WP 2012-09
April 2012

Working Paper

Charles H. Dyson School of Applied Economics and Management
Cornell University, Ithaca, New York 14853-7801 USA

SUPER-ADDITIONALITY: A Neglected Force in Markets for Carbon Offsets

Antonio Bento, Ravi Kanbur, and Benjamin Leard

Super-Additionality: A Neglected Force in Markets for Carbon Offsets

Antonio Bento†
The Charles H. Dyson School of Applied Economics and Management
Cornell University
432 Warren Hall
Ithaca, NY 14853
E-mail: amb396@cornell.edu
Phone: (607) 255-0626

Ravi Kanbur
The Charles H. Dyson School of Applied Economics and Management
Cornell University
221 Warren Hall
Ithaca, NY 14853
E-mail: sk145@cornell.edu
Phone: (607) 255-7966

Benjamin Leard
The Charles H. Dyson School of Applied Economics and Management
Cornell University
316 Warren Hall
Ithaca, NY 14853
E-mail: bpl47@cornell.edu
Phone: (804) 433-7287

†Corresponding author

Climate change mitigation programs classify two types of carbon offsets: Additional and non-additional. Additional offsets are offsets that correspond to actual reductions in emissions. In contrast, non-additional offsets are offsets that do not correspond to emissions reductions. These offsets are created because offset projects with business-as-usual (BAU) emissions below their assigned baseline can claim offsets up to the baseline without reducing emissions. Since the sale and use of non-additional offsets by firms in climate mitigation programs has the effect of raising aggregate emissions, an extraordinary amount of focus has been on ensuring that offsets are additional. However, we show here that there is an emissions component that has been neglected in current policy design. This component, which we call Super-additional reductions, are emissions reductions which do not lead to a supply of offsets. Super-additional reductions arise from offset projects with BAU emissions above their baseline. These projects are awarded a quantity of offsets that is lower than the project's emissions reductions. The presence of such emissions reductions without supply of equivalent offsets has the effect of lowering aggregate emissions and lessening the impact of non-additional offsets. Our numerical simulations show that super-additional reductions can be as large as the supply of non-additional offsets, and in some scenarios can even exceed them. Neglecting this component during the climate policy design process can lead to the setting of overly stringent baselines or other policy instruments, ultimately raising the compliance costs of achieving emissions reduction targets.

Complementing climate mitigation programs with carbon offsets supplied from uncapped sectors is recognized as a way of achieving emissions reduction targets at lower economic cost[1–5]. However, awarding offsets to carbon mitigation projects requires programs to set a project-specific baseline that attempts to measure the project's BAU emissions, or what the project would have emitted in the absence of the program. If offset project managers have more information on their BAU emissions than the regulator who assigns the project baseline, then the program will adversely select projects that are assigned a baseline above BAU emissions. These projects opt into the program because they can claim offsets up to the baseline while not reducing emissions. This process creates a supply of non-additional offsets. The exact quantity of non-additional offsets cannot be known with certainty because they are, by definition, a function of a hypothetical outcome (i.e. BAU emissions). Nevertheless it has been suggested that roughly 40 percent of projects (comprising 20 percent of the entire offset supply) in the largest carbon offset program, the Clean Development Mechanism (CDM), are non-additional[6]. When non-additional offsets are sold to firms under an emissions cap, they permit additional emissions to be released by the capped sector, leading to increase in aggregate emissions. The impact of these non-additional offsets on total emissions has been a cause for concern[7–12]. Policy makers have responded by proposing various instruments to control them, including more stringent baselines, trade ratios that specify how offsets convert to fungible emissions allowances, and limits on offset usage by the capped sector[13–15].

Non-additional offsets arise because of how emissions reductions are awarded relative to a project's baseline. But the award system also leads to reductions that do not generate offsets. Consider a potential supplier whose BAU emissions are $1,750$ tons but their baseline has been set at $1,000$ tons. Until the supplier reduces emissions by at least 750 tons, offset supply cannot begin. But if the price of offsets is sufficiently high, the project manager may find it profitable to reduce emissions further, to say 500 tons. In other words, the revenue from offsets supply of 500 tons more than compensates for the costs of the first 750 tons of mitigation and then the next 500 tons of mitigation (which generates the offsets supply). The actions of this project have served to reduce total emissions by 750 tons, since this reduction is not part of the offsets that are allowed to be supplied in the market. We call this reduction super-additional.

The supply of additional and non-additional offsets, the quantity of super-additional reductions and their impact on aggregate emissions depend on the decisions of offset projects (Table 1). We develop a model of a carbon offset program to identify the source of each of these components. Our model incorporates the feature that project developers have private information on their BAU emissions (see Methods). A policy maker sets baselines after observing a uncertain measurement of BAU emissions, which may be greater than, less than or equal to BAU emissions. This feature explicitly models the adverse selection problem that plagues carbon offset programs. To determine the emissions and compliance cost consequences of including offsets in climate mitigation programs, we assume that all offsets created are supplied to a representative capped sector. One offset that is supplied to the capped sector increases capped sector emissions by one unit. If less than one unit of emissions reductions by offset projects accompanies this offset, then aggregate emissions —

defined as the sum of offset project emissions and capped sector emissions — increase. In contrast, if more than one unit of emissions reductions by offset projects accompanies this offset, then aggregate emissions decrease.

The framework developed here assumes that the decision of a project to generate offsets will depend on four variables: its BAU emissions, u_i, its baseline, b_i, the price of offsets, p, and its marginal costs of mitigation, c_i. Given these, each project can calculate the profitability of reducing emissions sufficiently to generate offsets, and the optimal level of offset supply. Figure 1 gives a stylistic representation of different combinations of these variables that divide projects into different categories (see the Supplementary Information for a derivation of Figure 1). The ratio of project i's baseline to its BAU emissions, b_i/u_i, is shown on the horizontal axis while marginal costs of mitigation, c_i, is on the vertical axis. The price of offsets p is shown on the vertical axis.

Given the price of offsets, for some projects the costs of mitigation will be so high that they will not find it worthwhile to reduce emissions to generate offsets. These are projects in the regions A_1, A_2 and A_4. Projects in regions A_1 and A_2 cannot engage at all with the offsets market because their BAU emissions are above the baseline. However, projects in region A_4 do not reduce emissions but can nevertheless claim offsets because their BAU emissions are below their baseline b_i. These are projects that claim non-additional offsets. Allowing them in the market permits an increase in emissions from the capped sector, without any corresponding decrease in the uncapped sector. Projects in region A_5 also have BAU emissions below their baseline b_i, and so will supply non-additional offsets. However, their mitigation costs are low enough that they will find it profitable to reduce emissions to below their BAU level. Thus the supply of offsets from these projects will consist of both additional and non-additional offsets. Projects in region A_3 have BAU emissions above the baseline, but still low enough to find it profitable to reduce emissions below the baseline to earn a return from offsets. These projects will supply additional offsets, emissions reductions which correspond to offsets supplied to the market. However, they will also have emissions reductions which do not correspond to any offset supply, because offsets are counted from their baseline. These emissions reductions are what we have called super-additional. Projects in this region supply additional offsets and super-additional reductions.

