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MAXIMIZING THE IMPACT OF CLIMATE FINANCE: FUNDING PROJECTS OR PILOT PROJECTS?

Matthew J. Kotchen

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ABSTRACT

This paper contributes to the understanding of how to maximize the impact of publicly provided climate finance to leverage the private sector. Agencies seeking to promote private investment in support of climate change mitigation and adaptation may have a choice between subsidizing projects or pilot projects. Pilots are either scaled down versions of full projects or an experimental phase that generates better information about whether a full project is likely to succeed or fail. Drawing on insights about the value of experimentation for entrepreneurship and raising private capital, the theoretical model developed herein provides guidance about when subsidizing projects or pilots is more efficient.

Matthew J. Kotchen
School of Forestry & Environmental Studies,
School of Management,
and Department of Economics
Yale University
195 Prospect Street
New Haven, CT 06511
and NBER
matthew.kotchen@yale.edu

1 Introduction

The term "climate finance" refers generally to public and private financing from regional, national, and international entities in support of climate change mitigation and adaptation. The need for efficient deployment of climate finance is on the rise. In December 2015, representatives from 195 countries signed the Paris climate agreement, reaffirming the goal of limiting the global average temperature to less than 2 degrees Celsius above the preindustrial level (Article 2, UNFCCC 2015). With the agreement having entered into force in April 2016, achieving the Paris goal—or even something close to it—will require fundamental changes to the world's energy systems, including the promotion of greater energy efficiency and the scaling up of zero- and low-carbon sources of energy (IPCC 2014). The financing required to achieve the transition—in addition to growing financial demands for climate change adaptation—will be substantial. The World Economic Forum (2013) estimates the need for $700 billion per year above and beyond the $5 trillion per year in business as usual infrastructure investment through 2030.

The actual amount of global climate finance that took place in 2014 is estimated at $391 billion (Buchner et al. 2015). Of this amount, $148 billion (38 percent) was from public sources, and $243 billon (62 percent) was from private investment. While a significant majority of climate finance is raised and spent within the same country, the developed countries have pledged to scale up their provision of climate finance in developing countries to at least $100 billion per year by 2020 (UNFCCC 2009, 2015). In addition to public and private financial flows through bilateral channels, several multilateral agencies focus explicitly on climate finance, including the Global Environmental Facility (GEF), the Climate Investment Funds (CIFs), and the recently created Green Climate Fund (GCF). Multilateral development banks themselves are also increasing their already significant emphasis on climate finance. In 2015, for example, the World Bank set the goal of increasing climate related finance from 21 percent of its portfolio to 28 percent by 2020 (World Bank 2015).

Along with the growing demand and supply of climate finance has come greater recognition that public sources of funding alone will be insufficient to meet the challenges of climate change. The proverbial Holy Grail of climate finance is finding new and effective ways to use public money to leverage larger pools of private finance in support of climate change mitigation and adaptation. Indeed, the goal of using public resources to leverage the private sector is explicit in most channels of climate finance, and serves as the basis of political pressure to mobilize more. There is nevertheless surprisingly little economic research on how to most efficiently deploy public resources to achieve this goal.[1]

This paper contributes to the understanding of how to maximize the impact of publicly provided climate finance to leverage the private sector. I consider the specific question of whether public money is more efficiently spent on subsidizing projects or pilot projects. I define pilots as an experimental phase prior to project execution where the primary objective is to generate better information about whether a full project is likely to succeed or fail. Many climate related investments, such as renewable energy projects in developing countries, are associated with a high degree of uncertainty, with reasons ranging from administrative feasibility to political stability, in addition to basic financial viability. An experimental phase in the form of a pilot project enables learning more about a project's likely success before committing to the full, and potentially much larger, investment. Public agencies seeking to promote private investment may therefore have a choice between subsidizing projects or pilot projects. This paper provides guidance about when subsidizing one or the other is more efficient.

