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What is the Optimal Offsets Discount under a Second-Best Cap & Trade Policy?

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Abstract

Despite concerns about additionality, leakage, permanence, and verification, carbon offsets have been proposed as a core component of recent cap-and-trade proposals in order to contain costs, involve uncapped sectors in GHG reduction goals, and build mitigation capacity in developing countries. Discounting the value of offsets relative to GHG allowances (i.e., setting a trading ratio less than one) has been suggested as one approach to protect the integrity of the cap. This paper presents a simple theoretical model to derive the optimal trading ratio between offsets and allowances when coverage of emissions by the cap-and-trade and offsets programs is incomplete. I discuss the relationship between the trading ratio and the GHG cap and offsets baseline, which jointly determine the stringency of the policy. While a discount for leakage is always optimal, one notable result is that if "hot air" is introduced by setting either the baseline cap *or* the cap too leniently, an extra discount is warranted.

Key words: offsets, additionality, leakage, baseline, cap and trade, second-best theory

Subject Area: Climate Change, Environmental Policy, Pollution Control Options & Economics Incentives

JEL classification: D62, H23, Q54, Q58

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Introduction

Carbon offsets are a critical component of cap-and-trade proposals because of their potential to contain costs, involve uncapped sectors and countries in greenhouse gas (GHG) reduction goals, and build mitigation capacity in developing countries. However, many observers are skeptical that offset credits generate emission reductions equivalent to those from capped sources due to concerns about additionality, leakage, permanence, measurement, and verification (Lecoq and Ambrosi 2007; Olander 2008). Several design features have been incorporated into recent U.S. climate legislative proposals to address these concerns, including extending offset crediting to larger spatial scales, limiting the number of allowable offsets, and discounting the value of offset credits relative to allowances.

This paper addresses the last of these proposals by constructing a simple theoretical model to determine the socially optimal trading ratio between carbon offsets and allowances in a second-best world. The scenario I consider is second-best because coverage of all sectors and countries, whether through mandatory caps or voluntary offsets, is incomplete, creating potential for leakage—a situation likely to persist even if several major economies adopt comprehensive climate policies. I also examine the interaction between the optimal trading ratio and the offsets crediting baseline, which, in combination with the emissions cap, determines the stringency of the climate policy. The baseline serves as a proxy for additionality, since offsets credited against a higher-than-business-as-usual baseline include emissions reductions that would have occurred without the policy and can be considered non-additional.

The issues of leakage and additionality have received considerable attention in the literature on carbon offsets and other conservation programs. Empirical estimates of leakage in the forestry and agriculture sectors range widely, from nil to over ninety percent (Murray et al. 2004; Gan and McCarl 2007; Sohngen and Brown 2004; Wear and Murray 2004). Estimates of leakage in the energy and industrial sectors are more modest, and proposals such as output-based rebates for energy-intensive trade-exposed industries are likely to be effective in minimizing it further (Aldy and Pizer 2009; Fischer and Fox 2009; U.S. Government 2009).

Lack of additionality of project-based offsets credited under the Clean Development Mechanism and other voluntary opt-in programs has been raised as a concern due to inflated emissions baselines and adverse selection (Lecoq and Ambrosi 2007; Montero 1999, 2000; Bushnell 2010). Montero (2000) examined use of the offsets baseline as a policy tool to minimize adverse selection under uncertainty about firm-specific counterfactual emissions. Crediting offsets against a country, sector, or other highly aggregate baseline is another proposed solution to reduce leakage and adverse selection reflected in recent U.S. climate legislation (Plantinga and Richards 2008; Murray 2009). However, the literature has not seen extensive theoretical work evaluating optimal offset design to address both additionality and leakage.

Some research has examined the optimal trading ratio between offsets and allowances for GHGs and other pollutants to address uncertainty about offset measurement and permanence, particularly from non-point sources (Shortle 1987; Malik et al. 1993; Marshall 2010; Kurkalova 2005; Ranjan and Shortle 2007; Mignone et al.

2009). This paper does not address this potentially important rationale for discounting offset credits.

Results from the model illustrate the importance of leakage and stringency when setting the optimal trading ratio and baseline. When designed optimally, offset credits should always be discounted in proportion to the emissions leakage to uncovered sectors or regions, and the crediting baseline should be set jointly with the emissions cap to achieve a level of mitigation such that marginal abatement costs equal the marginal social damages from emissions. When the emissions cap and baseline are set exogenously at a level where marginal benefits of mitigation exceed marginal costs, then an extra discount is warranted to address the "hot air" in the system. Alternatively, if the trading ratio is set exogenously and does not account for leakage but the policymaker can choose the offsets baseline and/or emissions cap, the second-best allowance price is typically lower than the first-best level.

