonstration of the ambiguity is given in online Appendix A (available at the journal's online archive at http://www.aere.org/journals/). The lack of analytic results necessitates a simulation approach.

3 Empirical Approach

The broad empirical approach adopted here is to hypothesize that sectoral no-lose targets had been implemented in some prior year, perhaps as part of the 1997 Kyoto Protocol. Section 3.1 discusses estimation of abatement costs. Section 3.2 discusses how the regulator might set the crediting baseline. BAU emissions from transportation are observed and I use data from the International Energy Agency (2009), with 2007 being the most recent year. I do not attempt to estimate the carbon price, but rather undertake simulations under a range of plausible price scenarios.

3.1 Estimating Abatement Costs

I derive regionally specific abatement cost curves from the Global Change Assessment Model (GCAM), a regionally disaggregated integrated assessment model (Kim et al. 2006). I impose a series of carbon prices from 2020 onwards, and use GCAM to simulate abatement in 2020 at each price (percentage abatement in 2035 is very similar). Further details are provided in online Appendix B.

⁷ To see this, note that there is some **b** small enough so that at least one country participates while ensuring that no country has a baseline above BAU. This ensures that 0% of offsets are non-additional. Once **b** is large enough so that all countries participate, increasing each b_i by $\eta_i > 0$ means that both numerator and denominator increase by $\sum_i \eta_i$, and in the limit the percentage of non-additional offsets approaches 100%.

3.2 Setting the Crediting Baseline

Central Case

The central case that I consider in this paper assumes that the regulator estimates BAU in year *t* as a function of exogenous variables such as GDP in year *t*, *t*-1, *t*-2.... The formula for the crediting baseline is determined five years in advance (a five-year horizon). In the context of my data, this corresponds to the hypothetical implementation of sectoral no-lose targets in 2002, and a compliance year of 2007. I assume that the crediting baseline is set as a percentage of estimated BAU, and I simulate crediting baselines of between 70% and 130% of estimated BAU. This dynamic approach to setting the crediting baseline is only known ex post once GDP and other relevant variables are observed. A dynamic baseline is likely to minimize the errors in predicting BAU emissions compared to setting the absolute level of the baseline several years in advance, without the ability to adjust estimates to account for changes in macroeconomic and other conditions.

I estimate BAU emissions as a function of GDP (measured at purchasing power parity in 2000 U.S. dollars); GDP from manufacturing; final consumption expenditure; crude oil price; gasoline price; and time. I also include the lagged dependent variable as a regressor. The inclusion of manufacturing GDP accounts for the potential greater emissions intensity of manufacturing activity compared to a services-based economy, due to freight transportation. The time trend captures improvements in technical efficiency. The dependent variable is per capita transportation emissions, and so I do not include population as a predictor. Data are from the International Energy Agency (2009) and UN National Accounts (United Nations 2010). The fixed-effects models include an AR(1) error term. All variables except time enter in log form, with retransformed predictions made using Duan's smearing estimate (Cameron and Trivedi 2009: 103). I also estimated fixed-effects models with country-

specific coefficients for oil price, GDP and the lagged dependent variable, but these performed more poorly in predictive terms (results not shown).

I estimate the four plausible specifications shown in the center of Table 1 – two fixed-effects and two first-differenced specifications, each with a full and more parsimonious set of predictors. I assume that the regulator, through skill or luck, picked (6), which has the best predictive performance (lowest population-weighted mean square error for the out-of-sample prediction in 2007). Because of the five-year horizon, I use only data through 2002 in estimating the models.

Alternative Cases

I also simulate horizon periods of one year and ten years, corresponding to implementation of sectoral no-lose targets in 1997 and 2006 respectively. Although a one-year horizon period is unrealistic, it shows the effects of more accurate predictions. With the ten-year horizon, prediction errors might be expected to increase considerably. As before, I choose the specifications with the best out-of-sample predictive performance, corresponding to (1) and (10) in Table 1.