The model builds upon the notion of staged investment within the literatures on entrepreneurship and venture capital (Sahlman 1990; Gompers 1995; Gompers and Learner 2004), and in particular on Nanda and Rhodes-Kropf's (2016) model

[1] I am not aware of any theoretical economic research on the use of public resources to leverage the private sector in the context of mobilizing climate finance. Two empirical papers that evaluate the effectiveness of climate finance to leverage the private sector in international development are Buntaine and Pizer (2014) and Kotchen and Negi (2015). More conceptually, Stewart, Kingsbury and Rudyk (2009) provide an edited volume that considers a number of regulatory frameworks and areas of need for international climate finance. More recently, Fischer (2016) develops a theoretical model for the study of climate finance as a strategic export subsidy that is subject to both external benefits and free riding.

of financing entrepreneurial experimentation. The primary point of departure is inclusion of a public sector that not only takes account of public, non-market benefits, but also has the ability to subsidize private sector investment. The model is useful for identifying necessary conditions for a pilot to provide social benefits above and beyond a project itself. These are based on intuitive relationships between the expected value of additional information and the costs of obtaining it. A somewhat counterintuitive result is that pilots create value because they may reveal bad information rather than good information about projects. The reason is that sufficiently bad information from a pilot creates an opportunity to abandon a full project without having to make the entire investment up front. Analysis of the model also shows how the opportunity to conduct a pilot can make the difference between whether or not an investment is socially desirable, thereby creating new opportunities for efficient climate finance.

The most novel findings of the paper relate to optimal subsidy policy. I show that the choice of subsidizing projects or pilots depends on the characteristics of both and, more importantly, on an institution's objective function. Agencies engaged in public climate finance may reasonably seek to maximize social net benefits on a case-by-case basis or, alternatively, to maximize the social benefits per unit of the subsidy (i.e., the benefit-cost ratio). The former objective is consistent with the standard benefit-cost criterion, while the latter is more consistent with the aim of agencies that seek to maximize the climate benefits of a chosen set of projects subject to a budget constraint. I find that agencies seeking to maximize social net benefits should target projects or pilots depending on the size of a project's social benefits. Specifically, pilots are preferable when the benefits are smaller, because in these cases the additional information from a pilot has the potential to change a project's desirability. If, however, agencies seek to maximize the benefits per unit of the subsidy, then there is a clear policy recommendation: subsidizing viable pilots rather than projects is always more efficient.

Theoretical results about how to maximize the impact of publicly provided climate finance are the central contributions of what follows. The next section further motivates the notion of pilot projects as experiments that provide information using a simple example. Section 3 describes the basic setup of the model from a private sector and planner's perspective. Section 4 derives necessary and sufficient conditions for pilot projects to have social value. Section 5 establishes the main results about optimal subsidy policy. Section 6 concludes with broader policy implications and suggestions for further research in the nascent area of climate finance.

2 Pilots as Experiments

When the outcome of a new venture is uncertain, experimentation can provide valuable information to entrepreneurs and investors because they can learn more about potential outcomes without having to invest the full amount up front. After learning the results of an experiment, investors may abandon ventures that are less likely to succeed and better sort good from bad investments without needing to fully commit all of the necessary resources. The importance of experimentation for entrepreneurship is well-established. Kerr, Nanda, and Rhodes-Kropf (2014) provide a detailed review of the literature and show the ways in which experimentation explains why entrepreneurial ventures succeed in different industries, regions, and periods of time.

The aim of this paper is to show how lessons about the financing of entrepreneurial experimentation can inform more efficient climate finance. Specifically, I extend the model developed by Nanda and Rhodes-Kropf (2016) to include a public sector and thereby account for decisions that agencies are likely to face when looking to promote private sector investment in climate change mitigation and adaptation. Agencies may have the option to choose between subsidizing projects or pilot projects. The key idea is that pilot projects have potential value because of the information they may generate rather than profits, and thereby function as experiments. The following example illustrates the basic setup and some key ideas without the formal structure of a model, which is developed in the next section.

Example.—Consider a private sector project (e.g., a renewable energy project) that will cost $\$11M$ to execute. There are risks associated with the project, perhaps due in part to its proposed location in a developing country. Assume the chances of success or failure are 50-50. With success the project would generate revenue of $\$20M$, and with failure the project would generate zero revenue. The expected value of the project is

$$(.5 \times \$20M) + (.5 \times 0) - \$11M = -\$1M. \tag{1}$$

From a private-sector perspective, therefore, the project would not proceed.

