Think Globally, Act Globally: Opportunities to Mitigate Greenhouse Gas Emissions in Low- and Middle-Income Countries

Rachel Glennerster and Seema Jayachandran

Rachel Glennerster is Associate Professor of Economics, University of Chicago, Chicago, Illinois. Seema Jayachandran is Professor of Economics and Public Affairs, Princeton University, Princeton, New Jersey. Their email addresses are rglennerster@uchicago.edu and jayachandran@princeton.edu. We thank Jonathan Colmer, Rebecca Dizon-Ross, Elspeth Kirkman, and Rob Stavins for helpful comments and discussion; Erik Hurst, Nina Pavcnik, Tim Taylor, and Heidi Williams for valuable editorial guidance; and Meghana Mungikar and Juliana Sanchez Ariza for excellent research assistance.

Most environmental externalities are, to some degree, local. Conventional air pollutants in India or China primarily affect people living in those countries, even if a small part of the pollution reaches the United States.

Climate change is unusual in that it is a truly global externality: A ton of CO_2 emissions, or emissions of other greenhouse gases like methane and nitrous oxide, adds to the Earth's atmospheric levels of these gases, regardless of whether it was emitted in the United States or Spain or Kenya. The global nature of the problem makes it harder to solve, because a large share of the costs of worsening climate change are borne by those outside the borders of the emitting country. Moreover, while climate change will touch all countries, the effects will be uneven. Low- and middle-income countries are expected to be hardest hit, partly because of their geography – many are in already-hot regions, so warming leads to dangerously high temperatures – but also because livelihoods are more fragile, and the options for coping with climate change, from air conditioners to flood barriers, are often out of their financial reach.

However, the global nature of this externality also offers an opportunity. Because global atmospheric CO_2 decreases by the same amount whether a ton of emissions is reduced in the United States or Spain or Kenya, countries (or other actors) who want to reduce emissions of carbon dioxide and other greenhouse gases can seek the most cost-effective ways to reduce emissions anywhere in the world, not just within their borders.

This approach has not yet taken hold: The vast majority of mitigation takes place within the funders' borders, resulting in mitigation activity that is highly concentrated in a few countries, which is unlikely to be efficient. Climate financing for mitigation in Western Europe is $105 billion compared to $30 million in South Asia (Buchner et al., 2021) despite substantially higher population and land area in South Asia.[1] This imbalance exists despite provisions in the Kyoto Protocol, the 1997 international climate treaty, and the Paris Agreement, the 2015 climate treaty, for countries to meet their emissions targets by funding mitigation activity abroad.

In this article, we will argue that many of the most cost-effective opportunities for mitigation — that is, reduction in atmospheric CO_2 levels — are likely to be in low- and

[1] Mitigation funding is more concentrated than greenhouse gas emissions. Western Europe emits 3.1 billion metric tons of CO2e per year, which is 35 percent less than the 4.8 billion metric tons a year emitted in South Asia (Ritchie et al., 2023), but as we discuss below, emissions and mitigation being geographically aligned should not be the objective. Emissions of greenhouse gases other than CO2 are converted into their CO2-equivalent (CO2e) weight. Western Europe refers to Andorra, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and Vatican City and South Asia refers to Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka to match the categorization used by Buchner et al. (2021).

middle-income countries. The implication of this reasoning is that high-income countries, as well as multilateral agencies and philanthropists, could and should be tapping opportunities in low- and middle-income countries to achieve more mitigation for a given level of spending.

The Paris Agreement set a target of limiting global temperature rise to less than 2.0°C above pre-industrial levels, while positioning 1.5°C of warming as the preferable goal. Climate scientists have warned of dire consequences if the more ambitious 1.5°C target is not met because any additional warming brings the planet closer to catastrophic tipping points such as the collapse of Greenland's ice cap (Hoegh-Guldberg et al., 2019; Armstrong McKay et al., 2022). Under the Paris Agreement, countries set so-called "nationally determined contributions," which are their targets for greenhouse gas emissions, but there are large gaps between these current targets and the emissions cuts required to limit global warming to 1.5°C by 2030 (UNCC, 2021).

The UN Environment Programme (2021) estimated that staying below 1.5°C will require a 55 percent reduction in greenhouse gas emissions – or almost twice as much as the 30 percent cut needed for 2°C of warming (UNEP, 2021). What is needed to double, or at least dramatically increase, the amount of mitigation? Larger financial commitments from the world's governments are surely needed, but we must also search for and fund the most cost-effective sources of mitigation. If we could shift funding to mitigation projects that are twice as cost-effective as what we are currently doing, that would effectively double the impact of the funding that is raised.

Who should pay for carbon mitigation and where that mitigation is most efficiently conducted are two separate questions. Unfortunately, focus on the "who should pay" question has often obscured clear-eyed discussion of "where is the reduction most efficiently conducted," which is the primary subject of our article.

In this essay, we begin by introducing an "abatement cost curve," which shows that there are likely to be a range of ways for reducing carbon emissions across sectors and countries. We then turn to four reasons that climate mitigation in low- and middle-income countries is economically attractive: 1) many of the easiest and cheapest options to reduce greenhouse gas emissions have already been tapped in high-income countries; 2) immobile inputs that are used in mitigation projects, namely land and labor, are cheaper in low- and middle-income countries; 3) it is cheaper to build mitigation into new infrastructure in low-and middle-income countries than to retrofit existing infrastructure in high-income countries; and 4) general equilibrium considerations imply that a geographically balanced approach to mitigation across both high-income countries and low- and middle-income countries is needed. We also discuss forces pushing in the other direction—that is, reasons that carbon mitigation might be cheaper in high-income countries.

Although our focus in this essay is about where carbon mitigation should be conducted, the question of who shall pay cannot be sidestepped. High-income countries are responsible for most of the carbon already emitted as a result of human activity. Even today, after growth of economies and carbon emissions in places like China, India, and Indonesia, the richest 10 percent of the world is still responsible for about half of the world's greenhouse gas emissions. In addition, high-income countries have greater resources to pay for mitigation. However, a rapidly rising share of global emissions going forward will come from middle-income countries, as high-income countries' policy-makers point out. Thus, they argue that these countries should also bear some cost of and responsibility of action on their part. Here, we will not seek to advance these well-rehearsed arguments about how much high-income countries should pay for mitigation. However, we will explore some of the broader ethical and practical policy arguments for how actions and/or payments by high-income countries to mitigate carbon emissions might, on grounds of addressing a major environmental hazard more effectively, be usefully focused on low- and middle-income countries.

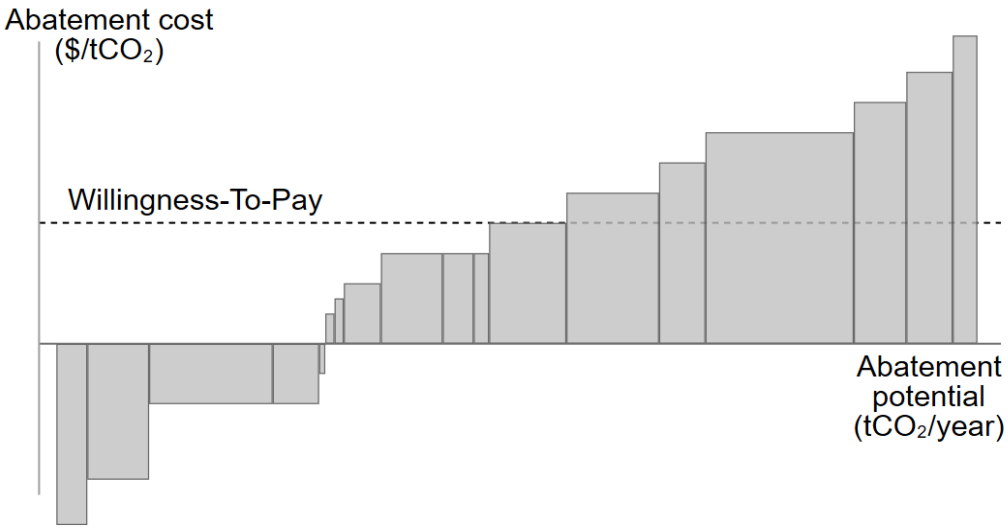
The Abatement Cost Curve

There are myriad greenhouse-gas-emitting human activities, which means that there are also myriad opportunities to reduce emissions. An abatement cost curve depicts the various available opportunities to reduce, or abate, greenhouse gas emissions, depicting the cost and size of each opportunity. We will refer to the abatement cost curve to help explain the different reasons there are low-cost mitigation opportunities in low- and middle-income countries.