While it seems reasonable to think that the regulator would adopt a similar approach, it is possible that it might, through luck or econometric skill, achieve greater predictive accuracy.⁸ For this reason, online Appendix C provides details of sensitivity tests. Here, I estimate 1,342,276 models (plausible combinations of 19 independent variables and 12 econometric specifications) for each horizon period and select the one with lowest mean square error for an out-of-sample prediction in 2007. While this leads to a modest improvement in predictive accuracy (Figure 4), there is no substantive impact on the simulation results

⁸ The regulator could also choose an approach with lower predictive accuracy – for example, through a politically negotiated or historically based crediting baseline. This would render sectoral crediting mechanisms even less attractive.

Table 1	Mode	l Specific	ations to	Estimate	e Busines	s as Usua	al Emissic	suo				
	(1)	(2)	(3)	(4)	(2)	(9)	(2)	(8)	(6)	(10)	(11)	(12)
	1 ye	ar horizon (d	ata through 20	06)	Central Ca	se: 5 year hori	izon (data thro	ugh 2002)	10 y	ear horizon (d	ata through 19	97)
Lag* Log dependent variable	0.818	0.844	-0.0324	-0.0228	0.0315	0.0320	0.0140	0.0161	0.0296	0.0386	0.0313	0.0425
	(0.00856)	(0.00737)	(0.0159)	(0.0153)	(0.0171)	(0.0166)	(0.0165)	(0.0160)	(0.0239)	(0.0227)	(0.0227)	(0.0215)
Log GDP	0.880	0.392	-4.318	0.328	-2.434	0.415	-4.495	0.361	-2.376	0.450	-4.095	0.431
	(0.672)	(0.0322)	(2.117)	(0.0337)	(2.465)	(0.0410)	(2.512)	(0.0400)	(3.221)	(0.0495)	(3.146)	(0.0478)
Lag 1 Log GDP	-0.251	-0.278	0.258	0.247	0.198	0.193	0.197	0.186	0.186	0.169	0.135	0.127
	(0.0350)	(0.0323)	(0.0355)	(0.0336)	(0.0398)	(0.0387)	(0.0390)	(0.0380)	(0.0508)	(0.0487)	(0.0482)	(0.0460)
Log ² GDP	-0.0513		0.536		0.336		0.567		0.317		0.512	
	(0.0791)		(0.251)		(0.291)		(0.297)		(0.384)		(0.374)	
Log ³ GDP	0.00162		-0.0211		-0.0137		-0.0225		-0.0126		-0.0199	
	(0.00307)		(0.00982)		(0.0114)		(0.0116)		(0.0151)		(0.0147)	
Log GDP from manufacturing	0.00217		0.0396		0.0142		0.0300		0.0449		0.0502	
	(0.00902)		(0.0184)		(0.0202)		(0.0199)		(0.0260)		(0.0249)	
Log final consumption	0.0250		0.182		0.173		0.182		0.199		0.187	
expenditure	(0.0209)		(0.0304)		(0.0344)		(0.0336)		(0.0438)		(0.0414)	
Log crude oil price	-0.0207	-0.0124	-0.0333	-0.00984	-0.00668	-0.00970	-0.00446	-0.00745	-0.0244	-0.0103	-0.0191	-0.00705
	(0.0248)	(0.00432)	(0.0237)	(0.00649)	(0.0251)	(0.00817)	(0.0242)	(0.00777)	(0.0302)	(0.0105)	(0.0289)	(0.00948)
Log gasoline price	0.00287		0.0485		0.0106		0.0120		0.0419		0.0412	
(Rotterdam spot)	(0.0274)		(0.0276)		(0.0297)		(0.0286)		(0.0394)		(0.0378)	
Time	-0.00356	0.000969	0.0274	0.00954	0.000144	0.00706	0.0183	0.00960	-0.0481	0.00876	-0.000178	0.00912
	(0.00232)	(0.000253)	(0.00819)	(0.00220)	(0.0189)	(0.00184)	(0.00967)	(0.00239)	(0.0270)	(0.00239)	(0.0150)	(0.00275)
Time ²	7.09e-05		-0.000294		0.000108		-0.000150		606000.0		0.000190	
	(3.54e-05)		(0.000124)		(0.000266)		(0.000154)		(0.000407)		(0.000251)	
Constant	-1.615	0.0109			7.452	0.644			8.059	0.494		
	(1.817)	(0.0719)			(1.175)	(0.0633)			(1.827)	(0.0945)		
Country fixed effects?	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Differenced?	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
ρ (autocorrelation coefficient)	.032	.018			.829	.836			.794	.803		
Z	3809	4162	3809	4162	3015	3194	3015	3194	1898	2048	1898	2048
R-squared	989.	066.	0.078	0.066	.834	.833	0.069	0.060	.843	.851	0.079	0.072
RMSE for 2007 prediction**	31.2	32.0	31.5	32.3	90.0	85.5	100.9	102.4	264.8	111.6	203.4	150.8
Standard errors in parentheses *Dependent variable is lagged or	e year (model	s 1 through 4), f	ive years (mode	Is 5 through 8)	and ten years (r	nodels 9 throug	h 12) respective	ly. ** Non-Ann	ex I countries on	lly, weighted by	population.	