Now assume there is an opportunity to run a pilot project that would provide better information about the likelihood of success, without requiring a commitment to the full project. We can think of the pilot as an experiment because it provides information. Assume that good information would increase the probability of success to .8, and bad information would decrease the probability to .2. Assume further that the chances of good or bad information are 50-50, and the cost of running the pilot is $\$3M$. This amount represents the net loss after accounting for any revenue the pilot may generate. Because the full project would never be profitable with realization of the bad outcome, the expected value of the pilot along with the full project option is

$$.5 \times (.8 \times \$20M - \$11M) - \$3M = -\$.5M. \tag{2}$$

It follows that from a private-sector perspective, the pilot would not proceed either.

Let us now shift gears from the private to the public perspective. Assume the successful project would generate $\$4M$ in non-market benefits (e.g., avoided damages from emissions). The expected value of these non-market benefits from carrying out the project is $.5 \times \$4M = \$2M$, which can be added to (1) to yield the expected social value of the project itself at $\$1M$. The project is therefore *socially* desirable, even if not *privately* profitable, and a climate finance subsidy would be warranted. The expected value of the non-market benefits from the pilot with the project option is $.5 \times .8 \times \$4M = \$1.6$, which adding to (2) yields net social benefits of $\$1.1M$.

The question of interest here is whether resources from a public agency would be better spent subsidizing the project or the pilot project. The answer in this example is the pilot because it costs less to subsidize ($\$.5M$ versus $\$1M$) and yields greater social net benefits (by $\$.1M$). Notice, however, that this finding is not necessarily intuitive because it recommends subsidizing a pilot project that costs $\$3M$ to run when the expected loss from the project itself is only $\$1M$. Intuition might suggest this is a waste of resources.

I now turn to a more general model to help illuminate why pilots may be advantageous and to identify circumstances when public climate finance should seek to focus on subsidizing projects or pilot projects. I also consider how the optimal strategy depends on whether the objective is to maximize net benefits (as shown here) or the alternative of maximizing the benefit-cost ratio.

3 Model Setup

Let $\$X$ denote the cost to implement a project. If successful, the project will generate revenue $\$V$ and non-market social benefits $\$H$. If the project fails, both the revenue and non-market social benefits will be zero. The probability of success is p, and the probability of failure is $(1-p)$. There is also an opportunity to run a pilot, the value of which is primarily more information about the probability of success and failure. Running the pilot has a net cost of $\$Y$. "Good" information means the probability of a successful project is g, and "bad" information means the probability is b. The probability of good information from the pilot is q and bad information is $(1-q)$. The unconditional probability of success from the pilot with the project option must match that for the project itself, requiring that

$$p = qg + (1 - q)b. \tag{3}$$

It is clear from this expression that the conditional probabilities must satisfy $g \geq p \geq b$.

I begin with the expected values of the project and pilot from a private sector perspective. The expected value of carrying out the project itself (denoted with subscript P) is

$$E_P^V = pV - X. \tag{4}$$

Notice that the non-market social benefits are not taken into account. The pilot with the project option (denoted with subscript PP) has an expected private value of

$$E_{PP}^V = q \max\{gV - X, 0\} + (1 - q) \max\{bV - X, 0\} - Y. \tag{5}$$

The two max operators in this expression reflect the way that the project need only take place if it has a positive expected value conditional on learning the good or bad information, and each outcome is weighted by its respective probability. The expected value also accounts for the pilot's up-front cost Y.

The private-sector perspective reflected in expressions (4) and (5) is identical to Nanda and Rhodes-Kropf's (2016) model of entrepreneurial experimentation. In what follows, I highlight some new insights applicable to the private-sector perspective, but the main point of departure is the inclusion of social, non-market benefits and the focus on a public rather than private perspective. In order to provide a potential role for efficient intervention in the form of public climate finance, I focus on cases where the private sector would *not* undertake the project or pilot project on its own. Specifically, I assume the expected values to the private sector of the project itself and the pilot with the project option are negative.

The private sector assumption: Both $E_P^V < 0$ and $E_{PP}^V < 0$.