In the abatement cost curve in Figure 1, each bar represents an activity that could reduce greenhouse gas emissions, such as reforesting deforested land or adopting hybrid vehicles (to displace gasoline-engine vehicles). While typically these activities are not delineated by location on an abatement cost curve, for our purposes, it is useful to sometimes think of separate bars for the same activity but in different locations, such as reforestation in high-income versus low- and middle-income countries.

The units along the horizontal axis of the figure are the feasible amount of abatement, often expressed in metric tons of CO_2-equivalent (tCO2e) per year—so that actions to reduce other greenhouse gases like methane and nitrous oxide can be shown on a common scale with carbon emissions. The width of a bar represents how large of an opportunity that activity represents; wider bars could achieve more of the mitigation that the world needs. The vertical axis is the cost per metric ton of carbon-equivalent for the

Figure 1: An abatement cost curve for greenhouse gas emissions



activity. The taller the bar, the more expensive that abatement cost. The bars are ordered by their height, with the lowest cost options on the left. The graph stops at some point on the right, ignoring other, more expensive options beyond those depicted. Some bars in our stylized abatement cost curve have a negative cost, which means they would save people money if they undertook them. Replacing incandescent light bulbs with LEDs bulbs is a classic example; although it requires some upfront money to buy and install the LEDs, they are more energy-efficient, so the savings in electricity bills more than covers the initial investment cost.

An abatement cost curve is a supply curve, and to see the equilibrium on the graph, one needs to overlay the demand curve. If the world were willing to pursue all projects up to a certain cost, the demand curve would be a horizontal line at that level – the willingness to pay – on the vertical axis. All the bars shorter than the willingness-to-pay – those to the left of where willingness-to-pay intersects a bar – would be implemented in equilibrium.

The abatement curve depicted here is a global one, but if we created different curves for different groups of countries, the bars for a particular activity would differ in width across countries because the composition of emissions varies across countries. Table 1 compares greenhouse gas emissions by sector for categories of countries with levels of per capita

Table 1: Breakdown of greenhouse gas emissions by sector, separately by income group

Sector	High income countries	Upper-middle income countries	Lower-middle income countries	Low income countries
Electricity and heat	33.0%	38.4%	23.1%	2.6%
Transport	24.5%	10.4%	10.2%	5.1%
Industry, manufacturing, and construction	12.9%	19.9%	13.8%	6.4%
Buildings	9.1%	4.9%	5.4%	3.4%
Aviation and shipping	5.9%	1.3%	0.7%	0.5%
Fugitive emissions	5.1%	8.3%	5.4%	3.3%
Waste	2.6%	3.2%	4.4%	4.6%
Other fuel combustion	1.1%	1.4%	1.2%	0.8%
Agriculture	7.4%	9.4%	18.9%	47.9%
Land-use change and forestry	-3.5%	-2.1%	14.8%	24.8%
Total	*100%*	*100%*	*100%*	*100%*

Notes: Ritchie et al. (2020). Fugitive emissions are leaks from pipelines, wells, appliances, storage tanks, pipelines, wells, or other equipment.

income, as defined by the World Bank for 2023: high-income countries (>$13,205 in per capita GDP), upper-middle-income countries ($4256 to $13,205), lower-middle-income countries ($1,086 to $4255), and lower-income countries (<$1085), and lower-income countries. The differences are stark. One-third of emissions in high-income countries come from electricity and heating, compared to less than 3 percent in low-income countries. Transport, including aviation and shipping, are much bigger contributors in high-income than in middle-income countries, and especially than in low-income countries where car ownership and usage are much lower. Meanwhile, land use change and forest loss are a major component of emissions in low and lower-middle-income countries, but not elsewhere. Similarly, agriculture is a major carbon-emitting sector only in low and lower-middle income countries.

We now turn to the four reasons for low-cost options in low- and middle-income countries.

Reason #1: The Easiest and Cheapest Options Have Already Been Tapped in High-Income Countries.

One reason for the mitigation bargains in low- and middle-income countries is that some cheap opportunities that are already being pursued in high-income countries remain untapped in low- and middle-income countries. Here, we discuss three economic drivers to explain this pattern.

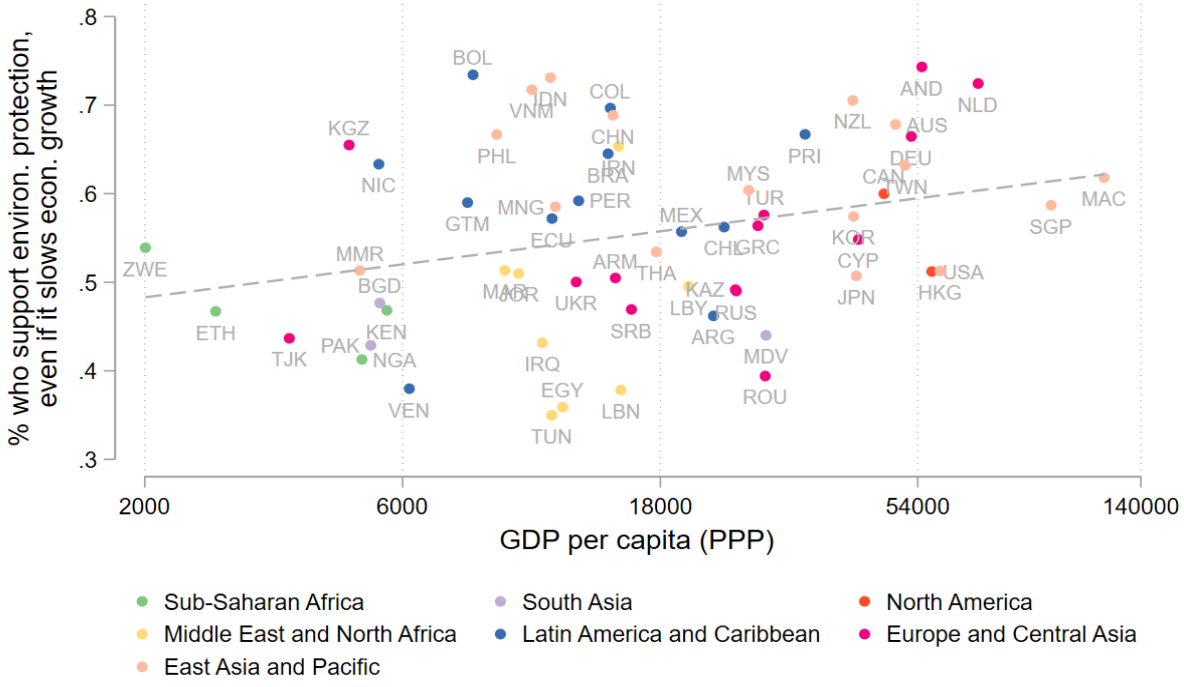
Differences in Willingness-to-Pay

We would expect households and governments in low- and middle-income countries to have a lower willingness to pay for carbon mitigation than their counterparts in high-income countries. Governments and citizens in low- and middle-income countries will—understandably — prioritize spending on basic needs and promoting economic growth, which could raise their relatively low standard of living, over contributing to the global public good of protecting the planet's health.