In the next section, I describe the model and focus on a case in which the policymaker can choose optimally the offsets trading ratio as well as the emissions cap and/or baseline. I then turn to cases in which the policymaker is constrained to selecting either the trading ratio *or* the GHG cap and/or baseline. Then I summarize the insights and policy implications gleaned from the model. The last section concludes.

Model

The model starts with a three-sector or three-country economy in which each sector or country emits greenhouse gases (GHGs) when producing a composite commodity. The model is generalizable to other pollutants, but GHGs provide a compelling case both because of their policy significance and because each unit of emissions causes the same global damages regardless of the sector or location, making leakage particularly pertinent. I focus on aggregate sector- or country-level emissions to be consistent with the international offsets provisions of recent climate legislative proposals such as the 2009 American Clean Energy and Security (ACES) Act.[2] It might also be more reasonable to assume the regulator has better information about aggregate than firm-specific marginal abatement costs to sidestep the adverse selection problem.

A single representative consumer derives utility from the consumption of three goods denoted by $x_1, x_2,$ and x_3, with respective emissions intensities $g_1, g_2,$ and g_3. Total GHG emissions are given by $G = g_1x_1 + g_2x_2 + g_3x_3$. Each good's production cost is represented by a convex cost function, $c_i(x_i)$.[3] GHG emissions harm social welfare according to a damage function, $D(G)$. Overall social welfare can be represented as $W = u(x_1, x_2, x_3) - c_1(x_1) - c_2(x_2) - c_3(x_3) - D(g_1x_1 + g_2x_2 + g_3x_3)$.

For the sake of simplicity, I do not explicitly include abatement costs in the model. Rather, sectors can reduce emissions by decreasing production of their respective goods. The cost to society of reducing emissions is therefore the foregone utility of consumption (net of production costs), which is a reasonable way of conceptualizing abatement costs at an aggregate societal level.

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[2] The model is flexible enough to accommodate alternative interpretations of the three sectors, e.g., they could represent three individual firms instead of three aggregate production units.

[3] A single aggregate cost function could instead be used to represent a case in which all three sectors use a common intermediate input that generates emissions (such as a fossil fuel). In this situation, leakage to non-regulated firms is even more likely because input costs for non-regulated firms decline when regulated firms reduce their consumption. The results and intuition that follow are also applicable to the common-polluting-input case.

In this paper, the policymaker is armed with a limited toolkit to address the social harm caused by GHG emissions. Specifically, she can implement a cap-and-trade program with mandatory coverage of emissions from sector 1, while the other sectors can voluntarily opt to earn offset credits from greenhouse gas reduction below a baseline. Assume for now that sector 2 opts into the offsets program, while sector 3 does not. (I return to the issue of endogeneity of participation in the offsets program later.) In other words, production in sector 1 is subject to an emissions constraint $\bar{G} = g_1 x_1 - \alpha(b - g_2 x_2)$, where $\bar{G}$ is the cap, b is the emissions baseline used for offset crediting, and α is the trading ratio between offset credits and GHG allowances, which is expected to be bounded by zero and one.

Assuming that firm profits from all three sectors accrue to a single representative consumer, a single private-sector maximization problem can be written as

$$\max_{x_1, x_2, x_3} u(x_1, x_2, x_3) - c_1(x_1) - c_2(x_2) - c_3(x_3) \text{ s.t. } \bar{G} = g_1 x_1 - \alpha(b - g_2 x_2).$$

The first order conditions for this maximization problem are

$$u_1 - c_1' - g_1 \lambda = 0 \quad (1)$$

$$u_2 - c_2' - g_2 \alpha \lambda = 0 \quad (2)$$

$$u_3 - c_3' = 0 \quad (3)$$

$$\bar{G} - g_1 x_1 + \alpha(b - g_2 x_2) = 0 \quad (4)$$

Here, λ is the shadow value of loosening the constraint—in other words, the marginal utility associated with consuming goods that result in an additional unit of emissions. It also, not coincidentally, represents the allowance price for GHG emissions in sector 1, serving as a signal of the social cost of emission reductions to the capped sector.

The first condition states that good 1 is produced at a level to equate the marginal utility of consumption with the marginal production cost plus the marginal value of the GHG allowances that must be surrendered, which equals the GHG allowance price times the good's emissions intensity. Likewise, the second condition shows that production of good two is determined by equating the marginal utility of consumption with the marginal production cost plus the marginal opportunity cost of the offset credits foregone by producing good 2. This opportunity cost is given by the allowance price times the emissions intensity, weighted by the trading ratio, α . While offsets provide sector 2 with an incentive to reduce GHG emissions, the incentive is less powerful than in sector 1 if the trading ratio is less than one. The third condition indicates that production in sector three is set by equating the marginal utility of consumption with the marginal production cost, absent any incentive to curtail production to mitigate GHGs. The final condition simply reiterates the emissions constraint.

