Adverse Selection and Emissions Offsets

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Abstract

Although international programs for carbon offsets play an important role in current and prospective climate change policy, they continue to be very controversial. Assymmetric information creates several incentive problems, include adverse selection and moral hazard, in offset markets. The current regulatory focus on additionality tends to paint all these problems with a broad brush without proper consideration of the context or their implications.

1 Introduction

While the advancement of market-based environmental mechanisms has been much celebrated in the economics literature over the past decade, the increasing popularity of these mechanisms has served to highlight shortcomings in their implementation. One major challenge for regulators has been to reach the proper scope, over both geography and industrial sectors, over which market-based mechanisms are allowed to operate. For localized pollutants, such as SOx and NOx, the problem has been localized "hot spots" of emissions that have been in a sense a result from a scope that is too broad, or at least fails to account for the differential damage caused by emissions from varying locations.[1]. In the climate policy arena, a large challenge has been to mitigate leakage of greenhouse gas (GHG) emissions from regions falling under caps to those without GHG regulations.[2]

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[1]Carlson, et. al, 2000, Muller and Mendohlson, 2009, Fowlie, 2010.

[2]Bushnell, et. al., 2008, Fischer and Fox, 2009.

In addition to these geographic issues, there are also concerns about inconsistent regulation across the polluting industries. For example, Fowlie, et al. (2008) find that the power sector has carried a far higher burden in reducing NOx emissions than has the transportation sector. Indeed, allowance trading, and other market-based mechanisms were largely intended to address such disparities. Unfortunately, several factors conspire to limit the reach of cap-and-trade systems even within a single regulatory jurisdiction. The costs of monitoring and implementing allowance trading systems has largely limited their application to large single-point sources to date. While the "upstream" regulation of mobile sources may be a viable option for some industries and pollutants, there are serious potential limitations when there is a large potential to limit process emissions.[3] In many cases important sources of emissions not included in legislation establishing regulatory authority, such as with agricultural sources and the clean water act. Further, some non-point sources of emissions, such as those associated with land-use, would be difficult to integrate into a cap-and-trade program under any circumstances. Last, some industries are more effective at deploying their political influence to deflect attempts to regulate their emissions as intensively as other industries.

In the face of these jurisdictional, economic, and political, limitations to the broad application of cap-and-trade, offsets have emerged as an appealing tool for attempting to breach the regulatory barriers between regions and sectors. The primary distinction between offset programs and other forms of regulation are that offsets pay firms to reduce their emissions rather than raise the costs of continuing to emit. The payments allow the process to work as a voluntary program, bypassing jurisdictional issues by in theory providing incentives for firms to self-regulate. The entire concept of offset programs is therefore closely related to the question of the 'reach' of traditional regulations. If all sources of emissions would fall under traditional regulations, there would be less need to extend those regulations through offsets.

Although the fundamental need for offsets is rooted in the limits of regulatory jurisdiction, today's programs are in fact motivated by a host of goals. A primary goal for many regulated industries is cost control. The prospect of a deep pool of offset projects providing a potentially low-cost supply of reductions creates an effective cap on allowance prices in a cap-and-trade system.[4] Among developing nations and many NGO's, offset

[3]Mansur, Forthcoming.

[4]The economic analysis of proposed GHG regulations by agencies such as U.S. Environmental Protec-

mechanisms have been seen as an important new source of capital to aid in development and the alleviation of poverty. For firms and individuals outside of sectors that might fall directly under a cap, such as the U.S. agricultural sector, an offset mechanism offers a potentially lucrative new source of revenue.[5] From the perspective of economic efficiency, the great promise of an offset market is the potential for reducing GHG emissions at a much lower cost. To the extent that low-cost options for reducing emissions exist in sectors that are not directly regulated under a cap, an offset market allows for these "low-hanging fruit" to be harvested in place of more expensive reductions from the capped sector.

The most significant current global offset program, the Clean Development Mechanism, emerged from the Kyoto treaty.[6] It combined the desires for flexible market-based mechanisms with the goal of financing a low-carbon development trajectory in emerging economies. Offset mechanisms comprise a prominent part of the proposed U.S. CO_2 market articulated in H.R. 2454 (the "Waxman-Markey" bill). There are also important roles for offsets in regional U.S. carbon markets such as in California and the northeast U.S., as well as voluntary carbon offset markets.

However, despite the alluring potential of offset mechanisms for reducing mitigation costs and overcoming jurisdictional boundaries, the programs remain quite controversial. At the heart of most criticisms of offset programs is the concern that the programs are not in fact yielding the emissions reductions implied by their transacted quantities. This problem relates to two fundamental attributes of offset programs. First, offset programs require a determination of an *emissions baseline* from which the attributable reductions can be measured. Assuming the institutional issues described above could be overcome, regulators should be able to reliably verify the actual emissions of a facility, or at least a sector. However, baselines (e.g. the emissions in the absence of an offset) by definition cannot be *observed* since they are the product of a "what-if" exercise. The regulator can hope to accurately measure the emissions of a facility after it registers for an offset, but can only estimate what those emissions would have been if the facility had not sold any offsets.

The second confounding attribute of offset programs is that participation in them is

tion Agency and the California Air Resources Board highlight the sensitivity of future allowance prices to the cost and availability of offsets.

[5]USDA, 2009.

[6]The evolution and growth of offset markets is recounted in Lecoq and Ambrosi (2007), and Grubb, et al. (2010).

voluntary. Unlike the participants in a cap-and-trade program, firms that sell offsets self-select, or "opt-in," to the programs. This combination of imperfect measurement of baselines and self-selection make offset regimes vulnerable to two classic regulatory problems; moral hazard and adverse selection. The latter involves paying too much to firms with already low emissions, while the former involves firms actively taking steps to inflate their baselines.