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Predictive Performance

Figure 4 shows the predictive performance of the models, in terms of the distribution of percentage errors in the estimate of 2007 BAU for each non-Annex I country. For comparison, the approximate upper bound to predictive accuracy (discussed in online Appendix C) is also shown.

The ability of the regulator to predict BAU emissions declines precipitously as the horizon year extends and the regulator needs to predict further in the future. While reasonably accurate predictions (within about 5%) can be made with a one-year horizon period, this is not the case when predicting five years out (the central case), and even less so when predicting ten years out. The approximate upper bound does not markedly improve predictive performance, suggesting that the particular econometric specifications employed here are not at fault. Rather, the issue is the inherent unpredictability of transportation emissions in rapidly growing developing countries.

This unpredictability is not surprising, given the limited accuracy of past efforts. For example, International Energy Agency (IEA) five-year forecasts for transportation energy use in industrialized countries have erred by between 2.5% and 13.8% (Linderoth 2002), and these aggregate figures mask larger errors when predicting individual countries. Five-year U.S. transportation energy forecasts, meanwhile, were off by an absolute average of 6.6% during the 1980s and 1990s (Winebrake and Sakva 2006). While the prediction errors in the central case presented here are more than twice as large (for the plausible estimate, the median error is 15.5% at a five-year horizon), this is not surprising given that the developing countries considered here are growing much more rapidly than the industrialized countries of the IEA forecasts.⁹ Indeed, the prediction errors are correlated with

⁹ See Levin and Aden 2008 for a case study regarding the difficulties of predicting CO₂ emissions from China.

GDP growth rates ($\rho = 0.18$). Note that with a one-year horizon, the median prediction error is 5.5%, and thus more comparable to the U.S. forecasts.¹⁰



Figure 4 Errors in Predicting BAU Emissions

3.3 Estimating Country Prediction Errors

As noted in Section 2, an individual developing country will have private information on its planned abatement efforts and broader energy policies that enable it to improve on the regulator's prediction of BAU. However, the country still estimates BAU emissions with error δ_i . I model the country's prediction error as a proportion of the regulator's prediction error, so that $\delta_i = \lambda \varepsilon_i$, $\lambda \in [0,1]$. If $\lambda = 1$ there is no asymmetric information and no adverse selection occurs – the country predicts just as badly as the regulator.

For clarity of exposition, the analysis in this paper assumes that the developing country has perfect information on BAU emissions, i.e. $\lambda = 0$. In Section 4.4 I show the sensitivity of my results to different levels of information asymmetry.

¹⁰ For the approximate upper bound, the median prediction error is 4.2% at the one-year horizon and 12.6% at the five-year horizon.