Under a first-best climate policy, an emissions cap or tax would be set to equate the marginal utility of consumption of each good minus its marginal cost and divided by its emissions intensity across all three sectors, such that

$$\frac{u_1 - c_1'}{g_1} = \frac{u_2 - c_2'}{g_2} = \frac{u_3 - c_3'}{g_3}. \qquad (5)$$

However, the first-order conditions show that under the incentives created by the cap-and-trade policy, the private sector instead equates

$$\frac{u_1 - c_1'}{g_1} = \frac{u_2 - c_2'}{g_2 \alpha} = u_3 - c_3' + \lambda.. \qquad (6)$$

This equality is the crux of the second-best world confronted by the policymaker when determining how to optimally set the parameters of the GHG constraint.

Case 1: Policymaker can choose trading ratio and cap/baseline

The policymaker's objective is to maximize social welfare, *W*, with respect to the policy tools at hand—$\bar{G}$, α, and *b*. To highlight the impact of these parameters on the social welfare function, I substitute out x_1 using the constraint imposed by the cap-and-trade program (equation (4)), rewriting the objective function as

$$W = u\left(\frac{\bar{G}+\alpha(b-g_2x_2)}{g_1}, x_2, x_3\right) - c_1\left(\frac{\bar{G}+\alpha(b-g_2x_2)}{g_1}\right) - c_2(x_2) - c_3(x_3)$$
$$-D(\bar{G}+\alpha b+g_2(1-\alpha)x_2+g_3x_3)$$

The first-order conditions of the policymaker's problem are

$$\frac{dW}{d\bar{G}} = \frac{1}{g_1}(u_1-c_1') - D' + \frac{dx_2}{d\bar{G}}\left[(u_2-c_2') - \frac{g_2\alpha}{g_1}(u_1-c_1') - g_2(1-\alpha)D'\right]$$
$$+\frac{dx_3}{d\bar{G}}\left(u_3-c_3'-g_3D'\right)=0 \tag{7}$$

$$\frac{dW}{d\alpha} = \frac{(b-g_2x_2)}{g_1}(u_1-c_1') - (b-g_2x_2)D' + \frac{dx_2}{d\alpha}\left[(u_2-c_2') - \frac{g_2\alpha}{g_1}(u_1-c_1') - g_2(1-\alpha)D'\right]$$
$$+\frac{dx_3}{d\alpha}\left(u_3-c_3'-g_3D'\right)=0 \tag{8}$$

$$\frac{dW}{db} = \frac{\alpha}{g_1}(u_1-c_1') - \alpha D' + \frac{dx_2}{db}\left[(u_2-c_2') - \frac{g_2\alpha}{g_1}(u_1-c_1') - g_2(1-\alpha)D'\right]$$
$$+\frac{dx_3}{db}\left(u_3-c_3'-g_3D'\right)=0 \tag{9}$$

Each of these conditions reflects the direct effect of the respective parameter on welfare, in addition to its indirect impact through its influence on the production of goods x_2 and x_3. Using conditions (1) – (3) from the private sector problem allows these equations to be simplified as follows.

$$\frac{dW}{d\bar{G}} = \lambda - D' - \frac{dx_2}{d\bar{G}} g_2(1-\alpha)D' - \frac{dx_3}{d\bar{G}} g_3 D' = 0 \tag{10}$$

$$\frac{dW}{d\alpha} = (b - g_2 x_2)(\lambda - D') - \frac{dx_2}{d\alpha} g_2(1-\alpha)D' - \frac{dx_3}{d\alpha} g_3 D' = 0 \tag{11}$$

$$\frac{dW}{db} = \alpha(\lambda - D') - \frac{dx_2}{db} g_2(1-\alpha)D' - \frac{dx_3}{db} g_3 D' = 0 \tag{12}$$

These simplified equations show that the direct effect of loosening the GHG constraint is given by the allowance value less the marginal social damages from GHG emissions. The direct effect of increasing the trading ratio is equal to the allowance price minus marginal climate damages times the total number of offsets. The impact of adding hot air to the program by increasing the baseline is equal to the allowance price minus marginal climate damages times the trading ratio. The final two terms in each of these three equations capture the indirect effects of changing these parameters on production covered under the offsets program and that outside of the cap.