We develop numerical simulations for a model of offset supply to yield some generic insights applicable to current and future carbon offset programs. Although we attempt to convey general conclusions, we must commit our analysis to specific parameters in simulating the model. Our central case values for the parameters that influence offset supply decisions are based on United States offset supply data (see Supplementary Methods for a complete description of the data and model calibration). Our simulations quantify how large super-additional reductions are relative to non-additional offsets.

We discovered that for a range of parameter values, the super-additional reductions exceed the supply of non-additional offsets if baselines are set stringent enough. Figure 2 shows the composition of offsets and emissions changes for a range of baselines on the horizontal axis, expressed as a proportion of observed BAU emissions. A proportion less than one implies that every project's baseline is less than its observed BAU emissions. The vertical axis measures offset supply and emissions changes in terms of million metric tons of CO_2 equivalent ($MMTCO_2e$).

The different curves show outcomes for the supply of non-additional offsets (NA), aggregate change in emissions (ΔE), and super-additional reductions (SA). The aggregate change in emissions is relative to a program that does not include offsets. If the price of offsets is high ($p = 40$) and when baselines are set to be less than 60 percent observed BAU emissions, super-additional reductions exceed the supply of non-additional offsets (Figure 2g,h,i). For this range of baselines, emissions decrease. A high offsets price encourages greater participation by project developers as the marginal returns to mitigating emissions is higher. Therefore it is more likely for projects with assigned baselines less than their BAU emissions to opt in and mitigate. This increases the quantity of super-additional reductions while having no effect on the supply of non-additional offsets. When the degree of uncertainty on BAU emissions is low (Figure 2g), less stringent baselines are necessary for aggregate emissions to fall. Low BAU emissions uncertainty implies that a project is more likely to receive a baseline that matches its BAU emissions. This has the effect of reducing the supply of non-additional offsets since there will be fewer projects that have baselines above their BAU emissions.

If the degree of uncertainty on observed BAU emissions is high, it is less likely for the quantity of super-additional reductions to exceed the supply of non-additional offsets (Figure 2c,f,i). A higher degree of uncertainty implies that projects have more extreme observed BAU emissions. A project that has an observed BAU emissions that is substantially larger than its BAU emissions is more likely to receive a baseline the exceeds its BAU emissions. This project will likely opt in and earn non-additional offsets. On the other hand, a project that has an observed BAU emissions that is substantially lower than its BAU emissions is more likely to receive a baseline so low that it will not longer find it profitable to opt in. In this case, the project does not participate in the program and does not generate super-additional reductions. When the price of offsets is low ($p = 10$, Figure 2c), this effect is amplified as projects have a lower revenue incentive to opt in and mitigate. In this case, project baselines must be very stringent — less than 35 percent of observed BAU emissions — for the quantity of super-additional reductions to exceed the supply of non-additional offsets.

For an offsets price of $p = 25$ and a medium level of uncertainty (Figure 2e), the net effect on emissions of creating an offsets market is zero when baselines equal 63 percent of observed BAU emissions. However, focusing on the supply of non-additional offsets — which is 44 MMTCO_2e under these conditions — would erroneously suggest that emissions would increase. The total effect of including offsets in a climate change mitigation program on emissions is thus overstated by focusing only on non-additional offsets.

Consequences of Neglecting Super-Additionality If policy makers ignore super-additional reductions, there will be a tendency to setting overly stringent baselines to control non-additionality. As a consequence, climate change mitigation programs will forego the economic benefits of additional offsets. There is evidence that current offset programs focus on non-additionality while ignoring super-additionality. Virtually all offset protocols set baselines to ensure against the possibility of over-rewarding projects. For example, in the

Joint Implementation Guidance on Criteria for Baseline Setting and Monitoring, there are two criteria that aim to minimize awarding projects with non-additional offsets[16]:

1. A baseline shall be established by taking account of uncertainties and using conservative assumptions. (p.4)

2. Taking into account that a baseline be established in a transparent manner and using conservative assumptions, explicitly explain the assumptions and substantiate choices. In case of uncertainty regarding values of variables and parameters, *the establishment of a baseline is considered conservative if the resulting projection of the baseline does not lead to an overestimation of emission reductions* or enhancements of net removals attributable to the JI project. (p. 14, italics added for emphasis)

California's cap-and-trade program under the Global Warming Solutions Act has a similar baseline stringency for forest-based offsets. The Air Resources Board Compliance Offset Protocol for U.S. Forest Projects estimates baselines for avoided conversion projects by characterizing and projecting the baseline and discounting for the uncertainty of conversion probability. The protocol states that "any inventory estimate will be subject to statistical uncertainty...to help ensure that estimates of GHG reductions and GHG removal enhancements are conservative, a confidence deduction must be applied to each year to the inventory of actual on site carbon stocks[17]."

If the objective of an offsets protocol is to the maintain environmental integrity of a climate change mitigation program, then super-additionality gives some additional leeway to protocol designers to set less stringent baselines. The additional leeway encourages a greater supply of additional offsets, leading to lower overall emission reduction costs. We quantify these benefits by simulating the model under two general baseline protocols. The first represents a protocol that minimizes the supply of non-additional offsets. This protocol neglects the quantity of super-additional reductions and sets stringent baselines to all projects to prevent the sale of non-additional offsets. The second represents a protocol that recognizes the quantity of super-additional reductions and sets baselines to ensure environmental integrity. This protocol selects project baselines so that the quantity of super-additional reductions equals the supply of non-additional offsets, which has the effect of keeping emissions unchanged. Over a range of offset prices, we find that the baseline protocol that minimizes the supply of non-additional offsets significantly reduces the supply of additional offsets (Table 2). For an offsets price of 25 dollars per ton of CO_2e, we find that the supply of additional offsets is 40 percent less relative to the baseline protocol that maintains environmental integrity (Table 2(b)). This result is insensitive to the offset price; for the range of offset prices considered, we find that the supply of additional offsets is between 36 percent and 43 percent less relative to the Maintain Environmental Integrity baseline protocol.

Recognizing super-additional reductions when setting baselines will increase the cost savings of including offsets in climate change mitigation programs. We estimate that the additional cost savings from this protocol can be substantial (Supplementary Table 10). We find that an additional 70−75 percent of compliance cost savings can be achieved when super-additional reductions are recognized when setting baselines (See Supplementary Information for a description of this calculation).

Implications of Neglecting Super-Additional Reductions for Instrument Choice in Carbon Offset Markets Concerns about the impact of non-additionality on total emissions have led to the development and use of other instruments such as trade ratios or limits on the use of offsets[18]. The use of these instruments to address non-additionality, however, is itself problematic. The use of a trade ratio, which effectively lowers the offsets price for the uncapped sector, cannot affect the supply of non-additional offsets, since these are given by the difference between the baseline and BAU emissions. A lower offsets price makes supplying additional offsets less profitable. As a consequence, fewer additional offsets will be supplied and a lower quantity of super-additional reductions will emerge from the offset program. The use of limits on offsets use by the capped sector cannot lower emissions because it will simply lower the equilibrium price of offsets, and thus again reduce the supply of additional offsets and the quantity of super-additional reductions.