Survey data suggests that environmental protection is a tougher tradeoff to make in low- and middle-income countries. The World Values Survey asks a representative sample of adults in many countries about their social, economic, political, and cultural values every few years. One question on the survey asks respondents which of the two statements better reflects their view:

> 1. Protecting the environment should be given priority, even if it causes slower economic growth and some loss of jobs.

Figure 2: Cross-country comparison of attitudes about environment-growth tradeoffs



Notes: Data are from the World Values Survey, Wave 7, collected between 2017 and 2022. GDP per capita is for the specific country's survey year and is based on purchasing parity power and expressed in 2022 USD.

2. Economic growth and creating jobs should be the top priority, even if the environment suffers to some extent.

Figure 2 plots the average responses, by country. The vertical axis is the proportion of people choosing the first, pro-environment position. The horizontal axis is the country's real GDP per capita. While there is a lot of variation unexplained by GDP per capita, support for protecting the environment, even when it slows growth and causes job loss, indeed tends to be higher as income rises.

In the context of the abatement curve in Figure 1, if willingness-to-pay has historically been lower outside of the high-income countries, then the marginal opportunity for abatement in low- and middle-income countries will be lower-cost than its counterpart in high-income countries. Or to put it another way, some of the abatement opportunities that remain in

low- and middle-income countries are less expensive than the best remaining opportunity in high-income countries.

One example is decommissioning coal-fired power plants in favor of cleaner power generation. The share of electricity generation from coal has fallen steadily in high-income countries over the past few decades but has grown, or at least not fallen, in middle-income countries. In 2021, 19 percent of electricity generation was from coal in high-income countries, versus over 45 percent in middle-income countries (Ritchie et al., 2022). In the US economy, this transition occurred partly because natural gas, a cleaner fossil fuel, became cheaper, but also because renewable alternatives became cheaper. Funding at least the start of a transition away from coal in low- and middle-income countries is a low-cost abatement opportunity, in part because of the dirty starting point. Relatedly, funding wind or solar power might be a more cost-effective way to reduce emissions in India – where 74 percent of electricity generation uses coal – than in the US, partly because renewables would typically be displacing a dirtier energy source in India, leapfrogging over natural gas.

However, differences in willingness to pay across countries still leave a puzzle: Why would any country not take advantage of the negative-cost opportunities for abatement? One possibility is that the cost estimates are wrong: for example, such estimates often omit policy implementation costs, like those related to new regulatory apparatus that is needed, as well as political costs. Nonetheless, there very likely are profitable opportunities that have not been pursued. Two answers to the puzzle of why they have not been pursued are limited access to capital and limited regulatory capacity, as we elaborate in the rest of this section. However, both of these explanations also suggest that low- and middle-income countries will have more negative-cost abatement options than high-income countries.

Limited Access to Capital

Mitigation opportunities often entail upfront costs, with the savings that cover those costs accruing over time. The cost of borrowing is higher for low- and middle-income country governments, mostly because the perceived risk of default is higher. Similarly, households in low- and middle-income countries have less access to capital because the financial sector is less developed.

Methane capture from landfills is an example where upfront spending could be recouped over time--in this case, via an income stream. Landfills generate methane, a greenhouse gas, as organic material decomposes. If no measures are taken to manage the methane, it escapes the landfill and adds to atmospheric greenhouse gas levels. Landfill gas is responsible for 2 to 4 percent of total greenhouse gas emissions worldwide (Markgraf 2016). But the release of the methane can be suppressed, for example by covering the

waste with a thin layer of soil or plastic each night. If a methane capture system is installed, the landfill gas can be captured and converted to electricity. Installing the system requires upfront spending, and the payoffs come over time via the income stream from the electricity. The profitability of such an investment will depend on whether the borrower has access to sufficient capital at a low enough interest rate. One projection estimates that the adoption of landfill methane capture in 70 percent of the world's landfills would have an initial cost of around $35 billion and then would subsequently avert 2.2 billion tCO2e by 2050 (Hawken 2017), implying a cost of roughly $22 per tCO2e, after accounting for time discounting. (For comparison, the world emitted 55 billion tCO2e in 2021, and the US Environmental Protection Agency estimates the economic and social benefits of mitigation are $51 per tCO2e averted.) Almost all of the untapped opportunity to fix highly-emitting landfills is in low- and middle-income countries (Maasakkers et al., 2022).

Another example of this phenomenon, at the household level, is adoption of energy-efficient cooking stoves. Berkouwer and Dean (2022) find that many households in Kenya do not adopt more energy-efficient stoves that reduce emissions and save the user money from fuel costs because they are credit-constrained. For a new energy- efficient stove that reduced charcoal use by 39 percent and saved households $237 from reduced charcoal use over its two-year lifespan, the average willingness to pay was only $12, which partly stems from a low ability to pay. Being offered a loan doubled the willingness-to-pay. Note that credit is not the only barrier: surely, there are other factors like inertia. This pattern of not adopting energy efficient options has been called the "energy paradox" and is seen in high-income countries, too (Gerarden et al., 2017).

Weak Regulatory Capacity

While estimates often suggest methane capture is a negative cost opportunity, adoption in high-income countries has often come about only when required by regulations. The fact that landfill operators were not adopting these technologies out of self-interest suggests several possibilities. For example, perhaps there is a lack of arbitrageurs who are willing to try to bridge the gap between landfill companies and electricity grid companies. Another possibility is that landfill methane capture is not actually a negative cost opportunity (or at least not in all circumstances), but if environmental benefits are taken into account, it could still be a positive step for social welfare.

Lack of regulatory infrastructure might also explain why some truly negative-cost options are not being adopted. An opportunity might be negative-cost when all parties' costs and benefits are included, yet stymied by agency problems. Agency problems arise if the individual who makes the decision to invest and incurs the upfront costs is not the one who enjoys the cost savings that later accrue. For example, high-quality insulation in a home would save on heating and cooling bills, but builders might underinvest if they do not

internalize the interests of the homeowner. Similarly, a landlord will not have an incentive to invest in weatherization of a rental unit if their tenants pay the energy bills. In theory, if these investments could be verified, the builder or landlord could recoup the investment through a higher selling price or higher monthly rent. But if the investments cannot be verified easily, or if homebuyers and renters are inattentive to them when they make decisions, regulation can be helpful in achieving the socially efficient outcome. In such cases, regulation essentially requires one agent to behave in the way that is aligned with the other agent's financial interests.

For the case of landfills, landfill operators could be required to use a covering over the waste or to install landfill gas capture systems. For this to be a viable way to change behavior, the government needs to have the capacity to enact the regulation, monitor compliance, and punish those not in compliance. However, regulatory capacity is often limited in low- and middle-income countries (Besley and Persson 2009). In particular, when the sector that needs to be regulated is diffuse, with many different actors to monitor, it might be a major challenge. But for concentrated sources of emissions, it seems feasible for many middle-income countries to take at least some steps to strengthen regulatory capacity. For example, Duflo et al., (2013) evaluated a successful regulatory reform in Gujarat, India, that disallowed industrial plants from choosing their own pollution inspectors, introduced auditing of the inspectors' work to check if their reports were accurate, and paid inspectors based on their accuracy. The intervention reduced by 80 percent the likelihood that inspectors falsely reported that noncompliant plants were compliant.

Thus, one investment opportunity is to fund the regulatory infrastructure that would enable more low-cost mitigation. Funding is also useful for lessening the political resistance to regulation. For example, funds could be used to help defray firms' costs to upgrade their plants to be in compliance, so that their profits take less of a hit. Compensating firms would raise the project's costs, but in some cases, these projects would still be bargains, when taking a global perspective.