This gives three equations with three unknowns: $\lambda, \alpha,$ and b. While there is no closed-form solution for $\bar{G}$ or b without imposing additional structure on the utility, cost, and climate damage functions, λ can be viewed as a proxy for the stringency of the constraint, and the policymaker can implicitly choose the carbon price in lieu of the cap and baseline. Using equations (10) and (11) yields the following solutions for λ and α:

$$\lambda^* = D' \tag{13}$$

$$\alpha^* = 1 + \frac{g_3 dx_3}{g_2 dx_2} \tag{14}$$

These results show that the optimal allowance price is simply the marginal damage from each unit of emissions. The policymaker can set a cap that yields this allowance price, given sufficient knowledge of preferences, production technology, and the climate damage function. For example, EPA's (2010) $20 core estimate of allowance prices in 2020 under the ACES Act is the same order of magnitude as the U.S. government's central estimate of the social cost of carbon (SCC) used in regulatory analysis for the same year of $25 (Interagency Working Group 2010).[4]

The optimal trading ratio is equal to one plus the change in emissions in sector 3 in response to a one-unit increase in emissions in sector 2, which is expected to be negative if the two composite goods are substitutes. In other words, the second term represents GHG emissions leakage from sector 2 to sector 3. Perhaps unsurprisingly, the optimal discount on offsets relative to allowances is exactly equal to the leakage to the uncovered sector anticipated to result from each offset credit. Estimates of leakage in response to a climate or conservation policy range widely and vary by sector and scale of the project, suggesting that it may be optimal to vary the trading ratio by offset type.

It might initially seem counterintuitive that the leakage rate from sector 1 to sector 3 does not appear directly in the optimal trading ratio. This absence is deceptive because of the fixed relationship between x_1 and x_2 under a cap-and-trade program. The effect of x_1 on emissions in sector 3 is already reflected implicitly; indeed, equation (14) is equivalent to setting the trading ratio such that $g_1 dx_1 = -(g_2 dx_2 + g_3 dx_3)$, i.e., a one unit increase in emissions from sector 1 is exactly offset by a one unit decrease in emissions from both sectors 2 and 3.

While the optimal trading ratio is expected to fall between zero and one in most circumstances, it is theoretically possible for it to fall outside of these bounds. For instance, if goods 2 and 3 are perfect substitutes and good 3 is more emissions intensive,

[4] Values reported in 2005 dollars.

then leakage rates could exceed 100%, yielding a negative trading ratio (i.e., a penalty for generating offsets). If the two goods are strong complements, emissions from good 3 could actually decline in response to offsets in sector 2, prompting a trading ratio greater than one. These two extreme cases are outside the realm of most policy discussions.

While the first-order equations produce straightforward results for λ and α, there is no unique solution for b; rather, b and $\overline{G}$ must be set jointly to achieve the optimal allowance price. (In fact, it is possible to show that equations (10) and (12) are exactly equivalent.) Raising either $\overline{G}$ or b would lower allowance prices, and there are infinitely many combinations of the two parameters that could achieve an allowance price equal to marginal damages. The division of the GHG emission reduction target between $\overline{G}$ and b is ultimately a distributional question rather than one of efficiency. If offsets are not additional—in other words, if they are credited against an overly high baseline—the best response is to tighten the cap on the regulated sector just enough to offset the hot air introduced into the system, as noted by Montero (2000). If the emissions cap is considered fixed, then setting an efficient baseline is a matter of selecting a target that achieves the right overall level of abatement based on climate damages and abatement costs, rather than a question of accurately predicting business-as-usual emissions in the offset sector.[5] If this outcome is infeasible, then the policymaker's options are more limited, as discussed in the next section.

Case 2: Policymaker can only choose trading ratio *or* cap/ baseline

[5] This point is similar to Bushnell's (2010) argument that it can still be advantageous to allow offsets from sectors following a "surprisingly clean development path" whose business-as-usual emissions are lower than originally estimated, though my results suggest that the total abatement target should be more ambitious in such a case. Of course, projected business-as-usual emissions can provide useful information to policymakers about likely abatement costs.

The equalities above represent the optimal allowance price (and implicitly, the optimal GHG cap and offsets baseline combination) and trading ratio when the policymaker can choose both of these parameters. Different solutions to these parameters could result when the policymaker can only choose one or the other, but not both. This situation might arise, for example, due to political constraints, or because information is incomplete when one parameter is set but improves before the other parameter is chosen.