The recognition and systematic incorporation of super-additionality into modeling and policy analysis helps to provide a better perspective for the design of markets for carbon offsets. It can mitigate the current tendency to adopt inappropriate levels of several policy instruments because of concerns about non-additionality: stringent baselines, tight trade ratios and limits on offsets use. Since super-additionality counteracts the effect of non-additionality on total emissions, it allows a greater role for focus on the economic benefits of offsets markets.

Methods Our model integrates the decisions of uncapped firms to supply offsets into a cap-and-trade program. We assume that capped firms purchase the entire supply of offsets from uncapped projects. Our change in emissions calculations are relative to a cap-and-trade program that prohibits a capped sector from using offsets for compliance.

We explicitly model the decisions of uncapped projects to supply offsets through a well-defined profit function. Projects in the uncapped sector make supply decisions based on five variables: BAU emissions, sequestration potential, an emissions baseline, the price of offsets, and a marginal cost of mitigation. Project i knows with certainty its BAU emissions, while the policy maker knows observed BAU emissions, which equal project-specific BAU emissions plus a project-specific emissions shock. Ex-post emissions are assumed to be common knowledge that the policy maker can perfectly observe.

Each project decides whether to opt-in and whether to mitigate. The decisions are based on a profit function defined by Supplementary Equation 3 in the Supplementary Information. Projects compare the profits of the different decisions and choose the combination that yields the highest profit. The decisions of the projects yield the different quantities of offset supplies and super-additional reductions (Supplementary Equations 4-11), which are used to calculate the change in emissions (Supplementary Equation 12).

We generate the supply of offsets and emissions effects with a simulation calibrated to United States emissions and mitigation cost data. We assume that there are 1000 potential projects that are capable of GHG mitigation. The distribution of marginal costs of mitigation is assumed to be uniform and is calibrated to match EPA estimates of mitigation cost curves for the United States forestry and agriculture sector[19]. BAU emissions of uncapped projects are also assumed to be uniformly distributed. The sum of initial emissions is calibrated through data on the total emissions of the uncapped sector[19]. For each iteration of the simulation, we generate data by drawing from the defined distributions of each characteristic for all of the 1000 projects. The projects then make profit-maximizing decisions, which lead to a supply of offsets, super-additional reductions and emissions changes. We perform 2000 iterations of this procedure to obtain an expected value for each of the key outputs.

We consider a wide range for the price of offsets, with a central value of 25 dollars per ton of CO_2 equivalent that approximates the Social Cost of Carbon[20]. The emissions shocks are independently and identically drawn from a normal distribution with mean zero and variance equal to the expected value of BAU emissions. Baselines are set as a function of observed BAU emissions. This yields an expected quantity of non-additional offsets equal to 30 percent of total offset supply when baselines are set to equal measured BAU emissions, a value consistent with survey data on the proportion of offset supply that is non-additional[6].

Given these assumptions, we vary the tightness of the baseline, from 0 percent to 100 percent of observed BAU emissions, and analyze the pattern of offset supply, and emissions changes stemming from the quantity of super-additional reductions and the supply of non-additional offsets. To establish how neglecting super-additional reductions affects offset supply and compliance costs, we consider an offset project baseline protocol that sets baselines in a way to minimize the supply of non-additional offsets. This protocol is compared to a less stringent one that recognizes the supply of super-additional reductions and sets baselines in a way that just maintains environmental integrity of the climate change mitigation program. Baselines set in this manner induce a supply of non-additional offsets that equal the quantity of super-additional reductions.

Sensitivity analysis around the basic assumptions including the standard deviation of emissions shocks, the price of offsets, the marginal cost of mitigation, and the correlation between BAU emissions and marginal costs of mitigation is reported in the Supplementary Information, and leaves our basic conclusions unchanged. Supplementary Tables 2-5 report the ratio of super-additional reductions to non-additional offsets and Supplementary Tables 6-9 report offset supplies for broad ranges of the parameters.

References

1. Brown, K. & Adger, W.N. Economic and Political Feasibility of International Carbon Offsets. *Forest and Ecology Management* 68(2-3): 217-229 (1994).

2. Chameides, W. & Oppenheimer, M. Carbon Trading Over Taxes. *Science* 315, 1670 (2007).

3. Lehmann, J. A Handful of Carbon. *Nature* 447: 143-144 (2007).

4. Basu, P. Forestry: A Green Investment. *Nature* 457: 144-146 (2009).

5. Victor, D. National Effects of Global Policy. *Nature Climate Change* 2, 24-25 (2007).

6. Schneider, L. Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of the CDM and options for improvement. *Oko-Institut: Institute for Applied Ecology* (2007).

7. Kintisch, E. California Emissions Plan to Explore Use of Offsets. *Science* 321, 23 (2008).

8. Maslin, M. & Scott, J. Carbon Trading Needs a Multi-Level Approach. *Nature* 475: 445-447 (2011).

9. Gillenwater, M., Broekhoff, D., Trexler, M., Hyman, J., & Fowler, R. Policing the Voluntary Carbon Market. *Nature Reports: Climate Change* 711(6): 85-87 (2007).

10. Schiermier, Q. Climate Credits. *Nature* 444: 976-977 (2006).

11. Schneider, L. Assessing the Additionality of CDM Projects: Practical Experiences and Lessons Learned. *Climate Policy* 9(3): 242-254 (2009).

12. Zhang, J. & Wang, C. Co-Benefits and Additionality of the Clean Development Mechanism: An Empirical Analysis. *Journal of Environmental Economics and Management* 62(2): 140-154 (2011).

13. Murray, B.C., Sohngen, B., & M.T. Ross. Economic Consequences of Consideration of Permanence, Leakage and Additionality for Soil Carbon Sequestration Projects. *Climatic Change* 80: 127-143 (2007).

14. U.S. Environmental Protection Agency. Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009. H.R. 2454 in the 111th Congress. Accessed January 1 2012. `http://www.epa.gov/climatechange/economics/pdfs/HR2454_SupplementalAnalysis.pdf` (2010).

15. Regional Greenhouse Gas Initiative. Overview of RGGI CO_2 Budget Trading System. Accessed January 1 2012. `http://www.rggi.org/docs/program_summary_10_07.pdf` (2007).

16. UNFCCC/CCNUCC Joint Implementation Guidance on Criteria for Baseline Setting and Monitoring. `http://ji.unfccc.int/Ref/Documents/Baseline_setting_and_monitoring.pdf` (2011).

17. California Environmental Protection Agency Air Resources Board. Compliance Offset Protocol U.S. Forest Projects. `http://www.arb.ca.gov/regact/2010/capandtrade10/copusforest.pdf` (2011).