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4 Simulation Results

4.1 Illustrative Scenarios

Figure 5 illustrates the essential structure of the results through showing the impacts of alternative crediting baselines for two scenarios. The first, shown in the two left panels, is a highly optimistic scenario – a one-year horizon period which minimizes the prediction error, coupled with a high carbon price of \$50 per tonne of CO_2 reduced. The second, shown in the two right panels, is a more realistic scenario using the central case (five-year horizon period) and a carbon price of \$20. In each case, the crediting baseline is set as a percentage of estimated BAU, ranging from 70% to 130%.

The top-left panel (optimistic assumptions) clearly illustrates how a more generous crediting baseline improves efficiency at the expense of greater transfers. (Transfers are calculated as the volume of non-additional offsets multiplied by the carbon price, on the assumption that developed countries adjust their own caps downwards to reflect the supply of non-additional offsets.) Below 74%, no country participates. At a stringent baseline of 74% of estimated BAU, all offsets are additional (solid line), but just two countries, Azerbaijan and Lebanon, participate. With a generous baseline of 116% of estimated BAU, almost all countries participate (dashed black line) but only 28% are additional.

The top-right panel (more realistic assumptions) shows similar trends, but the share of additional offsets is substantially reduced. Even at the maximum level of additionality, which is achieved when the crediting baseline is set at 83% of estimated BAU, less than one-quarter of offsets are additional and an even lower proportion of countries participate. Making the crediting baseline more generous increases the number of countries that participate, but at the expense of reducing the proportion of additional offsets down to as little as 10%.

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Both scenarios also indicate that it is almost impossible to secure net reductions in global emissions (gray dashed line). In the left panel, net reductions are achieved in only a narrow window at a crediting baseline of between 92% and 95% of BAU. Even the maximum volume is minimal (24 Mt CO_2 per year), and net reductions quickly become negative as the baseline is made more generous. While emission reductions in developing countries grow as the baseline is made more generous and more countries participate, this is more than countered by the growing volume of offsets that enable higher emissions in Annex I countries. In the right panel, net reductions are always negative, i.e. the volume of offsets is always greater than the volume of emission reductions in developing countries, regardless of the stringency of the crediting baseline.

Note that making the crediting baseline more stringent does not guarantee a greater proportion of additional offsets, as the relationship is not monotonic. This is because making the crediting baseline more stringent reduces both the volume of *non-additional* offsets and, because fewer countries participate, the volume of *additional* offsets. Moreover, the latter effect is discontinuous due to the binary nature of participation decisions, and all of the reversals and jumps in the figures are attributable to large countries participating at or above a particular crediting baseline. For example, in the right panels, the large jump at a crediting baseline of 80% is due to India's participation, which more than doubles the volume of additional offsets. A similarly marked jump at a crediting baseline of 109% is due to China's participation.



Figure 5 Impacts of Alternative Crediting Baselines

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The lower panels of Figure 5 explicitly show the efficiency gains and transfers from the same two scenarios. Efficiency gain (solid gray line) is the total economic gain from capturing lower-cost abatement opportunities in developing countries, assuming that the exogenously specified carbon price reflects constant marginal environmental damages and marginal abatement costs in Annex I countries. It is calculated as the sum of areas D and E in Figure 2. Rent (dashed black line) is the share of this efficiency gain that is captured by developing countries. Figure 5 suggests that developing countries capture the vast majority of the efficiency gain. The transfer (dashed gray line) represents payment to developing countries for non-additional offsets; when divided by the volume of additional offsets, it gives transfer per additional tonne (solid black line, plotted on the right axis). Again, the reversals and jumps in the figure are due to the binary nature of participation decisions; a large country's decision to participate substantially increases the volume of additional offsets, which lowers the transfer per additional tonne through increasing the denominator.

The optimistic assumptions in the lower-left panel suggest that there are substantial economic gains to be made from sectoral no-lose targets at a relatively modest transfer cost. With a crediting baseline set at 109% of BAU, the total efficiency gain almost reaches its maximum of about \$3.5 billion, with almost all of this accruing as rent to developing countries. At about \$79 per additional tonne, the transfer at this crediting baseline is relatively large but can be reduced to less than \$25 by making the crediting baseline slightly more stringent. With the more realistic scenario in the lower-right panel, however, these gains largely disappear. The lower carbon price reduces the maximum potential efficiency gain to about \$610 million, which is far outweighed by the transfers required to ensure that countries participate. Even at its minimum of \$62, the transfer per additional tonne is more than triple the carbon price, effectively quadrupling the cost of the offsets to Annex I countries.