Reason #2: Lower Opportunity Costs of Inputs in Low- and Middle-Income Countries.

The cost of mitigation in different countries will depend on the opportunity cost of the inputs used to achieve the mitigation. Where production of the abatement technology is intensive in inputs that are either sufficiently mobile that prices are similar across countries (for example, minerals) or particularly scarce and higher-priced in low- and middle-income countries (like capital and highly skilled labor) there may be no advantage in locating the mitigation in low- and middle-income countries. For example, forms of carbon capture

from the air that are intensive in capital and highly skilled labor may be best located in high-income countries, where these factors are more abundant (Wilberforce et al., 2021).

However, many important mitigation opportunities have a high intensity of immobile factors which have lower absolute prices in low- and middle-income countries because the opportunity cost of their use is lower. In particular, many mitigation investment opportunities require substantial inputs of land and unskilled labor, which can make the same type of mitigation activity less expensive in low- and middle-income countries than high-income countries.

For example, forest preservation and reforestation are intensive in land and unskilled labor. Many high-income countries have highly ambitious tree-planting plans as part of their net zero and biodiversity commitments: for example, the UK Chancellor announced plans to plant 30,000 new hectares of forest every year, while the European Union has announced plans to plant 3 billion trees by 2030. Both the economic and financial cost of reserving land for forest preservation or reforestation depends on the value of the alternative use to which this land would be put; for example, given that the main alternative use for forest land is agriculture, the opportunity cost depends on agricultural productivity per hectare in different countries.[2]

We consider three alternative approaches to estimating the economic and financial cost of forest preservation/reforestation by country. None of the approaches are without problems, but all suggest forest preservation/reforestation are between three and ten times more expensive in high-income countries than in low- and middle-income countries. Specifically, we compare cereal yields per acre, agricultural land rental values, and direct costs of forest preservation programs in different locations.

Cereal yields are a direct measure of the lost output if a hectare of land is moved from agricultural production to forest. As shown in Table 2, cereal yields per acre vary dramatically and are nearly ten times higher in New Zealand than the Democratic Republic of Congo. However, this difference overestimates the difference in opportunity costs of land, at least to some extent, because cereal production in New Zealand uses many more inputs (including fertilizer, capital, and high skilled labor) that also have opportunity costs.

An alternative measure of the opportunity cost of land is land rental values, which abstracts from differences in agricultural inputs between countries. In many low-income

[2] The economic cost is the output forgone from using the land for forest, while the financial cost is the monetary price that would have to be paid to preserve the land for forest which in turn reflects the return to alternative uses. In a perfectly competitive market the two would be equal.

Table 2: Cereal yields in Selected Countries and Regions with Forests (2020)

	Tons per hectare
Low and middle income countries with over 90 million hectares of forest	
Brazil	4.479
Indonesia	5.351
China	6.319
Democratic Republic of Congo	0.877
Low cereal yields but high forest coverage	
Liberia	1.065
Tanzania	1.651
Congo	0.883
Gabon	1.589
High income, high cereal yield	
United States	8.268
France	7.171
Germany	6.998
United Kingdom	6.967
New Zealand	8.728

Source: Ritchie et al. (2020).

Table 3: Rental prices of agricultural land

	Converted to 2020 US dollars	Ratio of US to other country's rental price
Ethiopia	$170.46	1.4
Malawi	$55.81	4.3
Tanzania	$72.74	3.3
England	$237.24	1.0

Source: Abay et al., 2021, Department of Environment, Food, and Rural Affairs, 2023, and IMF.

countries, land rental markets are distorted by challenges in land registration and collective land ownership, but they still tend to function better than land sales markets. Not all land is suitable for all mitigation purposes: desert land may be cheap but not suitable for forest preservation. Thus, we compare rental rates for currently productive agricultural land to lessen this concern, though we cannot eliminate it.

Abay et al. (2021) use data from the Living Standards Measurement Survey to estimate rental prices of agricultural land in selected sub-Saharan African countries. Mean prices (updated to 2020 US dollars) range from $56 per hectare per year in Malawi to USD $170 in Ethiopia, as shown in Table 3. In contrast, farm rents in the United Kingdom are $237 per hectare—that is, it is more than 4 times as expensive to rent agricultural land in the UK as in Malawi. This may well be an imprecise measure of the opportunity cost of using land in sub-Saharan Africa for reforestation/preserving forest because Africa's land rental markets are not very developed. We therefore turn to a third way of estimating the relative cost of reforestation/preserving forest in different countries which comes closest to the full cost of preservation, but for which less data is available.

The opportunity cost of forest preservation/reforestation is not just potential alternative uses for land, because it also requires labor to manage forests. Some of the labor is relatively low-skilled; other parts are higher-skilled. The most comprehensive comparator of the economic and financial costs of forest preservation/reforestation is therefore the direct cost of programs seeking to preserve or restore forests in different countries. Given the distortions in the market for land sales and the fact that creating forest reserves would often require displacing communities, a common approach to land conservation is to pay people to undertake conservation on their privately-owned land. This approach also mitigates concerns that current users of the land may not have sufficient say in decisions

on land sales or rentals, ensuring that they are getting sufficient compensation because they choose to voluntarily enter an agreement to preserve forests. To attract participants, the payments need to cover the person's costs to conserve, which includes lost income from the land and compensation for any labor. Jayachandran et al. (2017) found that offering households in Uganda just $28 per hectare a year not to cut down forest was successful in reducing deforestation by 50 percent, and with this program CO_2 emissions were avoided at a cost of $4 to $20 per metric ton (depending on assumptions). The similar Conservation Reserve Program, run by the US government, had a cost per metric ton of CO_2 avoided that was over 10 times as high as the Ugandan program (Claassen et al., 2008; Jayachandran et al,, 2017).

Although we have focused our discussion here on mitigation investments to protect or restore forests, these of course are not the only mitigation investments where the differential opportunity cost of land and labor are important determinants of mitigation costs. Solar farms and the water storage lakes associated with hydroelectric dams also have large land footprints (Lovering et al 2022 show ground mounted solar requires 5 times the land area per unit of energy produced as natural gas). While solar and hydro have important location restrictions (they need to be near large pools of electricity demand, which would otherwise be serviced by electricity generated by fossil fuels if they are to be cost-effective mitigation investments), these conditions are met in many low- and middle-income countries. Another example is enhanced rock weathering, a carbon capture technique that entails spreading crushed rock on fields. The technique requires land, labor, and access to mining residue, making middle-income countries well-positioned to implement it.

Reason #3: Build Green vs. Retrofit Green

Most of the infrastructural growth in the world will be in low- and middle-income countries in the coming decades. Infrastructure in these countries is at present relatively underdeveloped, plus population growth and urbanization will be faster in many of these countries. Indeed, three-quarters of the world's urban infrastructure that will exist in 30 years is yet to be built (Dasgupta, 2018). India, China, and Nigeria will alone account for about 35 percent of project urban growth by 2050 (UN DESA, 2018).

It is substantially cheaper to "build green" in low- and middle-income countries than to "retrofit green" in high income countries. The central reason is that the choice set is larger at the planning stage than after construction has occurred. At the planning stage, a builder has many options for achieving an energy-efficient goal that differ in cost, one of which is to temporarily ignore the goal and then plan to retrofit later. But when construction is

planned with energy conservation goals in mind, one of the builder's other options is very likely to be cheaper than retrofitting. After all, retrofitting involves an extra step of disassembly. Removing existing windows from a building and then replacing them with double-paned ones requires an extra step over installing the double-paned windows from the get-go. Indeed, retrofitting can sometimes even be more expensive than the entire cost of new construction, not just the extra costs to build green, because the decision-making about how to deconstruct and reconstruct sometime often relies on specialist knowledge to understand structural considerations (Cecconi et al., 2022).