18. Kollmuss, A., Lazarus, M., Lee, C., LeFranc, M., & Polycarp C. *Handbook of Carbon Offset Trading Systems, Fund Protocols and Standards*. Earthscan (2010).

19. U.S. Environmental Protection Agency. Updated Forestry and Agriculture Marginal Abatement Cost Curves. `http://www.epa.gov/climatechange/economics/downloads/Data-Annex-EPA-APA-Analysis-v2.1.zip` (2009).

20. U.S. Environmental Protection Agency. Technical Support Document - Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866. Interagency Working Group on Social Cost of Carbon, United States Government (2010).

21. Environmental Protection Agency. Data Annex Coverage and Caps: Emissions Inventory. `http://www.epa.gov/climatechange/economics/downloads/Data-Annex-EPA-APA-Analysis-v2.1.zip` (2010).

22. Fell, H. & Morgenstern, R. Alternative Approaches to Cost Containment in a Cap-and-Trade System. *Environmental and Resource Economics* 47: 275-297 (2010).

23. Fell, H., Burtraw, D., Morgenstern, R.D. & Palmer, K.L. Soft and Hard Price Collars in a Cap-and-Trade System: A Comparative Analysis. *Journal of Environmental Economics and Management* Forthcoming (2012).

24. Lucas, R.E. & Prescott, E.C. Investment Under Uncertainty. *Econometrica* 39:659-681 (1971).

25. Baldursson, F.M. & Karatzas, I. Irreversible Investment and Industry Equilibrium. *Finance and Stochastics* 1:69-89 (1997).

Table 1 | Offsets supply and emissions consequences of project decisions.

		Project i Baseline Relative to BAU Emissions		
		$\frac{b_i}{u_i} > 1$	$\frac{b_i}{u_i} = 1$	$\frac{b_i}{u_i} < 1$
Project i Decision	Mitigate	Additional Offsets Non-Additional Offsets Increase in Emissions	Additional Offsets No Change in Emissions	Additional Offsets Super-Additional Reductions Decrease in Emissions
	Do not mitigate	Non-Additional Offsets Increase in Emissions	No Offsets No Change in Emissions	No Offsets No Change in Emissions

Projects that mitigate emissions can generate a combination of additional and non-additional offsets as well as quantities of super-additional reductions. These are projects that fall into regions A_3 and A_5 in Figure 1. Projects that have a baseline larger than their BAU emissions $\left(\frac{b_i}{u_i} > 1\right)$ are located in region A_5 and generate additional and non-additional offsets. The supply of non-additional offsets from these projects increase aggregate emissions. Projects that have a baseline lower than their BAU emissions $\left(\frac{b_i}{u_i} > 1\right)$ are located in region A_3 and generate additional offsets and super-additional reductions. The quantity of super-additional reductions created by these projects lower aggregate emissions. Projects that mitigate emissions and have a baseline equal to their BAU emissions $\left(\frac{b_i}{u_i} = 1\right)$ only generate additional offsets. These projects do not lead to an emissions change. Projects that do not mitigate and do not produce offsets and lead to no change in emissions. Projects that do not mitigate but have a baseline larger than their BAU emissions $\left(\frac{b_i}{u_i} > 1\right)$ are located in region A_4 and generate non-additional offsets. These projects lead to an increase in aggregate emissions.

Table 2 | The effect of neglecting super-additional reductions when selecting baselines.

(a) Offsets Price = 10 dollars per ton

	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Baselines	$b_i = 0$	$b_i = 0.49\tilde{u}_i$
Total Offset Supply	88	158
Additional Offsets	88	137
Non-Additional Offsets	0	21
Super-Additional Reductions	−28	−21
Change in Emissions	−28	0

(b) Offsets Price = 25 dollars per ton

	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Baselines	$b_i = 0$	$b_i = 0.63\tilde{u}_i$
Total Offset Supply	186	353
Additional Offsets	186	309
Non-Additional Offsets	0	44
Super-Additional Reductions	59	44
Change in Emissions	−59	0

(c) Offsets Price = 40 dollars per ton

	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Baselines	$b_i = 0$	$b_i = 0.72\tilde{u}_i$
Total Offset Supply	352	672
Additional Offsets	352	613
Non-Additional Offsets	0	59
Super-Additional Reductions	−110	59
Change in Emissions	−110	0

The Minimize Supply of Non-Additional Offsets protocol is defined by setting project baselines that guarantee no supply of non-additional offsets. The Maintain Environmental Integrity protocol is defined by setting project baselines such that the expected supply of non-additional offsets equals the expected quantity of super-additional reductions. This protocol keeps expected aggregate emissions fixed. For each of the three offsets price cases, we assume a medium level of observed BAU emissions uncertainty.

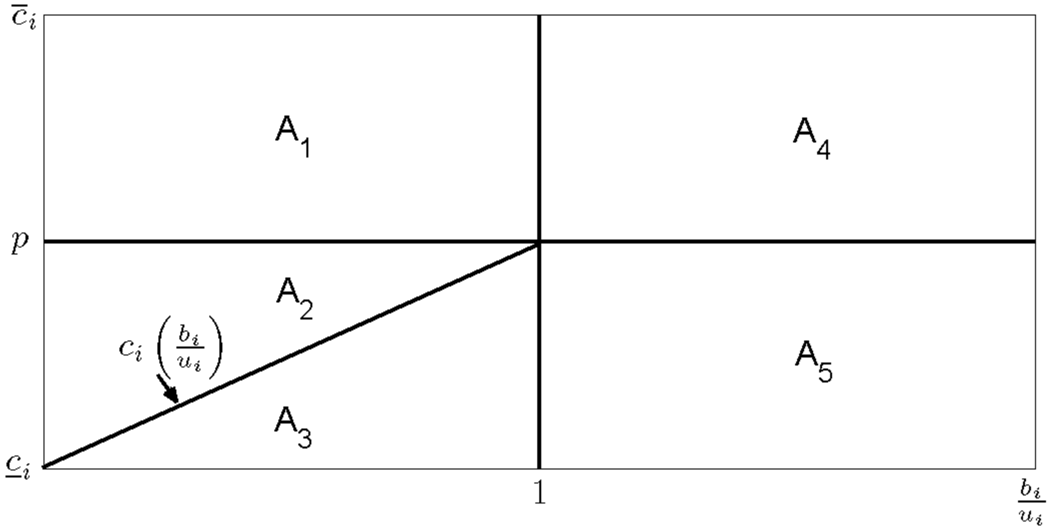

Figure 1 | Decisions of uncapped sector projects. The horizontal axis denotes the ratio of a project's assigned baseline (b_i) and its BAU emissions (u_i). The vertical axis measures a project's marginal cost of mitigation (c_i), where the horizontal line p represents the price of offsets. projects in regions A_1 and A_2 do not opt in. projects in regions A_3 and A_5 opt in and choose to mitigate. projects falling in region A_5 opt in but do not mitigate. Region A_3 includes projects that produce Super-Additional Reductions. The curve $c_i(b_i/u_i)$ denotes a zero-profit condition of the project profit-maximization problem (see the Supplementary Information for a formal definition and derivation).