In this paper, we focus on the problem of adverse selection. In this regard, the primary concern is the phenomenon that offset sales will be particularly attractive to firms' whose true baselines are lower than the regulators' estimates. These firms can essentially be paid for "reductions" that would have happened anyway. In the jargon of offset policy, this problem is known as *additionality*. In H.R. 2454, additional is defined as:

> The term additional, when used with respect to reductions or avoidance, or to sequestration of greenhouse gases, means reductions, avoidance, or sequestration that result in a lower level of net greenhouse gas emissions or atmospheric concentration than would occur in the absence of an offset project.

The additionality problem has come to dominate the debates over offset markets, and there is a large amount of enforcement language and effort put into trying to mitigate it. There is also a rich literature on environmental regulation under imperfect information that has also focused on this problem. In this literature, the main culprit is adverse selection. Particularly relevant for this discussion is the work of Montero (1999 and 2000), which examines the consequences of voluntary "opt-in" to a cap-and-trade program. These opt-in provisions, such in the US SO2 program, bear many similarities to offset mechanisms. In Montero's derivation, allowing opt-in produces a trade-off between the efficiency gains of lower-cost abatement and the "excess emissions" resulting from adverse selection. Although some of these voluntary facilities may provide less true abatement than expected, the abatement costs of these opt-in facilities may be dramtically lower than those under the cap. The intuition behind this trade-off is that, although opt-in may create excess emissions, the welfare loss from this excess is more than made-up for in savings on abatement costs.

Even beyond the trade-off articulated in Montero's work, some of the focus on additionality and the mechanisms deployed to combat it may be misguided in some context. As the model in this paper explores, there are conditions under which the sale of offsets improves efficiency even if there is no abatement cost advantages in the uncapped sector. The key element of the model is the uncertainty of emissions in the uncapped sector. At issue is the extent to which the overestimate of emissions baselines is a firm-specific or aggregate phenomenon. If the additivity problem stems from the fact that the regulator overestimated the baselines from the entire sector, then the implications of non-additionality in an offset program can be very different. The result is still less "abatement" than expected, but this does not necessarily translate into more emissions than expected.

2 A Two Sector Model

We construct a model of two polluting sectors. The first sector, labelled "capped" is directly regulated through a cap and trade program, while the second, "uncapped,"sector is not. Each sector is populated by many small firms, assumed to act in a perfectly competitive fashion with regards to the emissions and offset markets. The expected aggregate emissions, absent any regulation, in each sector is E_c and E_{uc}, respectively.

The focus of the model will be on the distribution of, and regulators knowledge of, "business as usual" or baseline emissions. As such I make several simplifying assumptions regarding other attributes of the market. We assume that the regulator cannot observe baseline emissions but can observe the *actual* expost emissions of both firms in the capped sector and firms that choose to sell offsets. Thus an offset sale is verified by observing zero emissions from a facility and it is assumed to achieve a reduction in emissions from the estimated baseline level of $\hat{e}$ down to a level of zero. We define marginal abatement costs as $c_c(a)$ in the capped sector and c_{uc} in the uncapped sector. These are represented by the dashed red lines in figure 1.

Assumption A1: An offset sale is verified by observing zero emissions from a facility and it is assumed to achieve a reduction in emissions from the estimated baseline level of $\hat{e}$ down to a level of zero.

Assumption A2: Abatement costs $c_c(a)$ are weakly increasing and weakly convex in the capped sector.

Assumption A3: Uncapped sector marginal abatement costs c_{uc} are constant.

Figure 1 illustrates the supply of abatement under perfect information, so total unregulated emissions, e.g. the "business as usual" (BAU) scenario, is represented as the intersection of the horizontal and vertical axis in figure 1. Reductions, or abatement, from BAU is represented by movement to the right along the horizontal axis. Total emissions from both sectors would therefore be expected to be $E_c + E_{uc}$.

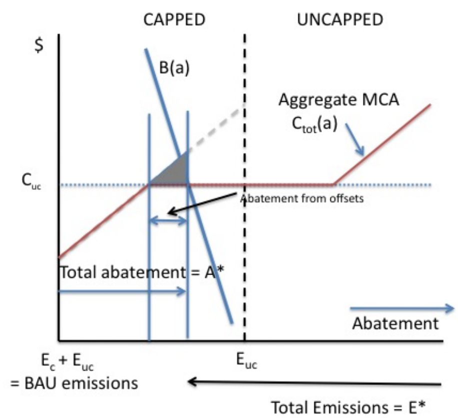

Figure 1: Offset Market with Perfect Information

Marginal abatement costs for the entire economy would be the horizontal sum of these functions, $c_{tot}(a)$, represented by the solid red line. The benefits of abatement are represented by the marginal abatement curve, B. These are the upward sloping and downward sloping solid lines, respectively, in figure 1. I assume here simply that the cap is set to achieve total abatement A*, implying emissions $q_{cap} + E_{uc}$. As shown here, the goal of limiting total emissions to $q_{cap} + E_{uc}$ can be achieved solely through mitigation by the capped sector.