Let us now shift focus to the public perspective. To keep notation compact, let $W = V + H$ represent the combined private and public benefits. The expected value of the project itself from the social perspective is

$$E_P^W = pW - X. \tag{6}$$

In parallel, the expected value of the pilot with the project option from the social perspective is

$$E_{PP}^W = q \max\{gW - X, 0\} + (1 - q) \max\{bW - X, 0\} - Y. \tag{7}$$

The only difference between these expressions and those above is inclusion of H in addition to V.

I now turn to the question of when the pilot has positive social benefits in comparison to the project itself. The key feature of the setup is that even if the private sector assumption holds, it is still possible for (6), (7), or both to be positive. The conditions of particular interest, as we will see, are those when the pilot can have positive social value above and beyond the project, or even when the project itself does not.

4 The Value of a Pilot

Let us first consider the project itself. Whether a project has positive social value depends simply on whether (6) is greater than zero, keeping in mind that the private sector assumption implies (4) is less than zero.[2] Having established the project as the baseline, it follows that whether a pilot project has positive social value depends on two conditions: it must yield benefits that are both greater than those for the project itself and greater than zero. The second condition is necessary to allow for the possibility that the pilot may have positive value even

[2]Throughout much of the analysis and discussion that follows, statements about value are more accurately described as expected values. Nevertheless, I often drop the "expected" modifier assuming the meaning is clear.

though the project does not. Specifically, it must hold that (7) is greater than (6) and greater than zero.

We can immediately prove two necessary an intuitive conditions for a pilot project to have positive social benefits.

Necessary Condition 1: $g > b$.

To prove this inequality, assume to the contrary that $g = b$. Substituting (3) into (7) yields $E_{PP}^W = \max\{pW - X, 0\} - Y < E_P^W$, which contradicts the possibility of the pilot having positive net benefits beyond the project. This result shows how there must be something to learn from the pilot in order for it to have value. If not, then $g = b = p$, and there is no difference between the good and bad information, nor the probability of success when viewed through the pilot or the project itself. Hence there is no potential benefit of the pilot to justify its additional cost.

The second condition requires the bad information to be sufficiently bad.

Necessary Condition 2: $bW - X < 0$.

Consider again a proof by contradiction. Assuming $bW - X \geq 0$, means that (7) can be written as

$$\begin{aligned} E_{PP}^W &= q(gW - X) + (1 - q)(bW - X) - Y \\ &= [pW - X] - Y \\ &= E_P^W - Y \end{aligned}$$

where the second equality follows from using (3) and rearranging. This expression implies that $E_{PP}^W < E_P^W$, and hence the pilot will provide no additional value if conditional on the bad information, the project would still have positive net benefits. The reason is that the project would be socially beneficial with or without the pilot, in which case the pilot only entails additional cost without the potential to change a decision about the social desirability of the project.

Building on the previous discussion and necessary conditions, we can now state the following proposition.

Proposition 1 *The pilot will have positive net social value if and only if* $E_{PP}^{W} > \max\{E_{P}^{W}, 0\}$*, and this is equivalent to satisfying*

$$q(gW - X) - Y > \max\{pW - X, 0\}. \tag{8}$$

Notice that the left-hand side depends only on the expected value of the project conditional on good information from the pilot. This is because, as we have already shown, a necessary condition for the pilot to have positive social value is that the project would not be socially beneficial conditional on bad information. Indeed, the value of the pilot arises because the project can be abandoned without having to ever invest X if the information is bad.

To build further intuition and see the applicability of Proposition 1, it is useful to consider how the net social value of a pilot depends on the magnitude of the potential benefits. We can consider changes to either the private or public components, V or H, simultaneously, nesting the insights into the study of W, while ensuring the private sector assumption continues to hold. Using (8), the social net benefit of the pilot can be written as

$$NB_{PP} = q(gW - X) - Y - \max\{pW - X, 0\}.$$

Treating W as a variable, we can then rewrite the expression as

$$NB_{PP}(W) = \begin{cases} q(gW - X) - Y & \text{if } W \leq X/p \\ -(1-q)(bW - X) - Y & \text{otherwise} \end{cases}, \tag{9}$$

where the second line follows by substituting in (3) and rearranging.