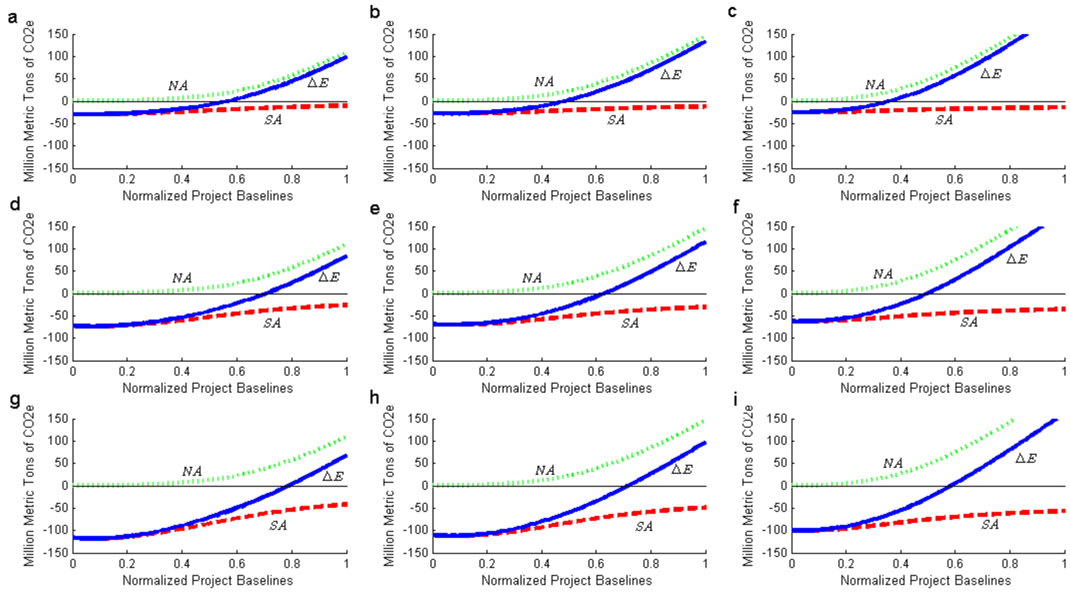

Figure 2 | The change in aggregate emissions relative to a program that does not include offsets, as a function of normalized project baselines. Panels in the same row are simulations that have a common offsets price. We consider three offset prices: Low ($p = 10$, **a,b,c**), medium ($p = 25$, **d,e,f**) and high ($p = 40$, **g,h,i**). Panels in the same column are simulations that have the same uncertainty on observed BAU emissions. We consider three levels of uncertainty: Low (**a,d,g**), medium (**b,e,h**) and high (**c,f,i**). Normalized project baselines are defined as a project's assigned baseline (b_i) divided by the project's observed BAU emissions ($\tilde{u}_i$). The change in emissions (ΔE) is defined relative to a climate mitigation program that does not include offsets. Its value is calculated by adding the supply of non-additional offsets (NA) and the quantity of super-additional reductions (SA). For low baselines, the change in emissions is negative as the quantity of super-additional reductions dominates the supply of non-additional offsets.

Supplementary Information for *Super-Additionality: A Neglected Force in Markets for Carbon Offsets*

Supplementary Methods

The Model

The model includes a capped and an uncapped sector. The capped sector is regulated by a well-functioning cap-and-trade program. We do not explicitly model the behavior of capped units or the allocation of permits. Instead we focus on integrating into the program decisions of uncapped projects that supply offsets. We assume that capped firms purchase the entire supply of offsets from uncapped projects. We quantify how including offsets in climate mitigation programs affects emissions relative to a program that does not include offsets. Including offsets raises emissions relative to a no-offsets program if there is a significant supply of non-additional offsets used by capped firms. In contrast, including offsets may reduce emissions relative to a no-offsets program if there is a significant quantity of super-additional reductions. The net emissions effect of including offsets in climate mitigation programs will depend on the magnitude of these two forces.

There are n uncapped projects that make a decision to supply offsets. Project i makes its decision based on four project-specific characteristics and the offsets price. The four characteristics include the marginal costs of mitigation (c_i), BAU emissions (u_i), sequestration potential (s_i) and an emissions baseline (b_i). Marginal costs are constant and are drawn from a cumulative distributional function $Z(c)$ with support $[\underline{c}, \overline{c}]$. BAU emissions lie within a support $[\underline{u}, \overline{u}]$ where each u_i is independently drawn from the cumulative distribution function $Y(u)$. Project i's sequestration potential is drawn from a cumulative distribution function $X(s)$ that has a support $[\underline{s}, \overline{s}]$.

The model has three periods. In period 1, project i observes its marginal cost of mitigation, BAU emissions and sequestration potential. In period 2, the policy maker measures BAU emissions $\tilde{u}_i$ of each project with uncertainty. Project i's measured BAU emissions, denoted by $\tilde{u}_i$, are equal to BAU emissions plus an emissions shock $\varepsilon_i \sim \mathcal{N}(0, \sigma^2)$:

$$\tilde{u}_i = u_i + \varepsilon_i. \qquad \text{(Supplementary Equation 1)}$$

Each project receives a baseline, b_i, that equals a proportion of measured BAU emissions:

$$b_i = \alpha \tilde{u}_i. \qquad \text{(Supplementary Equation 2)}$$

The proportion $\alpha > 0$ can be less than, equal to, or greater than one. In period 3, projects make opt-in and mitigation decisions based on their profit function

$$\pi_i = \max_{s_i \leq e_i \leq u_i} \left\{ p(b_i - e_i) - c_i(u_i - e_i) \right\}, \qquad \text{(Supplementary Equation 3)}$$

where p is the price of offsets. If $\pi_i \geq 0$, then project i opts-in and supplies a quantity of offsets equal to $b_i - e_i^*$, where e_i^* solves (Supplementary Equation 3). We assume that the policy maker perfectly measures ex-post emissions e_i^* for each project i.