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Moreover, under the optimistic scenario in the left panel, the steep increase in the transfer per additional tonne at a crediting baseline above 100% is relatively predictable. Once most countries have already opted in, further increases in the crediting baseline above 100% lead to an approximately linear increase in the total transfer and little change in the number of additional tonnes. In the right panel, the crediting baseline that achieves the local minimum transfer per additional tonne (here, \$62 at a crediting baseline of 83% or \$101 at a crediting baseline of 112%) is inherently unpredictable. As the local minima are achieved at the crediting baselines where large countries decide to participate, their locations cannot be predicted.

The relative positions of the total transfer and efficiency gain lines indicate whether there is potential for a Pareto-improving arrangement between Annex I and non-Annex I countries. In the left panel, total transfers are less than the efficiency gain for some crediting baselines, implying that it may be possible for non-Annex I countries to return some of the transfer – leaving both sets of countries better off. However, it is difficult to see how a politically feasible and practical mechanism could be developed to achieve this. With the more realistic central-case assumptions in the lower-right panel, no Pareto improvement is possible. That is, there is no side payment that could make sectoral crediting advantageous for both sets of countries, at least within the framework of this model.

The implications for the volume of offsets that can be achieved at a given price are illustrated for the central case in Figure 6. The cost per additional tonne is calculated as the (exogenous) carbon price divided by the share of additional offsets. Note that this is the cost from the perspective of the Annex I country or other offset purchaser – it includes the transfer payments for non-additional offsets, but not the cost to the developing country of reducing emissions to the crediting baseline. In almost all cases, the need to pay for non-additional offsets means that the price per additional tonne is very high – quintuple the carbon price or more over much of the range. Unless their abatement

cost curve is very steep, Annex I countries would likely forgo the purchase of offsets from sectoral crediting programs, and simply undertake additional abatement themselves.

Two surprising findings are revealed in Figure 6 (which can be interpreted as the "cost per additional tonne" curve from Figure 6, with the axis rescaled to show the volume of additional offsets rather than the crediting baseline). First, the price curve is not upward sloping over most of its range. Setting the crediting baseline to maximize the volume of additional offsets can yield both a higher quantity and a lower price. Second, increasing the exogenous carbon price makes little difference to the cost per additional ton. For example, at a carbon price of \$20 per tonne, the cost of 25Mt of additional offsets is approximately \$190 per additional tonne. At such a low carbon price, a generous crediting baseline of 107% has to be offered to secure 25Mt in additional offsets, and hence just over one in ten offsets is additional. At a carbon price of \$40 per tonne, 25Mt of additional offsets can be secured with a crediting baseline of 92%, and a cost of \$151 per additional tonne. While the cost per *tonne* is higher (\$40 rather than \$20), the higher share of additional offsets (26%) means the cost per *additional tonne* is lower. Sectoral no-lose targets perform far better in a world of higher carbon prices.



Figure 6 Supply Curve for Additional Offsets

4.2 Impacts of Carbon Price and BAU Estimation

The tradeoff between efficiency and transfer costs can be approximately captured by two variables – the percentage of countries participating, and the percentage of additional offsets. The three panels in Figure 7 plot these two variables for a range of carbon prices.

Participation decisions are relatively stable. Because expected abatement is small in relation to the regulator's prediction error, participation decisions hardly change with the carbon price, although there is some flattening of the curve as prediction errors increase. This flattening happens as the increased variance of prediction errors means that more countries receive a baseline of more than 100% of actual BAU at any crediting baseline, and thus will participate at any carbon price. The percentage of additional offsets, in contrast, exhibits large shifts in response to relatively small changes in either prediction errors or carbon prices. As noted above, making the crediting baseline more stringent (a lower percentage of estimated BAU) does not always increase the proportion of additional offsets.