That does not mean that this is the most efficient way of reaching that target, however. For the moment I will assume both that offsets are supplied competitively (e.g. at the marginal cost of abatement) and that there is no information problem. The regulator can observe baselines in the uncapped sector and all implied reductions are in fact realized. Under these assumptions, abatement from the capped sector is limited to sources whose abatement costs fall below the offset costs, c_{uc}. The capped sector abates an amount A^c, and the remainder is provided by the uncapped sector. Total savings equal the grey shaded area in figure. 1

Total emissions after offset sells can be expressed as

$$q_{cap} + \hat{e} * \theta_\gamma + \hat{e} * (1 - \theta_\gamma)$$

where θ_γ is the share of the uncapped sector selling offsets and is defined in more detail below. The second term represents the transacted offset amount, in terms of emissions and the third term is the expected remaining emissions from the uncapped sector. Were it not for the imperfect information, emissions would in fact be the expected $q_{cap} + \hat{e}$, the same as with no offsets, but under the assumptions of the model, at lower costs.

2.1 Model of adverse selection

We now consider the implications of imperfect information. The key information asymmetry lies in the estimates of *business as usual* (BAU), or baseline emissions, in particular for the uncapped sector. Here we depart from the standard asymmetry framework such as that utilized by Montero (2000) and more recently by Mason and ???? (2010). It is common in the mechanism design literature to assume that the regulator knows the distribution of information (here expected emissions, or "baselines") but does not know where any specific firm falls in that distribution. We treat this as a special case, but also want to account for the very real prospect that the regulator may not have perfect information about even the aggregate distribution of baselines. In particular the regulator may be wrong about the expected mean baseline.

More formally, let marginal emissions from the uncapped sector be

$$e_i = \bar{e} + a * (\theta_i - 0.5) \tag{1}$$

where $\theta_i \in [0, 1]$ is assumed to be distributed with density $f(\theta)$ and mean of 0.5. Note that half the population of uncapped firms will have baseline emissions below the mean $\bar{e}$, while the other half will have baselines above $\bar{e}$.

To sharpen the focus of the model, I further restrict the distribution of θ.

Assumption A4: Baseline emissions $e_i = e_i = \bar{e} + a * (\theta_i - 0.5)$ and θ is distributed uniformly $\in [0, 1]$.

The assumption of a uniform distribution of θ allows for an interpretation of θ_i as the share of firms selling offsets. The shift of 0.5 in equation 1 allows for e_i to equal $\bar{e}$ in expectation. While a restriction, the functional form of of (1) still allows for a wide range of distributions that capture the key elements of the model.

In particular, values are *affiliated*, with both a private component and a component that is shared across the entire population of uncapped firms. This framework allows for a parameterization of the degree to which the common or independent value aspects dominate. If $a = 0$, then baseline emissions are perfectly correlated across firms. At the other extreme, if $\bar{e} = .5a$, then the realized baseline emissions of every firm are independently determined. This is illustrated in Figure 3, which demonstrates how a varying level of a changes the distribution of individual firm emissions. The regulator does not ex-ante observe either component. It forms an expectation $\hat{e}$ of $\bar{e}$, that, as I discuss below, may be biased.

With imperfect information, the regulator estimates a baseline for firms in the uncapped sector. Under our framework, this takes the form of the expected emissions $\hat{e}$. Firms in the uncapped sector are then eligible to sell their offset emissions into the capped market at price p, which, absent restrictions on the use of offsets is assumed to equal the price of allowances in the capped market.

2.2 Offset Sales

We first define the marginal firm that would sell offsets under this structure, and then examine the resulting abatement costs and emissions levels that are implied by offset sales. An individual firm i in the uncapped market that sells offsets at price p will earn net profits equal to

$$\pi_i = p\hat{e} - c_{uc}e_i = p\hat{e} - c_{uc}[a(\theta_i - .5) + \bar{e}]. \tag{2}$$

The former term is the earnings from selling $\hat{e}$ offsets, which is equal to the level of abatement estimated by the regulator, and the latter term is the firm's cost of abating

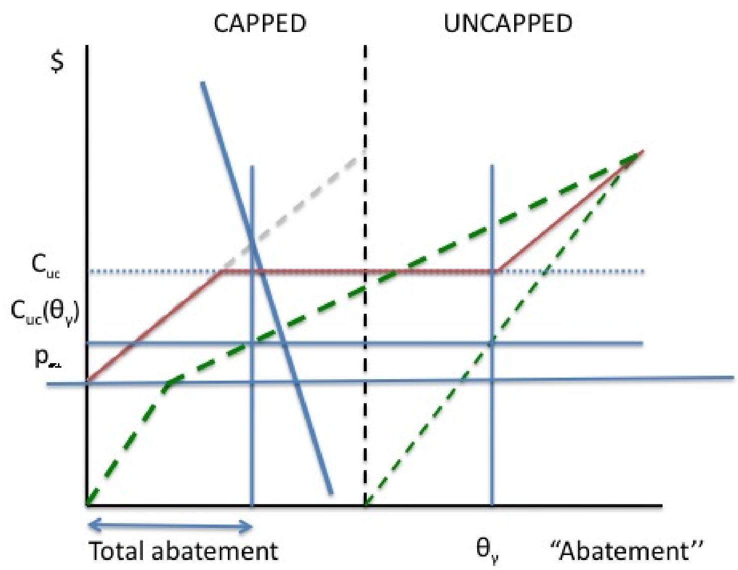

Figure 2: Offset Market with Perfect Information

from its true baseline level, e_i down to zero. With perfect information, the regulator would set $\hat{e} = e_i$ and a firm would sell offsets if the price was less than their marginal cost of abatement c_{uc}. With imperfect information, the marginal cost of selling offsets diverges from the true marginal cost of abatement since an individual firm may have to abate more or less than $\hat{e}$.