First, I assume that the policymaker faces an exogenous trading ratio and selects an allowance price (by way of setting a cap and offsets baseline) taking this ratio as a given. Solving equation (10) for $\hat{\lambda}$, the second-best allowance price, gives

$$\hat{\lambda} = D'\left[1 + g_2(1-\alpha)\frac{dx_2}{d\bar{G}} + g_3\frac{dx_3}{d\bar{G}}\right]. \tag{15}$$

This expression indicates that the second-best allowance price is determined by the marginal damages from emissions, scaled by any change in emissions that occurs in sectors 2 and 3 as a result of altering the cap on regulated firms. In other words, when the trading ratio does not appropriately discount the value of offsets for leakage, the remaining leakage should be reflected in the allowance price. To further illustrate how the optimal allowance price changes in response to the trading ratio, this expression can be differentiated with respect to α holding marginal climate damages constant for the sake of tractability, yielding

$$\frac{d\hat{\lambda}}{d\alpha} = D'\frac{g_2 dx_2}{d\bar{G}}\left(-1 + (1-\alpha)\frac{dx_2}{d\alpha} + \frac{g_3 dx_3}{g_2 dx_2}\frac{dx_3}{d\alpha}\right). \tag{16}$$

This equation shows that the effect of the trading ratio on the optimal allowance price is ambiguous. The sign of this expression depends on the degree of substitutability between the three sectors, their relative GHG intensities, and the trading ratio itself.[6] Since many combinations could result, I focus on a scenario that assumes some degree of substitutability between all three sectors, as is likely if they represent large, aggregate world regions or sectors of the economy. In this case, the term in brackets is expected to be negative for all $\alpha \leq 1$, but the sign of the first term—the effect of the regulated sector cap on sector 2's emissions—remains ambiguous. This is because lowering the allowance price has a direct effect of encouraging production in sector 2, but if offsets are credited at a lower rate than regulated emissions, then there is also an indirect leakage effect in which production can shift from sector 2 to sector 1. Equations (15) and (16) together indicate that as α approaches zero—an extreme case in which offsets are not allowed into the cap and trade program—the allowance price should decline to account for leakage to both sectors 2 and 3. In order to achieve this lower allowance price, the regulator would need to set a looser cap.

In the opposite case of $\alpha = 1$, when offset credits are treated as fully equivalent to capped-sector emission reductions, leakage between sectors 1 and 2 is not an issue, but the allowance price should still fall below the marginal climate damage rate to account for leakage to sector 3. This is not to say that the allowance price should drop dramatically; rather, it should fall just enough to counteract the remaining leakage in the overall economy. Instead of loosening the cap as in the previous case, the regulator might have to *tighten* the cap relative to the optimum to achieve this outcome. Loosening the cap could cause allowance prices to plummet as overvalued offset credits flood the market. Because the offsets sector receives credit for emission reductions that are partly eroded by leakage, a tighter cap is needed to counterbalance the excess credits. This

[6] The Appendix provides relevant comparative statics derivations.

tighter cap is not inconsistent with a slight fall in the allowance price because the offsets sector generates more emission reductions as a result of the higher offset price, allowing the regulated sector to do less.[7] The overall relationship between the trading ratio and the second-best allowance price follows an inverted-U shape passing through D', the optimal allowance price.[8]

The relationship between the allowance price and the trading ratio suggests that proposals for a "price collar" (Burtraw et al. 2009) could be advantageous to minimize the impact of an improperly set offsets trading ratio. A price collar, which releases extra allowances if prices rise to a predetermined ceiling and withholds allowances if prices sink to a certain price floor, would prop up allowance prices if excess allowances flood the market due to an overly high trading ratio, and conversely, would contain allowance prices if offsets are too limited. Equation (15) suggests an allowance price floor equal to marginal climate damages discounted by the leakage rate under the most extreme scenario of no participation by non-regulated sectors in offsets markets, while the price ceiling should not rise much higher than the marginal climate damage rate. The general results echo the findings of other research noting the complementarity between offsets and a price collar (Fell et al. 2010).

Turning to the case when the policymaker can't choose the emissions cap/offsets baseline combination but can choose the trading ratio, and again holding marginal

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[7] This situation illustrates the moderating effect that offsets have on allowance prices. With a tighter cap, an influx of offsets can sharply curtail the potential rise in allowance prices, as was shown in EPA's (2009, 2010) analyses of recent climate bills.

[8] Note that the preceding discussion assumes constant marginal climate damages. When marginal climate damages are increasing in emissions ($D'' > 0$), there is an additional effect: Because total emissions fall with a lower trading ratio (rise with a higher trading ratio), marginal climate damages are lower (higher), justifying a lower (higher) allowance price. Thus, the function will be flatter when this effect is incorporated.

climate damages constant, the second-best trading ratio is given by solving equation (11) for $\hat{\alpha}$:

$$\hat{\alpha} = 1 + \frac{g_3 dx_3}{g_2 dx_2} + \frac{(1-\lambda/D')(b - g_2 x_2)}{g_2 dx_2/d\alpha}. \qquad (17)$$

The trading ratio is again equal to one discounted by the emissions leakage that occurs when production in sector 2 decreases to generate offsets, but with an additional third term that depends on the discrepancy between the allowance price and marginal emissions damages, the offsets baseline, and the effect of the trading ratio on emissions from sector 2.