Figure 7 Alternative Price Scenarios

4.3 **Optimized Crediting Baselines**

In this section, I return to the three potential objectives of the regulator, discussed in Section 2.2. For each objective (maximize average offset quality, minimize global emissions and maximize efficiency), I calculate the optimal crediting baseline (as a percentage of estimated BAU, constrained to be within 70% and 130%) for various carbon prices under the central case five-year horizon period. Note that these results are ex-post optimal, in that the regulator may not be able to achieve them without knowing the precise emissions-weighted distribution of BAU prediction errors.

As shown in Figure 8, the offset quality objective is best served by setting a very stringent crediting baseline of just over 80%. However, at low-to-moderate carbon prices of \$30 or less, it is impossible to ensure that more than one-third of offsets are additional. There is also a high efficiency penalty for promoting offset quality, with less than one-quarter of countries participating. The second objective, minimizing global emissions, requires the regulator to set a slightly more stringent baseline, at the price of generating more non-additional offsets. The third objective, maximizing efficiency, meanwhile requires the baseline to be set as generously as possible to maximize the emissions-weighted number of countries that participate. However, some countries do not participate even with the most generous crediting baseline simulated of 130% of estimated BAU. The tradeoff in return for efficiency is a very high transfer payment of more than \$200 per additional tonne in most instances. Depending on the carbon price, the total transfer can exceed \$38 billion per year in payment for non-additional offsets.



Figure 8 Optimized Crediting Baselines

4.4 Relaxing Perfect Information

The previous analysis considered the case where countries, in contrast to the regulator, have perfect information over BAU emissions. As discussed in Section 2, some degree of information asymmetry is to be expected. At the least, countries will have private information on planned abatement efforts and energy policies, and normally they will have more detailed information than an international regulator on energy consumption trends. However, while the assumption of perfect information clarifies the analysis, it is unlikely to hold in practice, and this section relaxes the assumption through allowing λ (as defined in Section 3.3) to vary. $\lambda = 0$ is the perfect information case for the country (i.e., maximum asymmetry), while $\lambda=1$ means that a country can predict no better than the regulator.

The results (Figure 9) show that allowing for imperfect information on the part of a country does not fundamentally change the regulator's problem. Qualitatively, the same conclusions hold as with the perfect information case. The regulator must still trade off participation and additionality, and it is still very difficult for the regulator to secure a reasonable share of non-additional offsets.

The imperfect information cases do, however, lead to three complicating effects. First, as shown in the left panels of Figure 9, the participation curve becomes steeper as the degree of information asymmetry is reduced (i.e., as λ moves towards 1). At stringent crediting baselines, imperfect information reduces participation; a country is more likely to believe that it cannot profitably reduce emissions and sell offsets. At more generous crediting baselines of 100% or more of estimated BAU, imperfect information increases participation – a country is more likely to believe that it can make a profit. After all, if a risk-neutral country shares the regulator's estimate that the crediting baseline is above BAU, then it should participate, regardless of abatement costs or the carbon price.

Second, some participating countries will find that (contrary to their expectations) they make a loss. Some will not even reduce emissions to below the crediting baseline, while others will find that rents from offset sales are insufficient to cover the first increment of abatement (i.e., Area A is greater than Area D in Figure 2). As shown in the left panels of Figure 9, this occurs only with more generous crediting baselines, where a country (erroneously) believes that the crediting baseline is above BAU. With a carbon price of \$20 and λ =0.75, up to 26% of participating countries find that the costs of abatement exceed offset revenue. To the extent that countries are risk averse, the prospect of making a loss on abatement action will serve to reduce participation further. Third, some non-participating countries receive a windfall. Even without any abatement action, their emissions are lower than the crediting baseline and they sell (non-additional) offsets. (Recall that given the no-lose nature of the targets, and the assumption that a country's participation decision is private information, all countries will opt in to retain the possibility of selling offsets.) Interestingly, as information asymmetry improves environmental performance (or reduces transfer costs), at least at stringent crediting baselines (Figure 9, right panels). As countries gain better information about BAU, they can take more appropriate decisions about mitigation– i.e., participating when it is profitable to do so.