Defining Offset Supply and Emissions

The supply of offsets from project i, denoted by f_i, is given by

$$f_i = \begin{cases} b_i - e_i^*, & \text{if } b_i - e_i^* > 0 \\ 0 & \text{otherwise.} \end{cases} \qquad \text{(Supplementary Equation 4)}$$

The total supply of offsets, denoted by F, is defined as the sum of offsets from each project:

$$F = \sum_{i=1}^{n} f_i. \qquad \text{(Supplementary Equation 5)}$$

The supply of additional offsets from project i, denoted by f_i^A, is given by the difference between project i's BAU emissions and its emissions choice:

$$f_i^A = u_i - e_i^*. \qquad \text{(Supplementary Equation 6)}$$

The total supply of additional offsets, denoted by F^A, is defined as the sum of additional offsets from each project:

$$F^A = \sum_{i=1}^{n} f_i^A. \qquad \text{(Supplementary Equation 7)}$$

The supply of non-additional offsets from project i, denoted by f_i^{NA}, is given by

$$f_i^{NA} = \begin{cases} b_i - u_i, & \text{if } b_i - u_i > 0 \\ 0 & \text{otherwise.} \end{cases} \qquad \text{(Supplementary Equation 8)}$$

The total supply of non-additional offsets, denoted by F^{NA}, is defined as the sum of non-additional offsets from each project:

$$F^{NA} = \sum_{i=1}^{n} f_i^{NA}. \qquad \text{(Supplementary Equation 9)}$$

The quantity of super-additional reductions from project i, denoted by r_i, is given by

$$r_i = \begin{cases} b_i - u_i, & \text{if } b_i - u_i < 0 \text{ and } e_i^* < u_i^* \\ 0 & \text{otherwise.} \end{cases} \qquad \text{(Supplementary Equation 10)}$$

The total quantity of super-additional reductions, denoted by R, is defined as the sum of super-additional reductions from each project:

$$R = \sum_{i=1}^{n} r_i. \qquad \text{(Supplementary Equation 11)}$$

The change in emissions relative to a program without offsets, ΔE, equals the total supply of non-additional offsets plus the total quantity of super-additional reductions:

$$\Delta E = F^{NA} + R. \qquad \text{(Supplementary Equation 12)}$$

Deriving Equations that Generate Figure 1

We create Figure 1 by solving the problem of project i in (Supplementary Equation 3). If $c_i > p$, then the marginal cost of mitigation exceeds the marginal return of mitigation for project i. Therefore the project performs no mitigation by selecting $e_i = u_i$. In this case, profits are

$$\pi_i = p(b_i - u_i). \qquad \text{(Supplementary Equation 13)}$$

If $b_i < u_i$, indicated by region A_1 in Figure 1, then $\pi_i < 0$. In this case, project i will not opt in and will not perform mitigation. If $b_i > u_i$, indicated by region A_4 in Figure 1, then $\pi_i > 0$. In this case, project i will opt in but will not perform mitigation.

Now consider the setting where $c_i < p$. In this setting, the marginal cost of mitigation is less than the marginal return of mitigation for project i. If $b_i > u_i$, indicated by region A_5 in Figure 1, then $\pi_i > 0$. In this case, project i will opt in and will mitigate by selecting $e_i = s_i$. If $b_i < u_i$, represented by regions A_2 and A$_3$, then the project's decision depends on the sign of (Supplementary Equation 3). The project will mitigate emissions if the returns exceed the costs. The necessary condition for project i to mitigate is

$$p(b_i - s_i) - c_i(u_i - s_i) \geq 0. \qquad \text{(Supplementary Equation 14)}$$

The left-hand-side represents project i's profit if it selects $e_i = s_i$, while the right-hand-side represents project i's profit if it does not opt in. Solving (Supplementary Equation 14) for c_i yields

$$c_i \leq \frac{p(b_i - s_i)}{u_i - s_i}. \qquad \text{(Supplementary Equation 15)}$$

The curve $c_i\left(\frac{b_i}{u_i}\right)$ in Figure 1 represents the case when (Supplementary Equation 15) is binding. Figure 1 illustrates the case where a project has a sequestration rate equal to zero, $s_i = 0$. Projects with marginal costs above the curve do not find it profitable to opt in and mitigate emissions, represented by region A_2, while those with marginal costs below the curve achieve positive net revenue from opting in and mitigating emissions, represented by region A_3.

Calibration

The model is calibrated to observed emissions inventory data and Environmental Protection Agency (EPA) estimates of marginal mitigation costs and sequestration potential. Total Net BAU emissions are defined as the sum of emissions and sequestration among offset sources, which sum to 365 MMTCO2e[19]. Total Sequestration Potential is defined as the maximum quantity of sequestration that can occur among offset sources. In general, the larger the sequestration potential, the larger the supply of offsets. We obtain a value of $-1,027$ MMTCO2e by subtracting the EPA's estimate of the supply of offsets at a carbon price of 211 dollars from Total Net BAU emissions. This value represents an upper bound on the quantity of sequestration that can occur given marginal cost of mitigation estimates[19]. To calibrate the marginal cost of mitigation schedule, we require a value for total mitigation among all projects given an offsets price. We calibrate the marginal cost of mitigation schedule at our central price of 25 dollars. At this price, total mitigation among offsets suppliers is estimated to be 486 MMTCO2e. This mitigation comes from afforestation, animal waste, agricultural practices, forest management and soil sequestration[19].

We assume that the distributions for marginal costs of mitigation, BAU emissions and sequestration potential are uniform and independently distributed. We find that our results are not sensitive to this assumption by varying the correlation between the marginal costs of mitigation and BAU emissions (Supplementary Table 5 and Supplementary Table 9). Project-level BAU emissions are assumed to be have a mean equal to Total BAU emissions divided by the number of projects, with a lower bound equal to zero and an upper bound equal to two times the Total BAU emissions divided by the number of projects. Project-level sequestration potential are assumed to have a mean equal to Total Sequestration Potential divided by the number of projects, with an upper bound equal to zero and a lower bound equal to two times the Total Sequestration Potential divided by the number of projects. These assumptions ensure that the distributions are independent and that the project-level expected value of each variable equals the observed data divided by the number of projects. To calibrate our model to match the estimated mitigation at a carbon price of 25 dollars, we solve for the bound of the marginal cost of mitigation distribution that yields an expected supply of offsets curve that matches the marginal cost of mitigation point estimate obtained from the literature. Denote $C(q)$ as the cost of achieving a mitigation quantity of q. The mitigation cost function can be written as

$$C(q) = \int_{\underline{c}}^{\hat{c}} \int_{\underline{u}}^{\overline{u}} \int_{\underline{s}}^{\overline{s}} c(u - s) dX dY dZ, \qquad \text{(Supplementary Equation 16)}$$

where the quantity of mitigation is defined by

$$q = \int_{\underline{c}}^{\hat{c}} \int_{\underline{u}}^{\overline{u}} \int_{\underline{s}}^{\overline{s}} (u - s) dX dY dZ. \qquad \text{(Supplementary Equation 17)}$$

The variable $\hat{c}$ defines the cut-off between projects that mitigate and those that do not. The cost of mitigation function assumes that mitigation comes from projects with the lowest marginal costs. Given that the distributions for BAU emissions, sequestration potential and marginal costs are uniform, we can integrate (Supplementary Equation 17) to obtain

$$q = \frac{\hat{c} - \underline{c}}{\overline{c} - \underline{c}} \left(E[u] - E[s] \right). \qquad \text{(Supplementary Equation 18)}$$

Solving (Supplementary Equation 18) for $\hat{c}$ yields

$$\hat{c} = \frac{q(\overline{c} - \underline{c})}{E[u] - E[s]}. \qquad \text{(Supplementary Equation 19)}$$

Substituting (Supplementary Equation 19) into (Supplementary Equation 16) and integrating yields

$$C(q) = \frac{q^2}{2} \frac{\overline{c} - \underline{c}}{E[u] - E[s]} + q\underline{c}. \qquad \text{(Supplementary Equation 20)}$$

We set the lower bound of marginal costs equal to zero, $\underline{c} = 0$. Differentiating

(Supplementary Equation 20) with respect to q and solving for $\overline{c}$ yields

$$\overline{c} = \frac{C'(q)}{q}\left(E[u] - E[s]\right). \qquad \text{(Supplementary Equation 21)}$$

Observing data on marginal costs of mitigation ($C'(q)$), estimated mitigation (q), and expected BAU emissions and sequestration potential ($E[u]$ and $E[s]$, respectively) allows us to calibrate the upper bound of the marginal cost of mitigation distribution.