Let $\theta_\gamma$represent the type (or baseline) of the marginal offset selling firm. This firm is indifferent to selling offsets, such that $\pi_\gamma = 0$, or equivalently

$$p = \frac{c_{uc}[a(\theta_\gamma - .5) + \bar{e}]}{\hat{e}}. \tag{3}$$

Since offsets equal to $\theta_\gamma \hat{e}$ are sold at this price, reductions from the capped sector amount to $e_c - q_{cap} - \theta_\gamma \hat{e}$. Let $A^c = e_c - q_{cap}$ be the required amount of abatement from the capped sector. Since the capped sector is providing the consumer side of the offset market, this means the price can also be defined in terms of the marginal buyer of offsets, who will have abatement cost equal to

$$p = c_c'(A^c - \theta_\gamma \hat{e}) = \frac{c_{uc}[a(\theta_\gamma - .5) + \bar{e}]}{\hat{e}}. \tag{4}$$

This amount of abatement allows us to specify the emissions price in terms of abatement in the capped sector.

Lemma 1 *If abatement costs in the capped sector are convex, $c_c'' > 0$, the marginal offset baseline type θ_γ, is decreasing in $\bar{e}$.*

Proof. Using the equality defined in (4) we can apply the implicit function theorem to derive $\frac{d\theta_\gamma}{d\bar{e}}$. Consider the rightmost equality the inverse "supply" of offsets $S(\theta_\gamma, \bar{e})$ and the left equality the inverse demand for offsets, $D(\theta_\gamma)$, then

$$\frac{d\theta_\gamma}{d\bar{e}} = \frac{\frac{\partial S(\theta_\gamma, \bar{e})}{\partial \bar{e}}}{\frac{dD(\theta_\gamma)}{d\theta_\gamma} - \frac{\partial S(\theta_\gamma, \bar{e})}{\partial \theta_\gamma}} = \frac{c_{uc}/\hat{e}}{-c_c''\hat{e} - ac_{uc}/\hat{e}} = \frac{c_{uc}}{-c_c''\hat{e}^2} - \frac{1}{a}.$$

Given the assumption of convexity of abatement costs in the capped sector $c_c'' > 0$, we have $\frac{d\theta_\gamma}{d\bar{e}} < 0$.

■

In later sections, we will explore a specific example with further restrictions that greatly simplify the illustration of the results. This later restriction is not necessary for any of the results shown later, but does simplify the examples substantially. We now turn to the derivation of the levels of emissions that result from offset sales, with special focus on the question of imperfect estimates of the distribution of baselines.

2.3 Offsets and Excess Emissions

In the presence of imperfect information, the *actual* abatement can differ from that implied by the sales of offsets. The abatement provided by offsets will depend upon both the extent of adverse selection of low θ_i types into the offset program, as well as the overall shared unconstrained emissions level $\bar{e}$. There are, however, very different consequences in terms of actual emissions from each type of information asymmetry. Although, with a low actual baseline $\bar{e}$ many firms will be paid to do what they would have done anyway, the fact remains that *they did reduce their emissions.* The key issue is whether their participation in the offset market implies that there are other firms in the uncapped sector with abnormally large baseline emissions who did *not* participate. If the information shock is applied to the shared component of the baseline estimate $\bar{e}$ then this form of adverse selection effect would not be created.

Before we explore these alternative implications, we begin by examining the case where the forecast of aggregate baseline emissions is accurate (e.g. $\hat{e} = \bar{e}$). Because of the private information on baselines, the actual baseline for any subset of the capped sector may still be less than or greater than $\hat{e}$. Total emissions from the uncapped sector will be

$$E_{uc} = \bar{e} + a \int_0^1 \theta dF - 0.5a = \hat{e}. \tag{5}$$

To illustrate the self-selection of firms into the offset market, we return to the case where true abatement costs are equal in the two sectors, and normalized to 1. Figure 3 illustrates the results from introducing an offset market under these assumptions. Before introducing offsets the cap is set by intersecting the marginal benefits of abatement, $B(A)$, with the marginal cost of abatement in the capped sector, c_c, here assumed to equal 1. Although actual abatement costs are equal in the two sectors, the marginal cost of providing offsets, $e_i c_{uc}$, ia lower for half the uncapped population. This is because their true baseline emissions from which they must abate are lower than the regulator's estimate. The horizontal axis now represents the measured "abatement" that is transacted, rather than actual abatement. Note that offsets are actually more costly for those firms with higher than predicted baselines, because these firms would get less credit than they deserve for their reductions . Thus the firms with the lowest actual baselines have the lowest "costs," and in a competitive market these will be firms selling offsets. Recall that θ_γ is the marginal firm selling offsets. This will be the firm whose costs equals the permit price in the capped market, as illustrated in figure 3, which I denote as $c_{uc}(\theta_\gamma)$.

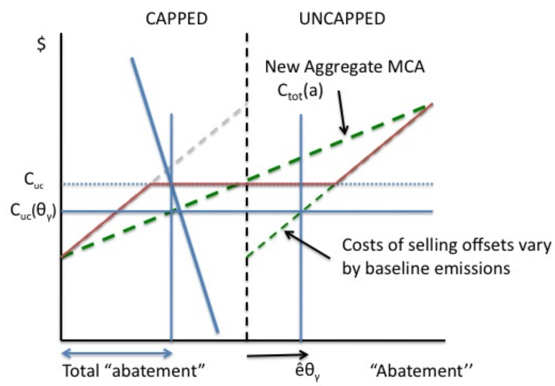

Figure 3: Offset Market with Independent Unbiased Emissions Rates

Since the share of the uncapped market selling offsets is θ_γ, the offsets transacted equals $\hat{e}\theta_\gamma$. Since the low-baseline firms participate and the high baseline firms do not, the actual reductions from the uncapped sector will be less than the offsets traded and total emissions from the uncapped sector will be greater than the official estimate of $(1-\theta_\gamma)\hat{e}$. The resulting emissions are illustrated on the left of figure **??**. Although the regulator's estimate of total emissions is correct, the self selection of low-baseline firms into the offset program leaves only high-baseline firms without abatement. The result, as summarized by the solid black area, is more emissions than anticipated from the uncapped sector and therefore more emissions overall.