The gray lines in the right panels show the extent to which non-additionality is due to nonparticipating countries (i.e., overall uncertainty over BAU), versus countries that participate and generate both additional and non-additional offsets (i.e., asymmetric information leading to adverse selection). Figure 9 clearly shows that with higher values of λ and with stringent crediting baselines, non-additionality is largely caused by overall uncertainty, rather than by asymmetric information. However, the problem of adverse selection remains. Even if the regulator were able to screen out offsets from non-participating countries (a difficult proposition in practice), additionality would still be as great a challenge as in the fully asymmetric information case of $\lambda=0$.¹¹

Thus, sectoral no-lose targets perform poorly regardless of whether uncertainty is shared by the country and the regulator (the overall uncertainty case), or whether the country has better information on BAU emissions (the asymmetric information/adverse selection case). In the first instance, shifting more risk onto developing countries – for example, by eliminating the "no lose"

¹¹ For example, assume a carbon price of \$20, λ =0.75, and that the regulator can observe the participation decision. The highest proportion of additional offsets that the regulator can achieve is 32%, at a crediting baseline of 100% of estimated BAU. With λ =0.25, the best the regulator can do is 35% additionality, at a crediting baseline of 86%.

provision and requiring countries that opt in to purchase offsets if their emissions exceed the crediting baseline – is one possibility to avoid granting windfalls to non-participating countries. However, this approach would penalize countries that participate but face unexpectedly high BAU emissions – they would not only pay their mitigation costs, but also need to make up the shortfall. Moreover, shifting additional risk to developing countries may not be politically feasible.



Figure 9 Effects of Reducing Information Asymmetries

The upper panels show results with a carbon price of \$20, and the lower panels assume a price of \$50. The left panels show the percentage of countries participating (*black lines*), and the percentage of countries that participate and make a loss (*gray lines*). The solid lines show the perfect information case, as considered earlier in this paper, and the dashed and dotted lines move the country's estimate of BAU emissions towards that of the regulator. Note that in the perfect information case, no country makes a loss. The right panels show the percentage of offsets that are additional (*black lines*), and of the non-additional offsets, the percentage that are generated by non-participants (*gray lines*). These non-participants do not expect to profitably reduce emissions, but receive a windfall as BAU turns out to be below the crediting baseline. The carbon price is \$20 in the upper panels, and \$50 in the lower panels.

5 Conclusions

In principle, sectoral no-lose targets are a compelling mechanism to provide incentives for emission reductions in developing countries. However, their feasibility is conditional on the ability of both individual developing countries and an international regulator to make reasonably accurate predictions of business-as-usual emissions. The results presented in this paper suggest that, at least for the transportation sector, the uncertainties in predicting BAU are extremely large relative to expected abatement. This is the case even when, as here, contemporaneous GDP and oil prices are used to make the predictions (i.e., the baseline is dynamic). As a result of the uncertainties, a large fraction of offsets are non-additional, rendering sectoral no-lose targets an unattractive option.

The efficient solution requires setting an extremely generous baseline – generous enough to compensate for the regulator's prediction error – to encourage as many countries as possible to participate. However, in this case, almost all of the resultant offsets will be non-additional. If Annex I countries were not to tighten their own emission caps in response, which is perhaps the most likely outcome, global emissions would be higher on the order of 500 Mt CO_2 per year. If Annex I caps are tightened, then environmental impacts are avoided but large transfers (payment for non-additional offsets) that can exceed \$10 billion per year are required. For comparison, the total mitigation assistance pledged under the Copenhagen Accord was just \$30 billion.