When the allowance price is set lower than optimally, and sector 2 generates a positive quantity of offsets—the situation of greatest policy relevance—this term is expected to be negative, indicating that an additional discount is warranted when the baseline is set too high.[9] This discount increases in size the bigger the gap between the allowance price and marginal climate damages and the higher the offsets baseline. The lower trading ratio helps to compensate for the introduction of "hot air" because each emission reduction foregone in the regulated sector is countered by *more* than one unit of reductions in sector 2 (even after accounting for leakage). Thus, the trading ratio

[9] Under these conditions, the sign of this third term depends on $\frac{dx_2}{d\alpha}$, which is likely negative because increasing the trading ratio should increase incentives for abatement in sector 2. However, there is an indirect positive effect since raising the trading ratio effectively relaxes the total GHG abatement target, hence lowering the allowance price. In the unlikely event that the lower allowance price more than offsets the higher trading ratio, it is theoretically possible that the net effect could be to increase sector 2 emissions, reversing the sign of the expression.

provides the policymaker with another lever to reduce emissions when the baseline is too lax, functioning as an “addititionality discount.”[10]

The opposite result also holds: If the allowance price is set *higher* than marginal climate damages but sector 2 still generates a positive quantity of offsets, a trading ratio higher than $\alpha*$ is optimal. In this case, it is desirable to introduce hot air into the program to reduce abatement costs because the target is too stringent. It is also worth noting that if the allowance price is higher than marginal climate damages but sector 2’s emissions exceed the baseline (implying that the sector would have to purchase emission credits from the regulated sector), the second-best trading ratio again drops below $\alpha*$. The lower trading ratio reduces the net tax on emissions in sector 2, helping to compensate for the excessively high carbon price. This unlikely situation could only occur under a non-voluntary offsets program.

This additionality discount is entirely additive to the leakage discount. Indeed, discounting offsets using a trading ratio remains an appropriate second-best policy instrument even when leakage is eliminated through complete coverage of all non-regulated emissions in an offsets program, as long as the baseline is not sufficiently stringent. Discounting is still effective as a way to “tighten” the cap and increase the actual level of abatement.

It is worth highlighting that this discount is warranted regardless of the source of the hot air—whether from non-additionality of offsets or from a regulated sector emissions cap that is too loose. Thus, it could be misleading to refer to the reduction in the trading ratio as an additionality discount. This is a somewhat counterintuitive result

[10] The support for a higher trading ratio is further reinforced when marginal climate damages are increasing in emissions; when the cap and baseline are too loose, marginal climate damages are increasing, justifying more abatement.

that suggests that even if offsets are entirely "real"—meaning that they are additional to business-as-usual emission reductions and cause no leakage—*it could still be optimal to discount them relative to allowances* if the covered sector cap is too loose. The offsets discount essentially allows the regulator to price discriminate as a means to achieve more aggressive emission reductions. This result provides a justification for a blanket discount on offsets by observers who consider the climate policy targets included in recent U.S. legislation to be insufficiently stringent.

Discussion: The Endogenous Opt-In Decision

The discussion thus far has assumed exogenous participation by sector 2 in the offsets regime and non-participation by sector 3. The focus in the existing offsets literature on adverse selection (e.g., Montero 2000, Bushnell 2010) highlights the importance of the baseline in the decision of a firm or entity to participate in a voluntary offsets program. This paper attempts to sidestep the issue of adverse selection at the individual firm level by focusing on sectoral or national crediting programs, which have been emphasized in recent U.S. climate legislation. Aggregate crediting programs have become still more plausible as major developing economies have proposed climate initiatives involving regulatory and market-based programs at the sectoral level, such as China's pilot cap-and-trade scheme for energy emissions (Reuters 2011).

However, it is still worth considering how the analysis might change if the endogeneity of the participation decision is considered. For example, Montero (2000) found that when regulators face a fixed pollution cap and uncertainty about firm-level abatement costs, the second-best offsets baseline should be set lower than expected emissions to extract additional information. That analysis did not consider the trading ratio as an additional policy lever to improve the efficiency of a second-best cap-and-trade program with offsets.

Sectors or countries will only opt in to an offsets program if offset net revenues more than compensate them for the decreased profits from producing emissions-intensive goods. The baseline and trading ratio are both important elements of this decision. Because the offsets baseline can be altered with no loss of efficiency as long as the emissions cap can be shifted in the opposite direction, it follows that the efficient baseline, while not unique, must be large enough to incentivize the maximum feasible level of participation in the offsets regime. (There could be some sectors for which participation is infeasible regardless of the payoff.) As the literature on leakage suggests, this level is not necessarily equal to pre-climate-policy business-as-usual emissions, since reduced production in the regulated sectors could raise the opportunity cost of foregone production among potential offsets participants.