Figure 1 illustrates the function graphically, along with the underlying expected values for the project and pilot evaluated at different levels of W, denoted $E_{p}^{W}(W)$ and $E_{pp}^{W}(W)$, respectively. The figure shows a case where Proposition 1

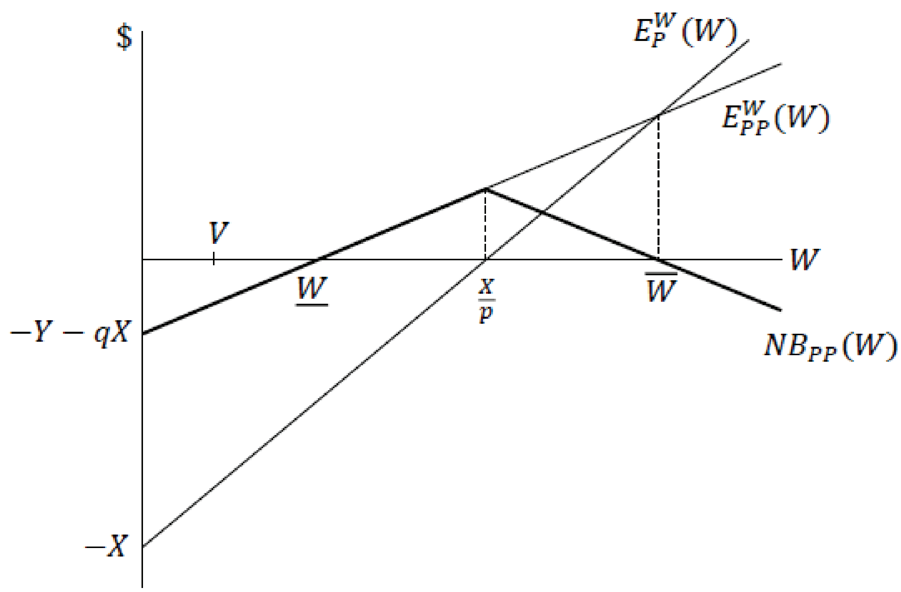

Figure 1: Graphical illustration of the expected values for the project, the pilot, and the net benefit of the pilot as a function of market and non-market social values

can be satisfied for some value of W. Neither the pilot nor the project have positive, net social value if $W \leq \underline{W}$. Keep in mind that satisfying the private sector assumption requires that $V < \underline{W}$. The pilot has positive, net social value and is preferable to the project if $W \in (\underline{W}, \overline{W})$.[3] Within this range, the net benefit of the pilot is simply the expected value of the pilot when the project itself has negative expected value; yet at sufficiently high levels of W, when the project has a positive expected value, the net benefit of the pilot is the difference between the expected values. The implication is that $NB_{PP}(W)$ is initially increasing in W, yet begins to decrease when the project itself has positive net social benefits. Then ultimately it is the project that has positive, net social value when $W > \overline{W}$.

Taken together, these results provide two general insights about the potential value of pilot projects from a social perspective. The first is that pilots only have greater net benefits over projects within a specific range of social benefits. Of particular interest is that part of this range is where projects themselves do not have positive, net social benefits. Hence the potential for conducting a pilot project can be pivotal for making a project socially desirable, even when neither the project or the pilot are beneficial from a private perspective. The second insight is that for projects with sufficiently high social benefits, pilots add no additional value to already sufficiently beneficial projects.

Let us now return to the assumption underlying Figure 1—that Proposition 1 can be satisfied for some value of W. It is straightforward to see from the figure that this requires $NB_{PP}(\frac{X}{p}) > 0$. Using (9), which follows from the fact that $NB_{PP}(\frac{X}{p}) = E^{W}_{PP}(\frac{X}{p})$, this inequality can be rewritten and interpreted as another necessary condition for a pilot project to have positive net social benefits.

Necessary Condition 3: $\dfrac{qg}{Y + qX} > \dfrac{p}{X}$.