One major opportunity is to reduce the need for air conditioning through so-called "passive cooling." Natural ventilation, plus choices about space configuration and building materials, can help maintain lower temperatures indoors when it is hot outdoors. This need would be great even without rising global temperatures, simply because demand for air conditioning increases with income. By 2050, energy demand from air conditioning is projected to be over 10 times the level in 2000, driven mostly by low- and middle-income countries (Isaac and Van Vuuren 2009). Another energy-saving opportunity that is easier to capitalize on at the initial building stage is to create a district cooling system that provides air conditioning to several interconnected buildings using a centralized cooling plant.

Building green versus retrofitting applies not just to buildings, but also other infrastructure such as transportation systems. The example of transportation infrastructure makes salient another cost of retrofitting, which is the disruption to people using the existing infrastructure. Constructing new public transportation in a crowded city often requires closures or causes slowdowns, plus displacement of business establishments and people. In contrast, in a nascent city, that infrastructure can be built with less disruption to existing patterns of life. One example of transportation systems being constructed in many cities is bus rapid transport, which involves a dedicated lane for buses so that they can travel rapidly even when regular lanes of traffic are jammed (Carrigan et al., 2013). Bus rapid transport has been especially popular in low- and middle-income countries. It reduces greenhouse gas emissions by displacing private vehicles and low-occupancy public transportation (like "matatus," which are privately owned mini-buses used as shared taxis), that may use older and more polluting fuels and vehicle technologies.

Reason #4: General Equilibrium Effects and the Benefits of Targeting

The integrated nature of the world economy means that action to mitigate carbon emissions in one country is likely to be partially muted by offsetting impacts in other countries. For example, if the extent of deforestation to produce palm oil in Indonesia or beef in Brazil declines, then the global price of these commodities will be higher than they

otherwise would have been, encouraging others to cut down forest to produce more palm oil and beef. These general equilibrium effects mean that the impact of mitigation may be less than a partial equilibrium estimate would suggest.

But even if general equilibrium effects mean a reduction in a harmful activity in one location is offset close to one for one by an increase in the same activity elsewhere (and evidence suggests it is not nearly so high), there can still be large gains from shifting an activity from a high to low carbon intensity location.

Palm oil production offers a good illustration: here we draw on Hsiao's (2022) detailed work on the carbon impact of palm oil, which represents 5 percent of all CO_2 emissions from 1990 to 2016. About five-sixths of the world's palm oil is produced in Malaysia and Indonesia. Some of the CO_2 emissions from palm oil production come from the destruction of the forests to make way for the palm trees. However, almost 90 percent of the emissions arise from the destruction of peat, which forms the first layer of soil under some parts of the forests. Refraining from palm oil production in the parts of Indonesia and Malaysia where the activity destroys peat would likely lead to some displaced deforestation; deforestation will occur elsewhere to meet the global demand for vegetable oil. But as Hsiao (2022) shows, production of the main alternative vegetable oils does not involve the destruction of peat: for example, growing more soybeans in Brazil. Thus protection of the forest in Indonesia and Malaysia that has peat would achieve 90 percent of its CO_2 benefit—even if it led to exactly the same amount of forest being cut down in another place—as long as that alternative forest did not have peat substrate.

Taking general equilibrium effects and displacement into account when prioritizing mitigation efforts, plus targeting mitigation efforts to geographic areas with high carbon costs compared to when the same activity is done elsewhere, requires global thinking. Because (relatively) climate-conscious high-income countries are more likely to have regulations against further destruction of areas with the highest carbon equivalent impact, and because high-income countries only represent roughly one-quarter of the Earth's land surface, it is unlikely that the big gains from this type of targeting strategy will occur within the borders of high-income countries.

The Economic Counterargument

Several economic factors push in the opposite direction to the reasons we have highlighted so far and suggest carbon mitigation in high-income countries will be potentially more cost-effective.

First, carbon emissions are higher per person in high-income countries, while low-income countries emit hardly any carbon at all. Some efforts to mitigate carbon emissions are most cost-effective when emission levels are high. For example, a US office building is typically kept at a lower temperature in summer than a comparable building in a poorer country. Insulating the US building has more payoff in reduced energy use, because the cooling use is more intense. The same reasoning applies more broadly to legal and regulatory change; for example, the reduction in carbon emissions that results from passing regulation to limit emissions from cars will be higher in countries with higher car ownership, all else equal.

Monitoring and enforcement, which are needed in a range of mitigation activities from payments for conservation to regulation, are more challenging in low- and middle-income countries. However, it is wise to be cautious about drawing strong conclusions here. People's perceptions of monitoring and enforcement of carbon mitigation actions in low- and middle-income countries are often formed from their knowledge of voluntary carbon "offset markets," (Bushnell 2010). These offset markets allow individuals in high-income countries to meet their carbon mitigation targets by, say, financing tree-planting in some low-income country. The carbon reductions from such offsets are indeed often dubious. But these offset markets are typically monitored by nongovernmental organizations with varying degrees of competence and limited checks on their over-claiming carbon benefits. Thus, the voluntary offset markets may not say much about the ability of governments in these countries to carry out monitoring and regulation of carbon mitigation efforts. However, one implication of this concern is that the returns to investing in high-quality, easy to implement monitoring of carbon mitigation action and outcomes may be high, a theme to which we return below.

Despite these counterarguments, we believe that for many important types of carbon mitigation, the costs are likely to be substantially lower in middle-income countries that already have relatively high and growing carbon emissions than in high-income countries, even when enforcement and lower carbon intensity are considered. This is particularly true for countries like China, India, Indonesia, and Pakistan, where climate warming emissions are on the rise, relatively cheap opportunities to reduce emissions have not yet been tapped, and policies and programs can be introduced at scale. While enforcement may not be as good as in high-income countries, the lower costs are likely to more than compensate for this.

For low-income countries, the calculus for costs of mitigation is somewhat different, because the quite low levels of energy use per capita in these countries can make it cost-inefficient to switch to renewables if there are fixed costs of switching. For example, when rural households in Kenya are subsidized to connect to the electricity grid they do move away from fuels like kerosene (which produces black carbon, a particularly damaging warming gas). However, the high fixed costs in linking households to the electricity grid and

very small quantities of energy used per household (both before and after) made the approach overall cost-inefficient (Lee et al., 2020). The small scale of land holdings in many low-income countries can also drive up the costs of getting access to sufficient land to undertake carbon mitigation investments at scale. However, land availability varies substantially by country, and as the Uganda payments-for-conservation example above shows, it is possible to introduce programs that involve large numbers of small farmers to achieve meaningful mitigation impacts.

The Ethical Counterargument

Consider two premises: 1) high-income countries are willing to commit substantial resources to carbon mitigation; and 2) our arguments that it is often more cost-effective to do carbon mitigation in low-and middle-income countries hold weight. It follows that if high-income countries were to transfer some of the resources they are already willing to spend to finance carbon mitigation in low- and middle-income countries, greater and faster progress on the important goal of carbon mitigation could occur. Such a scenario offers potentially large gains from trade, and thus scope for all nations to enjoy some of those gains.

A natural question then becomes how to assure that such policies are enacted with the consent of host countries, and certainly not carried out in a way that impoverishes or otherwise harms them. There are ethical arguments against this type of global marketplace for mitigation. Some of these critiques are based on the premise that there should not be market transactions for certain goods or services, or that such exchanges cannot be truly voluntary. We briefly discuss three ethical arguments against international trade in emissions reductions.