This is essentially the framework examined by Montero (2000). If I assume that the cap is set with optimal desired emissions levels in mind, this excess of pollution becomes a potentially serious problem. If abatement costs are lower in the uncapped sctor, however, there are also savings, as overall abatement expenditures are reduced. Montero demonstrates these trade-offs.[7]

2.4 Imperfect Information on the Distribution of Baselines

Having laid the foundations of the offset market under the assumption that the regulators estimate of aggregate emissions were accurate, we now derive more general outcomes when these estimates may be inaccurate. First, when offsets are sold, the actual emissions from the uncapped sector, which come from the portion $(1-\theta_\gamma)$ of firms that do not sell offsets, are

$$(1-\theta_\gamma))\left(\bar{e}-.5a\right)+a\int_{\theta_\gamma}^{1}\theta dF(\theta).$$

Note that emissions from the capped sector are $q_{cap}+\hat{e}\theta_\gamma$. This is the cap level plus the additional emissions permitted by the sale of offsets.

Since θ is uniform, total emissions from both sectors can be simplified to

$$q_{cap}+\hat{e}\theta_\gamma+\left(1-\theta_\gamma\right)\left(\bar{e}-.5a\right)+.5a-.5a\theta_\gamma^2 \tag{6}$$

By subtracting the emissions that would result if there were no offsets sold, $q_{cap}+\bar{e}$, we calculate the net increase in emissions from selling offsets as

$$\theta_\gamma\left(\hat{e}-\bar{e}\right)+.5a\theta_\gamma(1-\theta_\gamma) \tag{7}$$

Several important observations follow from the effect captured in equation (7). First, if expected emissions $\hat{e}$ overstate the actual average emission level $\bar{e}$, the introduction of offsets will definitely increase total emissions from the two sectors. For lower $\bar{e}$, the "costs" of selling offsets decreases as firms have to abate less due to their lower true baselines.

[7] If unlimited transfers are allowed, optimal emissions levels can still be obtained by anticipating the adverse selection and reducing the cap in the capped sector by the amount of excess emissions produced by the offsets.

Conversely, if the regulator underestimates average emissions, offsets may or may not increase total emissions. In this scenario, it is possible that firms may sell offsets even though they don't get full credit for them. This would occur if abatement costs were sufficiently low in the uncapped sector that the costs savings overcome the under-crediting. Even with the underestimate of the average, however, it would still be the lowest baseline types who would be first to sell offsets. Thus, while the average uncapped firm may not get enough offset credit, the lowest baseline among them may still be over-credited. The net effect is captured in (7), where the first term, which is negative when $\hat{e} < \bar{e}$, represents this "give-back" due to under-crediting, but the second term represents the effect of adverse selection within the uncapped population.

Last, if the forecast of average baselines is accurate, then $\hat{e} = \bar{e}$, and offsets can only increase aggregate emissions due to the adverse selection captured in the second term of (7).

The important point is that although the introduction of offsets can frequently lead to an increase in emissions, those increases will be the largest under conditions when they do the least harm. Although emissions always increase when baselines are overestimated and an offest program is used, this increase may push total emissions closer to the optimum. This is because actual emissions are lower for *all* uncapped firms, whether they sell offsets or not.

If we assume that the cap was set at an optimum level, taking into account emissions from the uncapped sector, then the desired aggregate emissions level (from both sectors) is $q_{cap} + \hat{e}$. In other words, the emissions cap may have been set with the assumption that $\hat{e}$ would be emitted from the uncapped sector. Using the framework from above, actual emissions without any offset sales would be $q_{cap} + \bar{e}$. When baselines are overstated, this quantity is below the capped target, and offset sales bring total emissions back toward the aggregate target.

We can now revisit the concept of excess emissions, which we define as emissisions created by offsets that are in excess of the aggregate emissions cap, $q_{cap} + \hat{e}$.

Definition 1 *Let the* excess emissions *caused by offsets be defined as the increase in emissions above the level expected by the regulator in the absence of offsets, that is caused by the introduction of offsets. Without offsets, expected emissions are* $q_{cap} + \hat{e}$*, and the deviation* *from this level would be driven by how far actual emissions in the uncapped sector deviate from expected emissions,* $\hat{e} - \bar{e}$ *.*

$$\theta_\gamma (\hat{e} - \bar{e}) + .5a\theta_\gamma(1 - \theta_\gamma) - \max(\hat{e} - \bar{e}, 0). \tag{8}$$

Using this definition, we can derive the following results relating to the overestimation and the underestimation of the mean baseline $\bar{e}$.

Result 1 *If* $\hat{e} > \bar{e}$ *then there will be excess emissions from offsets only if* $.5a\theta_\gamma > (\hat{e} - \bar{e})$ *.*

Proof. If $\hat{e} > \bar{e}$, then (8), reduces to $.5a\theta_\gamma(1 - \theta_\gamma) - (1 - \theta_\gamma)(\hat{e} - \bar{e})$. Recall that $0 < \theta_\gamma < 1$. Therefore total emissions will be greater than the expected level of $q_{cap} + \hat{e}$ only if $.5a\theta_\gamma > (\hat{e} - \bar{e})$. ■

This conclusion is illustrated in Figure ??. The overestimation of mean baselines implies that, absent offset sales, total emissions would be lower than expected by $\hat{e} - \bar{e}$. The offset sales, result in a combination of profit-taking and adverse selection, with the adverse selection component equal to the triangle $.5a\theta_\gamma$. The net effect will be above expected emissions levels only in the event that the adverse selection component overwhelms the "pleasant surprise."