If it is not politically possible to set the emissions cap low enough to counterbalance a baseline sufficiently high to maximize participation, then the overall level of abatement will be less than socially optimal. In either case, the optimal trading ratio should not change in response to the endogeneity of the participation decision; it should reflect leakage if some sectors remain uncovered, as well as any hot air introduced if the baseline and cap are jointly set too high.

Policy Implications

The preceding cases illustrate the roles of leakage and the stringency of the overall policy in setting the optimal trading ratio between offsets and allowances under cap-and-trade.

The model confirms the intuitive result that offsets should always be discounted in proportion to any emissions leakage to the uncapped sector. This result suggests that different trading ratios could be warranted to account for varying leakage rates across different offset types, and that the trading ratio should rise closer to unity as more participants opt into the system. Thus, an across-the-board discount like that applied to post-2017 international offsets in the ACES Act might not be the ideal way to implement a trading ratio.

The results also emphasize the linked nature of the policymaker's choices about abatement targets and offset trading ratios. Although the hot-air and leakage discounts are additive, they can act as backstops for each other. If hot air is introduced by either an inflated baseline *or* cap, offsets should be discounted as a correction against the lower total level of mitigation that would otherwise result. Conversely, an offsets baseline that increases the stringency of the GHG abatement target beyond the level where the allowance price equals marginal damages can induce additional leakage, reducing the marginal effectiveness of the policy. The trading ratio can be a useful lever to effectively relax the policy in this case.

The scenario in which policymakers face an exogenous trading ratio that deviates from the optimal solution but exercise some control over the emissions target is perhaps less likely to happen in practice. In the event that it does, then it becomes desirable to reduce the stringency of the overall policy to account for leakage. It may also make sense to support a price collar that moderates any adverse impacts from an improperly set trading ratio.

It is also worth emphasizing the caveat that these results do not account for any further adjustments to the trading ratio that might be justified to address the risks posed by measurement uncertainty and permanence. This model suggests that if the baseline is set correctly and all uncovered sectors participate in the offsets program, mitigating any leakage concerns, then the trading ratio should be equal to one; however, a discount could still be warranted to address the measurement and permanence issues.

Conclusions

This paper examines optimal and second-best offset design to account for the joint effects of leakage and hot air. While previous research has examined the issue of setting the baseline optimally in combination with a regulated sector cap, this paper incorporates the trading ratio between offsets and regulated emission reductions as an additional policy lever, in accordance with recent cap-and-trade legislative proposals. It demonstrates that adjusting the trading ratio between emission credits and offsets is indeed an appropriate second-best tool to address not only leakage occurring when coverage of emitting sectors is incomplete, but also hot air introduced when the combined abatement target is set sub-optimally—whether or not this hot air is introduced by non-additional offsets. Of course, complete coverage of all emitting sectors and countries under a mandatory cap-and-trade or voluntary offsets program with targets that equate the marginal benefits and costs of abatement remains the first-best solution to achieving climate goals efficiently rather than tweaking the allowance price and trading ratio.

The results also highlight the importance of accurate projections of leakage, marginal climate damages, and abatement costs for setting offset trading ratios and baselines. Empirical evidence to date suggests that leakage can vary widely depending on the offset type and scale of crediting, but existing estimates, particularly in the land-use and forestry sectors, may not be sufficiently robust to support their use as inputs into key policy parameters like the allowance price and trading ratio. Furthermore, estimates of the marginal social damages from GHG emissions differ by more than an order of magnitude (National Research Council 2009). Thus, more research is needed on the likely distribution of these parameters to support efficient offset design.

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Appendix: Comparative Statics Derivations

The private sector problem can be rewritten using the constraint to concentrate the problem in terms of sectors 2 and 3 as

$$\max_{x_2, x_3} u\left(\frac{\bar{G}+g_2\alpha(b-x_2)}{g_1}, x_2, x_3\right) - c_1\left(\frac{\bar{G}+g_2\alpha(b-x_2)}{g_1}\right) - c_2(x_2) - c_3(x_3).$$