The left-hand side is the ratio of the probability of project success to the expected cost of conducting the pilot with the project option. The right-hand side is the

[3]It is straightforward to solve for $\underline{W} = \frac{Y+qX}{qg}$ and $\overline{W} = \frac{(1-q)X-Y}{(1-q)b}$, assuming both values of W exist, as shown with the configuration of parameters in Figure 1 that allow for the possibility to satisfy Proposition 1.

ratio of the probability of project success to project costs, without the pilot option. Intuitively, we could multiply both sides by W to see that the condition requires the ratio of the expected social benefit to cost must be greater for the pilot in order for the pilot to have positive net social benefits. This condition is necessary but not sufficient because, as can be seen in Figure 1, the benefits W can still be too low or high to justify the pilot. Nevertheless, we will see in the next section how this condition is important for understanding optimal subsidy policy.

Before turning to subsidy policy, however, it is worth highlighting one more condition, which can be derived from Necessary Condition 3 and seen in Figure 1. We know from (3) that $p \geq qg$, so rearranging the previous condition yields the following.

Necessary Condition 4: $Y + qX < X$.

This implies quite simply that the expected costs for the pilot with the project option must be less than the costs for the project itself. This result is interesting because it underscores again how the value of the pilot arises because of the ability to abandon what might emerge as an undesirable project. Rearranging the condition as $Y < (1 - q)X$ shows how the pilot cost must be less than the expected cost savings from abandoning a bad project. Referring back to Figure 1, it is clear how lowering Y results in a vertical shift up of $NB_{PP}(W)$, thereby increasing the potential value of a pilot.

5 Optimal Subsidy Policy

The private sector assumption implies that the private net benefits of both the project and pilot are strictly negative. This means that a private sector entity would undertake neither without a strictly positive subsidy. The question of interest is which subsidy would a planner optimally choose—that for the project or pilot—and under what circumstances? The answer depends, as we will see, not only on features of the project and pilot, but also in an important way on reasonable variants of the planner's objective function.

The required subsidy for either the project or pilot is defined as the expected, net private sector loss. Assuming it is possible for the pilot to have positive net social value, these have the following magnitudes for the project and pilot project, respectively:

$$s_P = X - pV > 0 \tag{10}$$

$$s_{PP} = Y - q(gV - X) > 0. \tag{11}$$

It is straightforward to see in Figure 1 that a lower subsidy is required for the pilot than the project, because by assumption $V < \underline{W}$. More formally, we can derive the condition under which the required pilot subsidy is less than that for the project. Using (10) and (11), satisfying $s_P > s_{PP}$ is equivalent to satisfying $\frac{(X-Y-qX)}{p-qg} > V$, and it turns out that Necessary Condition 3 is sufficient to satisfy this inequality.[4] Hence we can assert that if Necessary Condition 3 holds, the pilot will always require a lower subsidy than the project. In other words, if the pilot has the potential to be socially desirable, it must require a lower subsidy. This, however, does not necessarily mean the planner should choose to subsidize the pilot. In what follows, I consider three cases that differ according to the objective function.

5.1 Net benefits with subsidy as transfer

Let us begin with the assumption that the planner seeks to maximize social net benefits and treats the subsidy payment as a transfer. This objective is consistent, for example, with the perspective of a country subsidizing pilots or projects for

[4] By Necessary Condition 4 (implied by Necessary Condition 3) and (3), the left-hand side is positive, so the condition will be satisfied if V is sufficiently small. We therefore need only show that the inequality is satisfied for the maximum value of V allowed by the Private Sector Assumption (i.e., $V = \underline{W} = \frac{Y+qX}{qg}$), in which case a bit of rearranging shows that the inequality simplifies to Necessary Condition 3.

which all benefits and costs accrue within its borders. In this case, the choice of whether or not to subsidize the pilot depends entirely on whether or not the pilot maximizes social net benefits, and the previous results carry over to inform the optimal subsidy policy.

Proposition 2 *If the objective is to maximize social net benefits, and subsidies are treated as transfers, then satisfying Proposition 1 is necessary and sufficient to recommend subsidizing the pilot.*

If we again consider how the results differ treating W as a variable, we can derive the optimal subsidy policy at different levels of the total benefits. The question is whether the planner would seek to subsidize the pilot, the project, or neither at different levels of W. The answer simply depends on which one yields the highest net benefits. Assuming the interesting case, where it is possible for the pilot to be preferred (i.e., all necessary conditions are satisfied), we have the following optimal subsidy policy:

$$s^* = \begin{cases} 0 & \text{if } W < \underline{W} \\ s_{PP} & \text{if } W \in [\underline{W}, \overline{W}] \\ s_P & \text{if } W \geq \overline{W}. \end{cases} \tag{12}$$

Referring back to Figure 1, this implies that the planner chooses net benefits consistent with $\max\{0, E_{PP}^W, E_P^W\}$ and the corresponding subsidy $\{0, s_{PP}, s_P\}$. Then, for the same reasoning described previously, the optimal policy is to provide no subsidy at sufficiently low levels of W, subsidize the pilot at intermediate levels of W, and subsidize the project itself at sufficiently high levels of W.