Result 2 *If* $\hat{e} - \bar{e} < 0$, *then there are excess emissions only if* $.5a\theta_\gamma > \frac{\theta_\gamma}{(1-\theta_\gamma)} (\bar{e} - \hat{e})$ *.*

Proof. This follows directly from the definition of excess emissions. In this case there are trade-offs between the relative costs of abatement in the two-sectors and the effect of adverse selection. ■

Note that as long as the payout is greater than their costs, $p\hat{e} > e_i c_{uc}$, firms will chose to sell offsets. If abatement costs are significantly lower in the uncapped sector, firms may therefore wish to sell offsets even though $\hat{e} < e_i$, and they have to abate *more* than they are given credit for in the offset market. This average "give back" by firms selling offsets, equal to $\theta_\gamma(\hat{e} - \bar{e})$ may or may not be sufficient to offset the adverse selection component, $.5a\theta_\gamma(1 - \theta_\gamma)$.

Result 3 *If* $a = 0$, *then offsets cannot produce excess emissions.*

Proof. if $a = 0$, then offsets increase emissions by $\theta_\gamma(\hat{e} - \bar{e})$. If $\hat{e} - \bar{e} > 0$ this does not sufficiently offset the overall surprisingly low emissions in the entire sector of $\hat{e} - \bar{e}$ as $\theta_\gamma \in (0..1)$. Total emissions will still be less than $q_{cap} + \hat{e}$. If $\hat{e} - \bar{e} < 0$, then offsets produce "additional" emissions of $\theta_\gamma(\hat{e} - \bar{e})$, which is negative.

■

Combined, these results reflect the factors that determine the extent to which adverse selection is harmful. In particular, the importance of the distribution of baselines is highlighted. If baselines are highly correlated amongst the uncapped population, then a is very small and there is relatively little damage from the adverse selection. If mean baselines are overestimated, the surprisingly low emissions from the entire sector is likely to dominate.

Conversely, if mean baseline emissions are underestimated, then emissions from the uncapped sector as a whole are surprisingly high. If costs in the two sectors are similar, selling offsets can increase the level of emissions, but likely not by much since most firms will have baselines above the regulators estimated level.

This result is similar but not necessarily identical to what would happen if both sectors were capped. If both were capped, then the lower baselines could lower the aggregate abatement necessary without requiring active abatement from the uncapped sector. This can be more efficient as active abatement still costs c_{uc}. If the abatement quantity required from the capped sector yields a marginal abatement cost, after accounting for the lower baselines, that is less than c_{uc}, it would be more efficient for all active abatement to come from the capped sector - even though less active abatement would be required due to the lower baselines. In this case the "maximal cap" would be more efficient. This efficiency penalty from offsets is therefore going to be the most severe when costs are high in the uncapped sector, but baselines are low.

These results also reveal how, somewhat ironically, the adverse selection problem can cause the most problems when the regulator has an accurate forecast of mean baselines. As the difference between $\hat{e}$ and $\bar{e}$ goes to zero, the adverse selection term $.5a\theta_\gamma$ will dominate and produce excess emissions.

In summary, the implications of the adverse selection problem is tied strongly to the assumptions about the distribution of "errors" in the forecast of business as usual emissions. If this error is independently distributed across firms, offsets can produce under-abatement. If the errors are highly correlated, however, the offset market can reveal information about the aggregate baseline and allow the abatement decisions of firms in the capped sector to adjust accordingly.

2.5 Constant Marginal Abatement Costs.

The derivations above imply a broad set of conditions under which offset markets compress the range of aggregate emissions. In particular, by permitting more "non-additional" sales under the circumstances where uncapped emissions are surprisingly low, aggregate emissions are less likely to fall substantially below the expected levels implied by the cap. This self-adjustment in the face of low emissions is to be weighed against the potential for exacerbating emissions in the event of surprisingly high emissions from the uncapped sector. If emissions baselines are highly correlated across uncapped firms, this risk is relatively small.

We now examine a case with constant marginal costs of abatement in the both sectors in order to illustrate the effects of offsets on the distributions of potential aggregate emissions.

Assumption A5: Marginal abatement costs $c_c = 1$ *in the capped sector and* $c_{uc} = \alpha c_c = \alpha$ *in the uncapped sector.*

Under this assumption we analytically derive θ_γ as a function of the emission baseline distributional parameters, $\bar{e}$ and a. Recall that the marginal uncapped firm to sell offsets will have its marginal cost of selling offsets equal to the permit price, or marginal cost of abatement, in the capped sector.

$$\theta_\gamma = \frac{c_c\hat{e} - c_{uc}\bar{e} + .5c_{uc}a}{c_{uc}a} = \frac{\hat{e} - \alpha\bar{e}}{\alpha a} + .5 \tag{9}$$

where α may be less than or greater than 1, depending upon the relative costs of abatement in the two sectors. Two further conditions on θ_γ must hold, namely that offset sales are non-negative and that total offset purchases must be no greater than the capped quantity in the capped sector. These boundary conditions would take precedence over (9).

$$0 < \theta_\gamma < \frac{E_c - q_{cap}}{\hat{e}}. \tag{10}$$

By combining (9) and (6) we can express total emissions in a market with offsets as

$$q_{cap} + \hat{e}\left(\frac{\hat{e} - \alpha\bar{e}}{\alpha a} + .5\right) + (1 - \left(\frac{\hat{e} - \alpha\bar{e}}{\alpha a} + .5\right))\left(\bar{e} + .5a\left(\frac{\hat{e} - \alpha\bar{e}}{\alpha a} + .5\right)\right) \tag{11}$$