One objection to trading in environmental protection is that no one should be detached from the world's problems, sacrificing only with their money and not their time or convenience or physical comfort. Goodin (1994) likens paying to offset environmental damage to the medieval practice of purchasing "indulgences" from the Catholic church to have one's sins forgiven. Those with money have license to do wrong things (like carbon emissions) and then absolve themselves of blame through money. Sandel (2012) makes a related, consequentialist argument that trading in environmental protection may erode people's sense of caring about the environment, and in that sense prove ultimately counterproductive.

This concern is multifaceted. In conventional pollution control, firms in polluting industries buy permits from the government to operate, and few would argue that such a policy is unethical because it is nothing more than allowing them to spend money to absolve

themselves of blame. Likewise, it is firms with deeper pockets that can afford the pollution-abatement equipment required to meet regulatory standards. It is not clear why using one's financial resources to reduce pollution domestically is ethically acceptable, but then becomes unacceptable if it involves a payment to reduce pollution in another country. Moreover, we certainly do not envision that efforts to mitigate carbon pollution in high-income countries would be eliminated, only that some of the resources would have greater effect if spent in low- and middle-income countries.

In consequentialist terms, attempting to create a regime in which each person takes on the same personal sacrifice in non-monetary terms would come at a high cost. Given limited resources to spend on climate mitigation, such a rule would probably have the practical effect that less mitigation would take place. As discussed earlier, low- and middle-income countries are expected to be hardest hit by climate change—both by the temperature and weather effects, and also in their lower level of resources to address these consequences—and so less success in reducing CO_2 levels would be devastating for the global poor. In addition, by passing up on these opportunities, the global poor would lose their share of the gains from trade alluded to above.

A second concern about environmental markets questions how voluntary they are. For example, Satz (2010) questions whether exchange can be truly voluntary when one party is vulnerable or desperate, using a motivating example of a poor country that needs money for basic services so badly that it agrees to house toxic waste (with potential long-term consequences for health and productivity) in exchange for immediate payments from a richer country. Arguably, the injustice here is the poor country's lack of good options, not the exchange. Preventing low-income countries from making choices they believe are welfare-improving for them risks making them worse off. Moreover, this specific concern seems less applicable for the case of climate change mitigation, as most mitigation projects have positive co-benefits for low- and middle-income countries, such as reduced conventional air pollutant levels or perhaps technology transfer. These incidental benefits represent some of the gains from trade enjoyed by low- and middle-income countries — how they benefit from being the site of mitigation activity.

A third concern is that even if the exchange is voluntary for the party engaging in it—say, the national or local government—it might not be voluntary and beneficial for the many individuals who are affected. Governments might be corrupt. Politicians might personally benefit, while their constituents do not. Costs imposed on the most powerless in society, like indigenous groups, might be ignored. We view this argument as especially pertinent, and believe there is an obligation for the high-income countries to consider and openly discuss the distributional consequences of a mitigation project within low- and middle-income countries. While countries have sovereignty over their people, a high-income country should not lean on sovereignty to fund efforts that knowingly exacerbate poverty

or lead to other harms that might be done. Nor, however, should high-income countries be paternalistic and assume that people poorer than themselves cannot make rational choices. A practical way forward is to prioritize paying for mitigation in democracies with functioning land rights and other legal rights, where compensation mechanisms are more likely to work and exploitative behavior, if it occurs, is likely to surface.

Some Policy Implications

In this section we ask what policies should be pursued to capture the carbon reduction benefits available from investing a larger proportion of carbon mitigation financing in low- and middle-income countries. We discuss to what extent carbon pricing – specifically, a carbon border adjustment tax – would help encourage the switch in the location of mitigation activity (the answer is only partly). Second, we look at the practical steps that would be needed to implement the vision we have laid out, in which much more mitigation activity takes place in low- and middle-income countries.

Would A Carbon Border Adjustment Tax Encourage Efficient Allocation of Mitigation Activity?

Carbon pricing is often the economist's first-best solution to climate change challenges, and imposing a tax on greenhouse gas emissions (and credit for carbon storage activity) in all countries would help address some of the missed low-cost opportunities raised in this article. However, a universal carbon tax is a long way off from being a political reality, and the more realistic alternative, already under development in the European Union, is a carbon border adjustment tax. Under a carbon border adjustment tax, imports are taxed based on the carbon content of the product and the carbon pricing in the exporting country. The adjustment seeks to equilibrate the carbon price of domestically produced and imported goods, creating an incentive for mitigating actions in the exporting country. The tax discourages rich countries from specializing in greener industries and just outsourcing dirtier production to other, usually poorer countries.

There is a large economic literature on carbon border adjustment taxes, and we do not attempt to summarize it here (for a starting point, the interested reader might begin with Fontagné and Schubert (2023)). Instead, we point out that even if carbon border adjustment taxes were implemented by all high-income countries, this would not achieve the gains in reduced CO_{2}-equivalent emissions from thinking globally about emissions opportunities we discuss in this paper.

First, carbon border adjustment taxes require substantial information on the carbon intensity of the product, and thus are likely to only be imposed (at least initially) on a few products with high carbon intensity, such as steel.

Second, carbon border adjustment taxes will only encourage countries to engage in mitigation on production of goods destined for export to countries imposing such a tax. They create no incentives for mitigating action on products produced for domestic consumption or for export to countries that do not impose such a tax. Third, carbon border adjustment taxes provide no incentive for low- and middle-income countries to undertake mitigation actions that are divorced from production, such as forest protection, capturing methane from waste, or enhanced rock weathering.

Finally, while carbon border adjustment taxes are likely to produce positive carbon reduction gains, they could have negative distributional impacts—effectively making low- and middle-income countries pay for mitigating carbon. In comparison, if high-income countries spend their mitigation funds wherever in the world achieves the highest impact, and pay the full costs including appropriate compensation for local land and labor, such negative distributional impacts are far less likely to occur.

The Skeleton for a Workable System of International Carbon Mitigation Payments

Designing and enacting a workable system in which high-income countries redirect some of the resources they are allocating to climate change mitigation in their own countries to achieve a greater level of emissions in low- and middle-income countries is a substantial task. Here, we suggest four principles that could guide the design of such a policy.

First, the "nationally determined contributions" to carbon mitigation by each country must take into account mitigation efforts outside a country's borders. The current international climate agreements incorporate this principle, but much more work is needed to operationalize and encourage it. Countries have made commitments about how much they will reduce carbon emissions, as part of the Paris Agreement and subsequent United Nations Conferences of the Parties. However, such commitments are primarily framed around emissions within the country's territory only. Thus, the incentive – really a distortion – is for countries to focus on carbon mitigation at home.

Article 6 of the Paris Agreement sketches out the possibility of cross-border trade in mitigation, either bilaterally (Article 6.2) or through a yet-to-be-established centralized marketplace (Article 6.4). The provisions for bilateral arrangements implicitly focus on high-income countries, while the centralized marketplace, through which one party would finance and receive emissions credit for another party's mitigation project, has yet to be

established (Fattouh and Maino 2022).[3] Making the ideas sketched out in Article 6 a reality, with a focus on unlocking the currently-underfunded opportunities in low- and middle-income countries, should be a priority for international climate policymakers.

Second, verification and monitoring of mitigation efforts needs to be improved. Abatement projects purchased through the international marketplace need to truly reduce emissions to deliver on the promise of more mitigation for less money. The private-sector offset market mentioned earlier was meant to provide a transparent marketplace where different mitigation options around the world could be supplied, and buyers could invest in the most cost-effective ones wherever they were located. However, the market has limited credibility because of concern that the credits overstate the amount of mitigation genuinely generated by the projects. The Clean Development Mechanism, which was established under the Kyoto Protocol to enable high-income countries to invest in mitigation in low- and middle-income countries, suffered the same problem.