5.2 Public benefits with subsidy as cost

Let us now modify the objective function to one where the planner cares only about the public, non-market benefits and treats the subsidy payment as a cost rather than a transfer. This objective may more accurately capture the aim of international climate finance, where transfer payments are often made through bilateral or multilateral channels between countries. For example, country A may consider bilateral aid to country B for a renewable energy project, where country A faces an opportunity cost of the subsidy, and benefits from the avoided greenhouse-gas emissions globally. In this case, the subsidy is a cost and only the public benefits are of concern.

Interestingly, this change to the objective has no affect on the optimal subsidy policy. To see why, we can rewrite the modified net benefits as equivalent to the net benefits considered previously. The expected net benefits for the project are

$$\begin{aligned} pH - s_P &= pH - (X - pV) \\ &= pW - X \\ &= E_P^W, \end{aligned}$$

and the expected net benefits for the pilot (assuming the necessary conditions are satisfied) are

$$\begin{aligned} q\max\{gH, 0\} - s_{PP} &= q\max\{gH, 0\} - (Y - q(gV - X)) \\ &= q\max\{gW - X, 0\} - Y \\ &= E_{PP}^W. \end{aligned}$$

Because this implies no change from the case analyzed previously, we can state the following result:

Proposition 3 *If the objective is to maximize net benefits—defined as the difference between the public, non-market benefits and the subsidy cost—then satisfying Proposition 1 is necessary and sufficient to recommend subsidizing the pilot.*

A further corollary is that the optimal subsidy policy defined as s^* in equation (12) remains the same even with modification of the objective function.

The key element of these results is that subsidies are set at the minimum amount to cover private-sector losses. In the context of climate finance, this is often referred to as subsidizing, or co-financing, only the "incremental cost" necessary to get projects up and running.[5] Here financing only the incremental cost implies the useful equivalency. The subsidy is either an implicit cost through the private sector (the previous subsection), or an explicit cost to the planner (this subsection), while in both cases, the only remaining benefits are those that are public and non-market. Hence the optimal subsidy policy is invariant to either objective function.

5.3 Ratio of benefits to costs

The third and final set of objective functions to consider is one where the planner seeks to maximize a benefit-cost ratio rather than net benefits. In many respects, this objective may be the most closely aligned with that of many climate finance institutions. Instead of evaluating projects on a case-by-case basis, the objective of providing climate finance may be to choose a portfolio of initiatives that maximize climate benefits subject to a budget constraint. Indeed, this is central to the multilateral institutions of the GEF, the CIFs, and the GCF referenced in the introduction. The same can be said for domestic programs such as the U.S. Department of Energy's loan guarantee programs in support of clean energy projects.[6] In such cases, choosing the alternatives that have the highest benefit to cost ratio is central to implementing an optimal climate finance strategy.

Here again, however, the circumstances may dictate what should count as benefits and costs. Should the focus be on public and private net benefits while treating the subsidy as a transfer? Or should only the public benefits count with the subsidy as an explicit cost? The previous discussion shows how the former might apply when the full scope is domestic, while the latter when it is international. Nevertheless, arguments can be made in favor of either among the

[5] In practice, setting subsidies equal to the incremental costs poses a number of challenges owing to asymmetric information and potential adverse selection. The problem is one of mechanism design with similarities to those considered in the literature on payments for ecosystem services. For examples see Ferraro (2008), Jack, Kousky and Sims (2008), and Polasky, Lewis, Plantinga and Nelson (2014).

[6] See https://energy.gov/lpo/loan-programs-office.

range of institutions—governmental and non-governmental—that provide climate finance. Here I consider both possibilities.