Table 1: Constant Marginal Cost Sample Parameters

Parameter	Value/Range
E_c	10
q_{cap}	2.5
$E_{uc} = \bar{e}$	5-15
$\hat{e}$	10
a	1,5,10
α	.75, 1, 1.25

as long as $0 < \theta_\gamma < \frac{(E_c - q_{cap}}{\hat{e}}$.[8]

We can further simplify (11) when looking at specific cases. For example, if $a = 2\bar{e}$,then $\theta_\gamma = \frac{\hat{e}}{\alpha a} = \frac{\hat{e}}{\alpha 2\bar{e}}$, and we can write total emissions as

$$q_{cap} + \bar{e} + \hat{e}\left(\frac{\hat{e}}{2\alpha\bar{e}}\right) - \bar{e}\left(\frac{\hat{e}^2}{(2\alpha\bar{e})^2}\right). \tag{12}$$

Another case of interest arises if we assume costs are equal in the two sectors, or $\alpha = 1$. In this case (11) simplifies to

$$q_{cap} + \bar{e} + .5\left(\frac{(\hat{e} - \bar{e})^2}{a} + (\hat{e} - \bar{e})\right) + .125a. \tag{13}$$

By assigning specific values to $\hat{e}$ and $\bar{e}$, we can illustrate the effect offsets have on total emissions.

In Table 1, we describe the range of parameters considered for this example. The expected mean baseline is $\hat{e} = 10$, and the actual mean baseline can range from $\bar{e} = 5$ to $\bar{e} = 15$. Actual emissions without offsets will be $q_{cap} + \bar{e}$. Actual emissions with offsets are defined by equation (11), for θ_γ that is bounded by 0 and $(E_c - q_{cap})/\hat{e} = .75$

Figure ?? provides a histogram of realizations for total emissions under the assumption that $\bar{e}$ is distributed according to a uniform, normal, or gamma, distribution. In each case, total emissions are plotted in the case where the cap is set at $.75\hat{e}$ in the capped sector and there are no offset sales, and again assuming that offsets up to $.75\hat{e}$ are allowed.

[8] If $\theta_\gamma = \frac{(E_c - q_{cap})}{\hat{e}}$,this becomes $q_{cap} + \hat{e}\frac{(E_c - q_{cap})}{\hat{e}} + (1 - \frac{(E_c - q_{cap})}{\hat{e}})\left(\bar{e} + .5a\left(\frac{(E_c - q_{cap})}{\hat{e}}\right)\right)$.

3 Discussion

As the previous sections demonstrate, the question of additionality can be viewed in two lights; the adverse selection view, in which offsets pay the "wrong" firms to reduce while other firms more than make up the difference, and one in which uncapped firms benefit from a coincidental, surprisingly clean development path. In some circumstances there can be an important distinction between the two types of additionality. If the offset market were dominated by the latter "pleasant surprise" phenomenon, offsets can play a useful role despite the additionality problem.

Of course the degree to which this distinction matters is closely linked to the level of the cap in the capped sector. In the context of Kyoto treaty the reductions implied are so modest that any prospect of a pleasant surprise would not come close to making up the overall reductions called for by the IPCC and other groups. In short, most view the Kyoto treaty as so lax that the world needs every ton of reductions it can produce. This is reflected in the fact that there has been relatively little market for excess reduction credits from Annex 1 Kyoto nations, such as Russia and the U.K., because those excess credits are viewed as coincidental. These credits, known as "hot air," have largely been shunned, although this picture could change as Kyoto deadlines approach.[9] The distinction also has less meaning in the context of voluntary offset markets, where there is no mandatory cap to be adjusted.

Looking forward to a post-Kyoto world, however, the implications change somewhat. If a significant share of developed nations commit to proposed targets of 50% to 80% reductions, a pleasant surprise scenario could influence thinking about the needed stringency of those caps.[10] The potential stringency of future caps is largely dependent upon a political process, and the potential role of offsets plays a part in those negotiations. Those close to this process acknowledge that a tighter cap in the U.S. would be much more likely to gain acceptance if offsets are a part of the picture. If caps in the developed world are set ambitiously enough, this may not be the kind of Faustian bargain that critics of offset markets make it out to be.

On the other hand, if the worst-case IPCC scenarios materialize, even 80 % reductions

[9] Grubb, et. al, 2010

[10] The Annex I nations under the Kyoto protocol account for roughly half of global GHG emissions today, but under the IPCC A2 scenario this share would decline to under 1/3.

from developed nations would be insufficient to achieve a stabilization of GHG at levels deemed acceptable by the IPCC. Active abatement would have to be pursued in developing countries. Even under these circumstances offsets can play an important role for some sectors of developing countries.