The key challenge is that credits are determined by comparing the actual carbon output with what would have happened otherwise. Both actual and counterfactual emissions are hard to estimate. This challenge is not specific to projects in low- and middle-income countries; it applies to any scheme that offers credit for investing in a mitigation project. But overcoming it is essential so that the marketplace is not giving high-income countries emissions credits for projects that would have happened anyway. A trustworthy intermediary that uses a rigorous standard when defining the counterfactual is a first step.

In addition, investment and innovation are needed to provide more objective, credible, and cheaper ways to monitor mitigation in low- and middle-income countries. For example, improved algorithms that use satellite data to construct more precise measures of the amount of carbon embodied in tree cover or other carbon-mitigating farming practices would be valuable. As development of these technologies are a global public good, they will be undersupplied by the private sector. Offering prizes for algorithms that can achieve these goals, which could then be made public, might be an efficient way to stimulate innovation in this area. While hard to operationalize, countries that invest in these innovations (or any other research and development that enables more cost-effective and larger-scale mitigation) ideally would receive credit for emissions reductions.[4]

[3] For example, the bilateral trade would be between countries that have set absolute mass-based targets for their emissions reductions relative to a reference year, most of whom are high-income.

[4] Investments in research and development to reduce carbon emissions can have high returns and, in general, are undersupplied both by the private sector and also governments seeking to achieve only their own climate targets. Ideally, the appropriate mitigation credit for an R&D investment would be calculated on the expected value of reduced emissions, so that funders do bear the risk that their particular R&D effort does not succeed, and do not avoid risky investments.

It is also worth encouraging bilateral arrangements between high-income and low- or middle-income countries. While there are advantages of a trusted intermediary certifying projects, in bilateral arrangements, countries would perhaps face more reputational damage if they claim credits for projects that do not deliver on actual emissions reductions or pursue projects that are exploitative of the local population.

Third, the anticipated local co-benefits of mitigation projects should be laid out explicitly, and then measured to the extent possible, to ensure that the low- and middle-income countries receive their fair share of the gains from trade. A political challenge to a robust international market for mitigation is that low- and middle-income countries may object to giving all the mitigation credit of a project funded by others, but within their borders, to the funding country. After all, they incur costs, perhaps to implement regulation or provide land. From an economist's perspective, the focus should be on how the gains from trade are shared rather than more narrowly on how mitigation credit is shared. The funding country could make financial transfers to the host country. There are also often incidental co-benefits, like reduced conventional pollution. Explicit accounting of the benefits for the low- or middle-income country, in whatever form they take, is important for ensuring that such arrangements are mutually beneficial.

Because such cross-border agreements would be voluntary, the low- or middle-income country's choice to participate means that it expects to be made better off by participating. But both parties being better off does not pin down how the gains from trade are split between them. Here, internationally agreed-upon guidelines that ensure an equitable split would be valuable. The potential surplus from cross-country mitigation agreements is large, so it should be possible to make participating in this type of exchange attractive for both funding and host countries.

Importantly, ensuring that the low- and middle-income participant receives a fair share of the surplus is different from the current Article 6 approach of requiring funders to contribute to a general adaptation fund whenever they fund mitigation projects in low- and middle-income countries. However well-intentioned, this "share of proceeds for adaptation" provision essentially taxes – and thus discourages – international trade in mitigation projects. Directing those proceeds specifically to the low- or middle-income country hosting the project would similarly shift financial resources from rich to poor countries, but without stifling international cooperation that could help the world achieve lower emissions.

Fourth, mitigation in low- and middle-income countries should not be treated as development aid. Currently, when high-income countries do fund mitigation projects in low- and middle-income countries, it is often thought of and counted as foreign aid. The justification is that there are co-benefits that accrue to the country where the project operates: for example,

switching from coal to solar electricity reduces local particulates which otherwise would damage local health.[5] But as long as mitigation in low- and middle-income countries is seen as aid, and not as a central part of high-income countries own effort to reduce emissions, it will always be small and fail to reflect the potentially large gains set out in this paper. Moreover, diverting aid budgets to mitigation risks reducing actual development assistance. The amount spent on a mitigation project is not a measure of the benefit to the low- or middle-income country. Only the increase in well-being in the low- or middle-income country, in the form of local environmental co-benefits or surplus from job creation, for example, constitute foreign aid to that country. This local surplus will often be modest relative to the total project budget because many of the project costs are to offset the host country's opportunity costs of participating in mitigation projects or to purchase inputs produced elsewhere. Most of the spending should be considered an investment in the global public good of climate change mitigation, not aid.

These questions of how to quantify (and who gets credit for) mitigation outside a country's borders, and whether it should be considered aid or not, may seem arcane, but they are the key to unlocking additional emissions reductions as high-income countries redirect some of their mitigation spending to the highest-return locations.

A Coda on Funding Adaptation

While our discussion has mainly focused on mitigation of carbon emissions, we close by touching on the role of high-income countries in funding adaptation to climate change in low- and middle-income countries (Fankhauser, 2017). The economic issues differ here. Mitigation efforts are a global public good: lower emissions in one part of the world help the rest of the world. In contrast, most efforts to help people adapt to climate change have their effects locally. A levee helps the community in which it is built. Food aid sent to a drought-stricken area helps people in that community cope. Thus, funding adaptation, unlike mitigation, in low- and middle-income countries is not a way for high-income countries to achieve their abatement goals faster or less expensively. Instead, it is a way to help the world's poor; many types of adaptation are squarely in the category of development aid.

However, some efforts to improve adaptation can represent, if not truly global public goods, at least cross-national public goods that could help in low- and middle-income

[5] On the one hand, local co-benefits are a reason to invest at home, to help one's own citizens. On the other hand, these co-benefits mean that investment in mitigation in low- and middle-income countries has a redistributive benefit.

countries at large. Aid agencies of high-income countries have an important opportunity to invest in these areas.

One example is research and development of technologies that facilitate adaptation. We have already noted that investment in technological innovation is undersupplied by the market and social returns from innovation have been estimated at twice the private returns (Aghion et al., 2013). The additional distortions in markets in low- and middle-income countries suggest that that innovation is even more undersupplied for their challenges (Kremer and Glennerster, 2004). Investment in climate-resilient crops offers an example. A large body of literature documents high returns to investments in innovation in agriculture in low- and middle-income countries: one meta-analysis suggests an average return of 100 percent a year (Alston et al., 2000). Other work has found that countries with agriculture that is more distant (biologically) from that found in high-income countries have experienced the least innovation in the past, suggesting substantial further innovation is possible (Moscona and Sastry, 2021). Finally, a randomized evaluation of the impact of introducing flood-tolerant rice (developed through the public research centers) showed a 10 percent increase in rice yields (Dar et al., 2013).

Social science research on behavior change could offer high returns, as well. Change is hard for people, and climate change will require people to change their habits and choices. Understanding how to encourage adoption of (say) the new drought-resistant seeds is essential. An example of how social science research can impact behavior change and technology adoption is the work on the drivers of health technology adoption which has arguably helped save millions of lives. As one example, the free mass distribution of anti-mosquito bednets has been estimated as reducing malaria deaths by four million in sub-Saharan Africa between 2000 and 2014 (Bhatt et al., 2015).

No amount of mitigation effort will avert climate change; climate change is already upon us. Thus, finding and pursuing the high-return opportunities for adaptation should also be a priority.

References

Abay, K. A., Berhane, G., Hoddinott, J. F., & Tafere, K. (2021). Assessing response fatigue in phone surveys: Experimental evidence on dietary diversity in Ethiopia (Vol. 2017). International Food Policy Research Institute.