Let us first define the ratio of public benefits to the corresponding subsidy, in parallel with the previous subsection. Because the subsidies remain set at the incremental value, there are no remaining private benefits. It follows that the project ratio can be written as

$$r_P = \frac{pH}{s_P} = \frac{pH}{X - pV},$$

and the pilot ratio as

$$r_{PP} = \frac{qgH}{s_{PP}} = \frac{qgH}{Y - q(gV - X)}.$$

Both ratios will be greater than one assuming the net benefits for the project and pilot are each positive, a requirement for potentially warranting a subsidy.

To compare the two alternatives, consider the question of when the pilot has a greater ratio. After a few lines of rearranging terms, it follows immediately that

$$r_{PP} > r_P \iff \frac{qg}{Y + qX} > \frac{p}{X},$$

which is simply Necessary Condition 3. Multiplying both sides by W, it is also a relationship between the ratio of all benefits to costs, treating the subsidy as a transfer, as in subsection 5.1. We therefore have an equivalence again, and can summarize the key results as follows:

Proposition 4 *If the objective is to maximize the benefit-cost ratio—defined as (i) the public, non-market benefits over the subsidy cost; or (ii) all social benefits to costs, treating the subsidy as a transfer—then satisfying Necessary Condition 3 along with* $W > \underline{W}$ *is sufficient to always recommend subsidizing the pilot over the project.*

Proposition 4 means that even if the pilot does not maximize net benefits, it can still maximize the ratio of benefits to costs. Moreover, when it maximizes the ratio of benefits to costs, it will also maximize the ratio of public benefits to subsidy costs. Importantly, the conditions underlying this result are also weaker than those for maximizing the net benefits: satisfying the necessary conditions from Section 4 are sufficient. In particular, with a focus on benefit-cost ratios rather than net benefits, it no longer holds that the project is preferred to the pilot at sufficiently high levels of the public benefits. Instead, there is a clear policy recommendation for the optimal provision of climate finance: it is always optimal to subsidize pilots rather than projects.

6 Conclusion

International efforts to address climate change are growing increasingly reliant on climate finance. A lesson from the run up to the 2015 Paris agreement was that many developing countries consider climate finance from developed countries as a quid pro quo for their own commitments to reduce emissions (Kotchen 2015). There is also growing demand in all countries to finance climate change resilience and adaptation, in addition to mitigation. Central to effective and efficient deployment of climate finance is the need to use public money to leverage significantly larger amounts of private investment, yet surprisingly little research has focused on how to accomplish this goal.

As an early contribution to what will surely be an emerging literature, this paper considers how to maximize the impact of publicly provided climate finance to leverage the private sector. The question of interest is one that many agencies already face: should they target subsidies towards projects or pilot projects, where the later provides better information about a full project's likely success? The model builds on Nanda and Rhodes-Kropf's (2016) setup for financing entrepreneurial experimentation, with the difference being the inclusion of a public sector. An important result is that the opportunity to conduct pilots can expand the set of socially beneficial, climate-related investments. The model also illustrates the somewhat counterintuitive scenario where it can be optimal to subsidize a pilot project that costs more than the subsidy needed for a project itself.

With respect to optimal subsidy policy more generally, the results differ in important ways depending on an agency's objective function. If agencies consider investments on a case-by-case basis with the goal of maximizing social net benefits, then decisions about whether to subsidize a project or pilot project depend importantly on the size of the non-market social benefits. In this case, pilots are preferred when the social benefits are lower because the information they reveal could lead to prudent abandonment of the project at an early stage. If, however, the agency seeks to maximize the benefits per unit of the subsidy, then the policy recommendation is to always subsidize the pilot rather than the project.

While the theoretical results of this paper provide useful guidance for more efficient, publicly provided climate finance, many opportunities for future research remain. For example, within the context of the base model, other topics that could be accounted for in future extensions include risk aversion, differences between private and public costs of conducting a pilot, and how the information revealed by a pilot may be endogenous to its costs. Additionally, given the importance of setting subsidies at their minimum (i.e., incremental) cost, further research would be particularly useful on mechanism designed in the deployment of climate finance to address problems of asymmetric information between the private and public sectors.

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