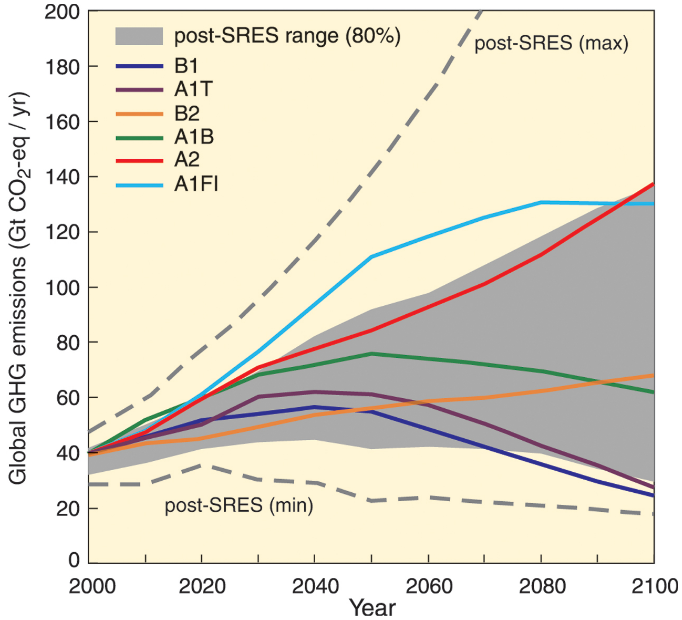

Figure 4: Emissions Trajectories of IPCC Scenarios

An examination of the IPCC scenarios (figure 4) for future BAU GHG emissions reveals just how much scope there is for an impact of a coincidentally clean development path. There is a great deal of uncertainty about future emissions, with much of that uncertainty falling in the developing world. While fossil-fuel intensive, high population scenarios imply roughly a tripling of emissions by 2100, other scenarios imply a peak around 2050 followed by a steady decline.

Another key question is therefore whether additionality is likely to reflect adverse selection or common low baselines. In the case studied by Montero (2000), power plants that opted into the SO2 program had low baselines because their output was reduced, to be replaced by other plants. The case studies of the CDM appear to be different matters. There is evidence that many projects earned emissions reduction credits while not meeting the broad definition of additionality. The power plant projects identified in India and China may very well have not been additional, but their construction did not imply higher output from some other power facilities.

4 Implications for Offset Market Design

The above discussion attempts to highlight three implications. First, not all forms of additionality should be viewed as equally onerous to the effectiveness and efficiency of emissions caps. Second, the perverse incentives to manipulate baselines are an equally serious concern with no redeeming qualities. Third, offset markets can produce several other types of unintended consequences such as leakage, but those risks apply to almost any measures directed at reducing GHG emissions at less than a global scale. The current regulatory focus on additionality tends to paint all these problems with a broad brush without consideration of the context or their implications.

With these observations in mind, it is useful to consider the various policy tools that have been adopted or considered in order to address the perceived difficulties with offset mechanisms. Importantly, two frequently mentioned solutions, capping the number of offsets and discounting their effectiveness, do not address these problems very well. A cap on the number of offsets allowed into a market can limit the overall severity of the adverse selection problem, but by less than commonly thought. If adverse selection is a serious problem, the projects that are allowed would be the ones with the lowest baseline draws. If the baselines in the uncapped sector are instead highly correlated and much lower than expected, then limits on offsets restrict the ability of the mechanism to adjust to the "pleasant surprise" and allow for fewer reductions in the capped sector.

A devaluation of offsets treats all projects as equally non-additional. As I have argued above, if this truly were the case and caps were strict enough in the capped sector, this is precisely when additionality does not reduce efficiency. In fact it produces the exact same outcome as if the uncapped sector were under a mandatory cap and had been allocated allowances equal to its expected baseline. In either case, emissions are reduced and the uncapped sector reaps a windfall. However, both sectors benefit from the added participation of the uncapped sector relative to a case where that participation is limited. If instead baselines are uncorrelated, and additionality is a serious problem, only the most extreme non-additional projects are likely to be financially viable at the reduced returns provided by a generic devaluation.

The solution identified by Montero is very different. A first-best reduction can be achieved if the cap were further tightened in anticipation of the excess emissions yielded from adverse selection in the uncapped sector. This allows full participation by the uncapped sector, but still reaches the same overall emissions aggregated over both sectors. Unfortunately, this approach is both politically difficult and depends upon accurately predicting, on a sectoral level, the severity of the adverse selection problem.

To date the primary bulwark against additionality concerns has been a review process that has been simultaneously criticized as too onerous to allow for substantial investment and also inadequate in weeding out non-additional projects.[11] While some are concerned this may fatally delay investments, others feel that the incentive problems can only be adequately managed within a small program.

Those concerned with streamlining the review process are attracted to a shift away from project-specific review to a more programmatic approach. This offers several potential benefits. First, a programmatic approach can greatly lower the transactions costs of review and certification relative to the value of the offsets produced. Second, such an approach can help access a broader array of activities including energy efficiency and prevention of deforestation that have been largely absent from markets such as the CDM. Last, a program level review can focus on risks, at an industry level, of the "bad" form of adverse selection while being less concerned with correlated, coincidental reductions. For example, investments in building efficiency may very well prove to be economic in the absence of offset programs, and therefore not truly additional. But even if that is the case, increased efficiency in one building is unlikely to imply *worse* efficiency in others. A programmatic approach can also mitigate the moral hazard problem at the facility level by reducing the importance of the actions at a specific facility. However, there are still concerns about government level incentives.

Last, one tool that has not been applied to offset markets is the application of randomized trials. For example, a population of applications could be chosen to supply offsets while another set is retained as a control group against which to judge the actions of the accepted population. This may be usefully combined with a shift in focus to evaluation at the program or sector level. Such approaches have been usefully applied to address similar adverse selection and moral hazard problems in programs that pay for reductions in energy use.[12] Atypical increases in emissions from countries or firms that become eligible for offsets relative to those that are not would indicate an inflation of baselines. Measuring the reductions from offset eligible projects *relative* to others can detect adverse

[11] Grubb, et. al. 2010, Victor and Wara, 2008.
[12] Wolak, 2010.

selection relative to a common baseline, but it would also discount gains from commonly shared (e.g. coincidental) reductions. Since, returning to the earlier discussion, there are circumstances in which it is beneficial to allow credits for those coincidental reductions, the treatment of these shared effects would depend upon the stringency of overall caps.

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