The standard deviation of the BAU emissions shocks is set to equal the expected value of BAU emissions, so that 68 percent of the emissions shocks are less than the expected value of BAU emissions. This yields an expected quantity of non-additional offsets equal to 30 percent of total offset supply when baselines are set to equal measured BAU emissions, a value consistent with prior literature[6]. We also consider low and high standard deviation values that appear in Figure 2. The low and high standard deviations are equal to 75 percent and 150 percent of the expected value of BAU emissions, respectively. Our model's calibrated parameter values appear in Supplementary Table 1.

Calculating the Economic Cost of Neglecting Super-Additional Reductions

For the purposes of quantifying the economic cost of neglecting super-additional reductions, we model the capped sector in a hypothetical U.S. cap-and-trade program as a single, cost-minimizing unit that is represented by a marginal abatement cost (MAC) schedule. This is a standard assumption used to evaluate the compliance costs of cap-and-trade programs[22,23]. In addition, this approach mimics the equilibrium outcome of a set of competitive firms[24,25]. The capped sector MAC schedule is assumed to be increasing with a constant slope that matches processed simulation output of the EPA's analysis of the most recent U.S. climate change bill, the American Power Act (APA). We set the slope of the MAC schedule equal to 2.83×10^{-8} \$ /ton^2, so that

$$MAC_{capped}(q) = 2.83 \times 10^{-8} q, \qquad \text{(Supplementary Equation 22)}$$

where q denotes capped sector abatement in tons of CO_2 equivalent. This yields a capped sector total abatement cost (TAC_{capped}) schedule

$$TAC_{capped}(q) = 1.415 \times 10^{-8} q^2, \qquad \text{(Supplementary Equation 23)}$$

where total costs are denoted in dollars. We assume that capped sector required abatement, denoted by $\overline{q}$, is equal to 450, 1,100 and 1,760 so that the equilibrium offsets price under the Minimize Supply of Non-Additional Offsets protocol equals $p = 10$, $p = 25$ and $p = 40$, respectively. To solve for total compliance costs when offsets are not allowed, we substitute the reduction target into (Supplementary Equation 23). To solve for capped sector abatement, offset supply and costs when offsets are allowed, we allow the offsets price (p) to be endogenously determined by the market-clearing condition that the sum of the quantity of abatement by the capped sector and the supply of offsets equals the reduction target:

$$A(p) + F(p) \geq q, \qquad \text{(Supplementary Equation 24)}$$

$A(p)$ and $F(p)$ denote the quantity of abatement by the capped sector and offset supply by uncapped units for an offsets price equal to p. As $F(\cdot)$ is a stochastic function, we take an average of 2000 simulations to calibrate an expected supply of offsets schedule. We assume that capped sector abatement is solved by setting the marginal abatement cost equal to the offsets price (which, in equilibrium, will equal the allowance price):

$$A(p) = \{A : MAC(A) = p\}. \qquad \text{(Supplementary Equation 25)}$$

Supplementary Table 1 | Parameter values.

Parameter description	Parameter	Value
Lower Bound of Marginal Costs of Mitigation	$\underline{c}$	0
Upper bound of Marginal Costs of Mitigation	$\overline{c}$	72
Lower Bound of BAU emissions	$\underline{u}$	0
Upper Bound of BAU emissions	$\overline{u}$	0.730
Lower Bound of Sequestration Potential	$\underline{s}$	-2.054
Upper Bound of Sequestration Potential	$\overline{s}$	0
Standard Deviation of Emissions Shocks	σ	0.353
Offsets Price	p	25

Cost and price parameters are reported in (year 2000) dollars per ton of CO_2 equivalent. Emissions and sequestration parameters are reported as million metric tons of CO_2 equivalent.

Supplementary Table 2 | Ratio of super-additional reductions to non-additional offsets: Varying the standard deviation of emissions shocks.

		Baseline Relative to Observed BAU emissions				
		20%	40%	60%	80%	100%
Standard Deviation of Emissions Shocks (σ)	$0.5E[u]$	138.24	20.56	4.40	0.96	0.27
	$0.75E[u]$	58.14	8.95	2.03	0.59	0.24
	$E[u]$	30.94	4.80	1.20	0.43	0.21
	$1.5E[u]$	11.98	1.92	0.58	0.27	0.16
	$2E[u]$	5.8	0.96	0.35	0.18	0.11

A ratio above 1 implies that the quantity of Super-Additional reductions exceeds the supply of Non-Additional offsets. Our central setting assumes a standard deviation equal to the expected value of BAU emissions ($\sigma = E[u]$).

Supplementary Table 3 | Ratio of super-additional reductions to non-additional offsets: Varying the price of offsets.

		Baseline Relative to Observed BAU emissions				
		20%	40%	60%	80%	100%
Price of Offsets (p)	5	6.12	0.97	0.24	0.09	0.04
	15	18.62	2.90	0.73	0.26	0.13
	25	31.07	4.80	1.20	0.43	0.21
	35	45.65	6.75	1.69	0.60	0.29
	45	55.60	8.71	2.16	0.78	0.38

A ratio above 1 implies that the quantity of Super-Additional reductions exceeds the supply of Non-Additional offsets. The price of offsets is denoted in (year 2000) dollars per ton of CO_2 equivalent. Our central setting assumes a price of offsets equal to 25 dollars per ton.

Supplementary Table 4 | Ratio of super-additional reductions to non-additional offsets: Varying the marginal cost of mitigation.

		Baseline Relative to Observed BAU emissions				
		20%	40%	60%	80%	100%
Marginal Cost of Mitigation	5	124.98	19.01	4.69	1.68	0.83
	15	51.60	8.05	1.99	0.72	0.35
	25	31.07	4.80	1.20	0.43	0.21
	35	22.05	3.45	0.81	0.33	0.15
	45	17.24	2.69	0.67	0.24	0.12

A ratio above 1 implies that the quantity of Super-Additional reductions exceeds the supply of Non-Additional offsets. The marginal cost of mitigation is denoted in (year 2000) dollars per ton of CO_2 equivalent. This value is used to calibrate the cost of mitigation curve. Low values imply cheaper mitigation opportunities and a more compressed distribution of marginal costs. Our central setting assumes a marginal cost of mitigation of 25 dollars per ton.

Supplementary Table 5 | Ratio of super-additional reductions to non-additional offsets: Varying the correlation between marginal costs of mitigation and BAU emissions.