The first-order conditions for this problem are

$$\begin{aligned} &-\frac{g_2\alpha}{g_1}(u_1 - c_1') + u_2 - c_2' = 0 \qquad \rightarrow \qquad \frac{u_1 - c_1'}{g_1} = \frac{u_2 - c_2'}{g_2\alpha}, \\ &u_3 - c_3' = 0 \end{aligned}$$

and second-order conditions are given by

$$U_{22} = \left(\frac{g_2\alpha}{g_1}\right)^2 u_{11} - \frac{2g_2\alpha}{g_1}u_{12} + u_{22} - \left(\frac{g_2\alpha}{g_1}\right)^2 c_1'' - c_2'' < 0$$

$$U_{33} = u_{33} - c_3'' < 0$$

$$|J| = \begin{vmatrix} \left[\left(\frac{g_2\alpha}{g_1}\right)^2 u_{11} - \frac{2g_2\alpha}{g_1}u_{12} + u_{22} - \left(\frac{g_2\alpha}{g_1}\right)^2 c_1'' - c_2''\right] & \left[u_{23} - \frac{g_2\alpha}{g_1}u_{13}\right] \\ u_{23} - \frac{g_2\alpha}{g_1}u_{13} & u_{33} - c_3'' \end{vmatrix} > 0.$$

These conditions yield the following comparative statics for the effect of lowering the regulated sector cap, $\bar{G}$, on production in sectors 2 and 3.

$$\frac{dx_2}{d\bar{G}} = \frac{\begin{vmatrix} -\frac{1}{g_1}\left[u_{12} - \frac{g_2\alpha}{g_1}(u_{11} - c_1'')\right] & \left[u_{23} - \frac{g_2\alpha}{g_1}u_{13}\right] \\ -\frac{1}{g_1}u_{13} & u_{33} - c_3'' \end{vmatrix}}{|J|}$$

$$sign\left\{\frac{dx_2}{d\bar{G}}\right\} = sign\left\{\frac{1}{g_1}\left[-\left(u_{12} - \frac{g_2\alpha}{g_1}(u_{11} - c_1'')\right)(u_{33} - c_3'') + u_{13}\left(u_{23} - \frac{g_2\alpha}{g_1}u_{13}\right)\right]\right\}$$

The sign of $\frac{dx_2}{d\bar{G}}$ is ambiguous. When goods produced in all three sectors are substitutes, it becomes positive as α moves close to 1 and the GHG intensity of sector 2 increases relative to sector 1. The sign becomes negative if α = 0.

$$\frac{dx_3}{d\overline{G}} = \frac{\begin{vmatrix} \left(\left(\frac{g_2\alpha}{g_1}\right)^2 u_{11} - \frac{2g_2\alpha}{g_1}u_{12} + u_{22} - \left(\frac{g_2\alpha}{g_1}\right)^2 c_1'' - c_2'' \right) & -\frac{1}{g_1}\left[u_{12} - \left(\frac{g_2\alpha}{g_1}\right)(u_{11} - c_1'') \right] \\ u_{23} - \frac{g_2\alpha}{g_1}u_{13} & -\frac{1}{g_1}u_{13} \end{vmatrix}}{|J|}$$

$$sign\left\{\frac{dx_3}{d\overline{G}}\right\} = sign\left\{ -\frac{1}{g_1}\left[u_{13}(u_{22} - c_2'' - \frac{g_2\alpha}{g_1}u_{12}) + \left(\frac{g_2\alpha}{g_1}\right) u_{23}(u_{11} - c_1'' - \frac{g_1}{g_2\alpha}u_{12}) \right] \right\}$$

Again assuming that goods produced in all three sectors are substitutes, this expression is negative, indicating that when the cap is loosened, production falls in the uncovered sector.

Turning to the effect of the trading ratio on production in sector 2, the comparative static result is given by

$$\frac{dx_2}{d\alpha} = \frac{\begin{vmatrix} -\frac{b}{g_1}\left[u_{12} - \frac{g_2\alpha}{g_1}(u_{11} - c_1'') \right] + \frac{g_2}{g_1}(u_1 - c_1') & \left[u_{23} - \frac{g_2\alpha}{g_1}u_{13} \right] \\ -\frac{b}{g_1}u_{13} & u_{33} - c_3'' \end{vmatrix}}{|J|}$$

$$sign\left\{\frac{dx_2}{d\alpha}\right\} = sign\left\{ \frac{g_2}{g_1}(u_1 - c_1')(u_{33} - c_3'') - \frac{b}{g_1}(u_{33} - c_3'')\left[u_{12} - \frac{g_2\alpha}{g_1}(u_{11} - c_1'') \right] + \frac{b}{g_1}u_{13}\left(u_{23} - \frac{g_2\alpha}{g_1}u_{13} \right) \right\}$$

The net effect of the trading ratio on production in the offsets sector is determined by two countervailing forces. A direct negative effect means that incentives for abatement increase with the trading ratio. However, increasing the value of offsets to firms in sector 2 also loosens the overall abatement target, which could reduce pressure to limit production. In practice, the first effect is expected to dominate, leading to an overall negative sign.