Large transfer payments may be justifiable from an ethical or equity point of view, in that they will tend to flow from some of the largest emitters to countries that bear little historical responsibility for CO_2 emissions. Politically, however, monetary transfers of this magnitude are almost certainly unacceptable. Moreover, as BAU cannot be calculated ex post, neither can additionality or the amount of transfer to a particular country; thus, transfers cannot be made in lieu of direct overseas development assistance for mitigation or adaptation.

An alternative regulatory approach would be to focus not on efficiency, but on environmental goals or minimizing transfer payments. The regulator might seek to maximize global emission reductions or the percentage of additional offsets. However, such an approach will leave sectoral no-lose targets largely irrelevant, as the baseline would be set so stringently that few countries participate. At low carbon prices, moreover, even such stringent baselines are insufficient to ensure that most offsets are additional.

The results here assume that governments can pass on the carbon price signal to firms and consumers, or enact regulations to achieve the same goal. They ignore the potential for national governments to manipulate emissions data. They also assume that both the regulator and individual countries have perfect information on abatement cost curves and carbon prices. To the extent that these assumptions do not hold, the potential for sectoral crediting mechanisms may be even bleaker than suggested here.

The inability to make precise predictions about transportation emissions, particularly over a five- to ten-year time horizon, is hardly surprising. Even in the much more static and data-rich environment of the U.S., predictions of regional travel demand models can err by 6% (Rodier 2004; see also Flyvbjerg et al. 2005; Transportation Research Board 2007). Despite a sophisticated energy modeling system, aggregate five-year U.S. transportation energy forecasts were off by an average of 6.6% during the 1980s and 1990s (Winebrake and Sakva 2006; see also Fischer et al. 2009).

Nor is the problem of predictive performance limited to transportation, which suggests that similar analyses might reveal problems of uncertainty and adverse selection in other sectors. Even in those considered more "straightforward," such as the electricity generation sector with its uniform product, there are large uncertainties in estimating baselines (Zhang et al. 2006). In the U.S., the 6.6% average error for transportation compares to 8.0% for industrial production, 5.3% for commercial, and 2.8%

for residential (Winebrake and Sakva 2006). Similar, the International Energy Agency's predictions for industrial energy demand in individual countries are no better than those for transportation energy demand (Linderoth 2002). Fischer et al. (2009) also suggest that the commercial and industrial sectors can be more difficult to predict than transportation. Thus, while this paper analyses only the case of transportation, it would be wise to be cautious about the feasibility of similar crediting mechanisms in other sectors.

To the extent that policymakers wish to pursue sectoral no-lose targets, they might be advised to focus on sectors and countries where the prediction error is likely to be small in relation to expected abatement. This implies that an "open to all" system might not be the most attractive option. Instead, sectoral no-lose targets might be implemented on an invitation-only basis to specific countries for specific sectors where emissions have historically been relatively easy to predict. Furthermore, sectoral crediting might only be implemented once the carbon price reaches a given threshold, as another way to increase the volume of expected abatement relative to prediction errors.

An invitation-only system might also bring to bear non-financial pressures on countries to participate. The analysis in this paper assumes that participation decisions are made solely on financial grounds. However, political pressure on countries might promote greater participation and improve performance on all three metrics – offset quality, participation and global emissions.

Critiques of offsets and other tradable credit-based approaches to reducing emissions in developing countries have already identified a wide range of challenges, such as inattention to sustainable development co-benefits; the focus on shorter-term, measurable projects; and payment of the market clearing price rather than incremental cost for emission reductions, which reduces the abatement that can be secured for a given sum of money. This paper provides further evidence that the more we study offsets and similar crediting mechanisms, the more problems we uncover. Both policy design

and estimates of abatement potential in developing countries need to take into account the impacts

of uncertainty, information asymmetries and other barriers to realizing the full potential. Meanwhile,

researchers and policymakers might usefully compare offsets against other potential climate policy

instruments such as results-based agreements, grants and technology transfer (Kerr and Millard-Ball

2012). While tradable credits offer many attractions in principle, not least the ability to equalize

marginal abatement costs across sectors and countries, other instruments may offer more robust

ways to fund mitigation in developing countries in practice.

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