Aghion, P., Van Reenen, J., & Zingales, L. (2013). Innovation and institutional ownership. *American Economic Review, 103*(1), 277-304. doi:10.1257/aer.103.1.277

Alston, J. M., Chan-Kang, C., Marra, M. C., Pardey, P. G., & Wyatt, T. (2000). A meta-analysis of rates of return to agricultural R & D. Retrieved September 19, 2022, from https://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/125334/filename/125335.pdf

Armstrong McKay, David I. et al. (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. Science377, eabn7950(2022).

Bhatt, S., Weiss, D., Cameron, E. *et al.* The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. *Nature* 526, 207–211 (2015). https://doi.org/10.1038/nature15535

Berkouwer, S. B., & Dean, J. T. (2022). Credit, Attention, and Externalities in the Adoption of Energy Efficient Technologies by Low-Income Households. *American Economic Review* 112(10).

Besley, T., & Persson, T. (2009). The Origins of State Capacity: Property Rights, Taxation, and Politics. *American Economic Review*, 99(4), 1218–1244.

Buchner, B., Naran, B., Fernandes, P., Padmanabhi, R., Rosane, P., Solomon, M., Stout, S., Strinati, C., Tolentino, R., Hithungo, W., Zhu, Y., Meattle, C., & Guzman, S. (2021). *Global landscape of climate finance 202*1.

Bushnell, J. B. (2010). The Economics of Carbon Offsets, National Bureau of Economic Research Working Paper No. 16305.

Carrigan, A., King, R., Velásquez, J.M., Duduta, N., & Raifman, M. (2013). Social, Environmental and Economic Impacts of Bus Rapid Transit. World Resources Institute policy report.

Cecconi, F., Khodabakhshian, A., & Rampini, L. (2022). Data-driven decision support system for building stocks energy retrofit policy. *Journal of Building Engineering*, *54*.

Claassen, R., Cattaneo, A., & Johansson, R. (2008). Cost-effective design of agri-environmental payment programs: US experience in theory and practice. *Ecological economics*, 65(4), 737-752.

Dar, M., de Janvry, A., Emerick, K. et al. Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefitting socially disadvantaged groups. *Sci Rep* 3, 3315 (2013).

Dasgupta, A. (2018). IPCC 1.5° Report: We Need to Build and Live Differently in Cities. https://www.wri.org/insights/ipcc-15deg-report-we-need-build-and-live-differently-cities

Department for Environment and Rural Affairs (2023). Farm Rents England 2021. https://www.gov.uk/government/statistics/farm-rents/farm-rents-england-2020#:~:text=For%20those%20agreements%20with%20a,to%20%C2%A3190%20per%20hectare. Downloaded on June 5, 2021.

Duflo, E., Greenstone, M., Pande, R., & Ryan, N. (2013). Truth-telling by third-party auditors and the response of polluting firms: Experimental evidence from India. *Quarterly Journal of Economics*, 128(4), 1499-1545.

Dupas, P. (2014). Short-run subsidies and long-run adoption of new health products: Evidence from a field experiment. *Econometrica, 82*(1), 197-228. doi:10.3982/ecta9508

Fankhauser, S. (2017). Adaptation to Climate Change. Annual Review of Resource Economics, 9(1), 209–230.

Fattouh, B., & Maino, A. (2022). *Article 6 and Voluntary Carbon Markets*. Oxford Institute for Energy Studies.

Fontagné, L., & Schubert, K. (2023). The Economics of Border Carbon Adjustment: Rationale and Impacts of Compensating for Carbon at the Border. *Annual Review of Economics*, *15*(1), annurev-economics-082322-034040.

Gerarden, T. D., Newell, R. G., & Stavins, R. N. (2017). Assessing the Energy-Efficiency Gap. Journal of Economic Literature, 55(4), 1486–1525.

Goodin, R. E. (1994). Selling Environmental Indulgences. Kyklos, 47(4), 573–596.

Hawken, P. (2017). *Drawdown*: *The most comprehensive plan ever proposed to reverse global warming.* New York: Penguin.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Guillén Bolaños, T., Bindi, M., Brown, S., Camilloni, I. A., Diedhiou, A., Djalante, R., Ebi, K., Engelbrecht, F., Guiot, J., Hijioka, Y.,

Mehrotra, S., Hope, C. W., Payne, A. J., Pörtner, H.-O., Seneviratne, S. I., Thomas, A., … Zhou, G. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science*, 365(6459).

Hsaio, A. (2022). Coordination and Commitment in International Climate Action: Evidence from Palm Oil, Princeton University working paper.

Isaac, M. and Van Vuuren, D. P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy policy*, 37(2):507–521.

Jayachandran, S., De Laat, J., Lambin, E. F., Stanton, C. Y., Audy, R., & Thomas, N. E. (2017). Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation. *Science*, 357(6348), 267-273.

Kremer, M., & Glennerster, R. (2004). *Strong Medicine: Creating Incentives for Pharmaceutical Research on Neglected Diseases*. Princeton University Press.

Lovering J, Swain M, Blomqvist L, Hernandez RR (2022) Land-use intensity of electricity production and tomorrow's energy landscape. PLoS ONE 17(7): e0270155. https://doi.org/10.1371/journal.pone.0270155

Lee, K., Miguel, E., & Wolfram, C. (2020). Experimental evidence on the economics of Rural Electrification. *Journal of Political Economy, 128*(4), 1523-1565. doi:10.1086/705417

Maasakkers, Joannes D., Daniel J. Varon, Aldís Elfarsdóttir, Jason McKeever, Dylan Jervis, Gourav Mahapatra, Sudhanshu Pandey et al. "Using satellites to uncover large methane emissions from landfills." Science Advances 8, no. 31 (2022): eabn9683.

Markgraf, C. (2016). Financing Landfill Gas Projects in Developing Countries. Published online at https://www.ccacoalition.org/en/resources/financinglandfill-gas-projects-developing-countries. [Online Resource]

Moscona, J., & Sastry, K. (2021). Inappropriate technology: Evidence from Global Agriculture. *SSRN Electronic Journal*. doi:10.2139/ssrn.3886019.

Parry, Ian, Peter Dohlman, Cory Hillier, Martin Kaufman, Kyung Kwak, Florian Misch, James Roaf, and Christophe Waerzeggers. 2021. "Carbon Pricing What Role for Border Carbon Adjustments?" IMF Staff Climate Note 2021/004.

Ritchie, H., Roser, M., & Rosado, P. (2020). CO_2 and Greenhouse Gas Emissions. Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-emissions' [Online Resource]

Ritchie,H., Roser, M., & Rosado, P.(2020) "Share of electricity production by source, Upper-middle -income countries". Published online at OurWorldInData.org. Retrieved from: 'https://docs.google.com/document/d/1mfxJ8Ljvm8HzZZKLhosU6NnLuBYcG6YNf4Q_ftB-S9c/edit?pli=1' [Online Resource]

Sandel, M. J. (2012). *What Money Can't Buy: The Moral Limits of Markets*. New York: Farrar, Strauss, and Giroux.

Satz, D (2010). *Why Some Things Should Not Be for Sale: The Moral Limits of Markets*. Oxford: Oxford University Press.

UNCC (2021). COP26 the Glasgow Climate Pact. Retrieved September 19, 2022, from https://ukcop26.org/wp-content/uploads/2021/11/COP26-Presidency-Outcomes-The-Climate-Pact.pdf

UN DESA (2018). 68 percent of the world population projected to live in urban areas by 2050, says UN. Retrieved September 19, 2022, from https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

UNEP (2021). Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered. http://www.unep.org/resources/emissions-gap-report-2021

US EPA, O. (2015). Overview of Greenhouse gasses [Overviews and Factsheets]. https://www.epa.gov/ghgemissions/overview-greenhouse-gasses

Wilberforce, T., A.G. Olabi, E.T. Sayed, KElsaid, and M. A Abdelkareem (2021). Progress in carbon capture technologies, *Science of The Total Environment*, 761.