		Baseline Relative to Observed BAU emissions				
		20%	40%	60%	80%	100%
Correlation Coefficient ($\rho_{u,c}$)	−0.8	42.52	6.33	1.44	0.46	0.22
	−0.4	37.44	5.58	1.31	0.45	0.21
	0	30.07	4.80	1.20	0.43	0.21
	0.4	24.46	4.11	1.09	0.42	0.21
	0.8	18.60	3.41	0.99	0.40	0.20

A ratio above 1 implies that the quantity of Super-Additional reductions exceeds the supply of Non-Additional offsets. Our central setting assumes no correlation between marginal costs of mitigation and BAU emissions.

Supplementary Table 6 | The effect of neglecting super-additional reductions when selecting baselines: Varying the standard deviation of emissions shocks.

		Additional Offsets		Total Offset Supply	
		Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Standard Deviation of Emissions Shocks (σ)	$0.5E[u]$	210	352	210	380
	$0.75E[u]$	197	330	197	366
	$E[u]$	186	309	186	353
	$1.5E[u]$	170	275	170	318
	$2E[u]$	159	246	159	285

Offset quantities are reported in $MMTCO_2e$. Our central setting assumes a standard deviation equal to the expected value of BAU emissions ($\sigma = E[u]$).

Supplementary Table 7 | The effect of neglecting super-additional reductions when selecting baselines: Varying the price of offsets.

		Additional Offset Supply		Total Offset Supply	
		Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Price of Offsets (p)	5	37	54	37	65
	15	116	179	116	205
	25	186	309	186	353
	35	261	445	261	497
	45	335	580	335	641

Offset quantities are reported in $MMTCO_2e$. Our central setting assumes a price of offsets equal to 25 dollars per ton of CO_2 equivalent.

Supplementary Table 8 | The effect of neglecting super-additional reductions when selecting baselines: Varying the marginal cost of mitigation.

		Additional Offset Supply		Total Offset Supply	
		Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Marginal Cost of Mitigation	5	796	1,230	796	1,353
	15	310	535	310	594
	25	186	309	186	353
	35	133	215	133	245
	45	103	165	103	190

Offset quantities are reported in $MMTCO_2e$. The marginal cost of mitigation is denoted in (year 2000) dollars per ton of CO_2 equivalent. This value is used to calibrate the cost of mitigation curve. Low values imply cheaper mitigation opportunities and a more compressed distribution of marginal costs. Our central setting assumes a marginal cost of mitigation of 25 dollars per ton of CO_2 equivalent.

Supplementary Table 9 | The effect of neglecting super-additional reductions when selecting baselines: Varying the correlation between marginal costs of mitigation and BAU emissions.

		Additional Offset Supply		Total Offset Supply	
		Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Correlation Coefficient ($\rho_{u,c}$)	-0.8	171	311	171	357
	-0.4	181	310	181	351
	0	186	309	186	353
	0.4	188	306	188	343
	0.8	189	304	189	337

Offset quantities are reported in $MMTCO_2e$. Our central setting assumes no correlation between marginal costs of mitigation and BAU emissions.

Supplementary Table 10 | The economic cost of neglecting super-additional reductions.

(a) Offsets Price = 10 dollars per ton ($\overline{q} = 450$ $MMTCO_2e$)

	No Offsets	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Capped Sector Abatement	450	361	311
Offset Supply	0	89	139
Capped Sector Abatement Costs	2,865	1,841	1,366
Offset Mitigation Costs	0	455	526
Total Compliance Costs	2,865	2,296	1,892
Cost Savings	–	569	973

(b) Offsets Price = 25 dollars per ton ($\overline{q} = 1,100$ $MMTCO_2e$)

	No Offsets	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Capped Sector Abatement	1,100	881	752
Offset Supply	0	219	348
Capped Sector Abatement Costs	17,122	10,987	8,006
Offset Mitigation Costs	0	2,728	3,294
Total Compliance Costs	17,122	13,715	11,300
Cost Savings	–	3,407	5,822

(c) Offsets Price = 40 dollars per ton ($\overline{q} = 1,760$ $MMTCO_2e$)

	No Offsets	Minimize Supply of Non-Additional Offsets	Maintain Environmental Integrity
Capped Sector Abatement	1,760	1,410	1,189
Offset Supply	0	350	571
Capped Sector Abatement Costs	43,831	28,137	20,005
Offset Mitigation Costs	0	6,973	8,548
Total Compliance Costs	43,831	35,110	28,553
Cost Savings	–	8,721	15,278

To accurately estimate the cost savings from offsets, we solve for an endogenous offsets price for a given capped sector reduction target ($\overline{q}$). The price scenarios represent the equilibrium price under the Minimize Supply of Non-Additional Offsets protocol. To achieve higher (lower) prices, we adjust the abatement requirement of the capped sector down (up). The offsets price is slightly lower under the Maintain Environmental Integrity protocol because there is a larger supply of offsets. Capped sector abatement and uncapped sector offsets are denoted in $MMTCO_2e$. Compliance costs are denoted in millions of (year 2000) dollars.

OTHER A.E.M. WORKING PAPERS

WP No	Title	Fee (if applicable)	Author(s)
2012-08	Creating Place for the Displaced: Migration and Urbanization in Asia		Beall, J., Guha-Khasnobis, G. and R. Kanbur
2012-07	The Angolan Economy – Diversification and Growth		Kyle, S.
2012-06	Informality: Concepts, Facts and Models		Sinha, A. and R. Kanbur
2012-05	Do Public Work Schemes Deter or Encourage Outmigration? Empirical Evidence from China		Chau, N., Kanbur, R. and Y. Qin
2012-04	Peer Effects, Risk Pooling, and Status Seeking: What Explains Gift Spending Escalation in Rural China?		Chen, X., Kanbur, R. and X. Zhang
2012-03	Results Based Development Assistance: Perspectives from the South Asia Region of the World Bank		O'Brien, T., Fiszbein, A., Gelb, A., Kanbur, R and J. Newman
2012-02	Aid to the Poor in Middle Income Countries and the Future of IDA		Kanbur, R.
2012-01	Does Kuznets Still Matter?		Kanbur, R.
2011-21	Meeting multiple policy objectives under GHG emissions reduction targets		Boisvert, R., and D. Blandford
2011-20	The Theory of Biofuel Policy and Food Grain Prices		Drabik, D.
2011-19	Factors Influencing Adoption of Integrated Pest Management in Northeast Greenhouse and Nursery Production		Gómez, M.
2011-18	Urban Agglomeration Economies in the U.S. Greenhouse and Nursery Production		Gómez, M.
2011-17	Evaluating the Impact of the Fruit and Vegetable Dispute Resolution Corporation on Regional Fresh Produce Trade among NAFTA Countries		Gómez, M., Rizwan, M. and N. Chau
2011-16	Does the Name Matter? Developing Brands for Patented Fruit Varieties		Rickard, B., Schmit, T., Gómez, M. and H. Lu