Journal of Environmental Economics and Management 92 (2018) 270–281

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Maximizing the impact of climate finance: Funding projects or pilot projects?☆

Matthew J. Kotchen [a,b,*], Christopher Costello [b,c]

[a] Yale University, New Haven, CT 06511 USA
[b] National Bureau of Economic Research, Cambridge, MA 02138 USA
[c] University of California, Santa Barbara, CA 93106 USA

ARTICLE INFO

Article history:
Received 25 June 2018
Revised 27 July 2018
Accepted 15 August 2018
Available online 3 October 2018

Jel codes:
G38
H4
Q58

ABSTRACT

When and how should public agencies provide finance to the private sector in support of climate change mitigation and adaptation? We distinguish theoretically between *pilot projects*, whose main objective is to obtain information about the desirability of a climate-related project, and *full projects*, which are at-scale and are often quite risky. When a successful project has distinct private and public benefits, a publicly-funded subsidy may be warranted to induce a pilot project, a full project, or both. We draw on insights about the value of experimentation for entrepreneurship and raising private capital to derive insights about when subsidizing projects or pilots is more efficient. We find that pilot projects have many virtues not previously examined, and these often render them the optimal target of public subsidies to the private sector.

1. Introduction

The term “climate finance” refers 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. Achieving global, national, and local mitigation and adaptation goals requires fundamental changes to the world’s infrastructure and 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 these transitions is substantial. Estimates indicate a need on the order of $700 billion per year above and beyond the $5 trillion per year in business as usual infrastructure investment through 2030 (World Economic Forum, 2013).

The actual amount of global climate finance that took place in 2016 is estimated at $383 billion (Buchner et al., 2017). Of this amount, $141 billion (37 percent) is from public sources, and $242 billon (63 percent) is from private investment. While a significant majority of climate finance is raised and spent within the same country, developed countries have pledged to scale up their spending that takes place 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 Environment 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

☆ We are grateful to Till Requate and two anonymous referees for comments and suggestions that significantly improved the paper. The authors have no conflicts of interest to report.

* Corresponding author.
E-mail addresses: matthew.kotchen@yale.edu (M.J. Kotchen), costello@bren.ucsb.edu (C. Costello).

https://doi.org/10.1016/j.jeem.2018.08.009
0095-0696/

on climate finance. The World Bank, for example, has 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. We are 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 (2015) and Kotchen and Negi (2016). More conceptually, Stewart et al. (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.

This paper contributes to the understanding of how to maximize the impact of publicly provided climate finance to leverage the private sector. We consider the specific question of whether public money is more efficiently spent on subsidizing full projects or pilot projects. We 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 full projects or pilot projects. Indeed, initiatives that promote pilot projects are commonplace in most development finance institutions.

We build upon the notion of staged investment within the literatures on entrepreneurship and venture capital in order to provide guidance about when subsidizing pilots or projects is more efficient.[1] In particular, we extend Nanda and Rhodes-Kropf's (2016) model of financing entrepreneurial experimentation. Our 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 in projects and pilots. The model is useful for identifying necessary conditions for a pilot to provide social benefits above and beyond a project itself. We show, somewhat surprisingly, that a pilot creates value because it may reveal that the project is likely to have a bad outcome, rather than a good one. The reason is that a sufficiently bad outcome 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 underlying mechanism is that pilots create the potential for realizing quasi-option value as generally understood in the environmental and natural resource economics literature (Arrow and Fisher, 1974). The decision of whether to undertake the full project is effectively delayed while potentially valuable information is revealed in the pilot stage.

The most novel findings of the paper relate to optimal subsidy policy. A subsidy for the project or pilot is warranted only if the private sector would not undertake either on its own, yet there exist sufficiently large social, non-market benefits. We show that the choice of subsidizing projects or pilots depends simultaneously on the characteristics of both, and we solve for the conditions when one or the other is preferable. Optimal subsidies for a pilot project must account for the opportunity cost of foregoing a full project immediately. Interestingly, full project subsidies must in some cases be set to discourage pilot projects on the part of the private sector. This counterintuitive result arises because of different incentives on the part of the public and private sectors. In particular, we show that when the public sector prefers to see a full project, it may seek to discourage the private sector from learning potentially valuable information that would discourage it from doing so. In such cases, subsidies that reduce a project's costs are also more cost-effective than subsidies that increase its benefits. More generally, we find that agencies seeking to maximize social net benefits should target projects or pilots depending on the anticipated size of a project's social benefits.

The next section develops a simple example to further motivate the notion of pilot projects as experiments that provide information. Section 3 describes the model's setup from a private sector and planner's perspective. Section 4 derives necessary and sufficient conditions for pilot projects to have social value. Section 5 considers the question of when to subsidize projects or pilots and by how much. Section 6 extends the basic model to endogenize the size of a pilot project, showing the ways in which it expands the conditions under which pilots have potential value. Section 7 concludes with broader policy implications and suggestions for further research in the nascent area of climate finance.

[1] Key papers on staged investment include Sahlman (1990), Gompers (1995), and Gompers and Lerner (2004).

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. The importance of experimentation for entrepreneurship is well-established. Kerr et al. (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.

Our aim in what follows is to show how lessons about the financing of entrepreneurial experimentation can inform the efficient deployment of public climate finance. Specifically, we extend the model developed by Nanda and Rhodes-Kropf (2016) to include a public sector and thereby account for decisions that institutions are likely to face when looking to promote private sector investment in climate change mitigation and adaptation. Agencies often have the option to choose between subsidizing full projects or pilot projects that private agents would not otherwise undertake. The key idea is that pilot projects have potential value because they generate information (as opposed to profits) and therefore function as experiments.

A Motivating 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. 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

$$(0.5 \times \$20\text{M}) + (0.5 \times 0) - \$11\text{M} = -\$1\text{M}. \tag{1}$$

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 further 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 a good outcome would increase the probability of success to 0.8, and a bad outcome would decrease the probability to 0.2. Assume further that the chances of a good or bad outcome are 50-50, and the cost of running the pilot is \$2.95M. This amount represents the net loss after accounting for any revenue the pilot may generate. Because the full project would never be profitable in the case of the bad outcome, the expected value of the pilot along with the full project option is

$$0.5 \times (0.8 \times \$20\text{M} - \$11\text{M}) - \$2.95\text{M} = -\$0.45\text{M}. \tag{2}$$

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 $0.5 \times \$4\text{M} = \$2\text{M}$, which can be added to (1) to yield the expected social value of the project itself at \$1M. In expectation, then, the project is *socially* desirable, even if not *privately* profitable, and a climate finance subsidy would be warranted to tip the private sector calculus in favor of the project. Now, with respect to the pilot, the expected value of the non-market benefits is $0.5 \times 0.8 \times \$4\text{M} = \$1.6$, which adding to (2) yields social net benefits that are again positive at \$1.15M.

A question of central interest here is whether resources from a public agency would be better spent subsidizing the full project or the pilot project. The answer in this example is the pilot because it yields greater social net benefits (by \$.15M). Notice, however, that this finding is not necessarily intuitive because it recommends subsidizing a pilot project that costs \$2.95M to run when the expected loss from the project itself is only \$1M. In cases like this, we use our general model to show how pilots add value because they may reveal that a project is actually not worth doing.

Now suppose instead that the non-market benefits had been larger, \$6M rather than \$4M. This change would not alter the private sector decision because the private payoffs for the project and pilot remain unchanged at −\$1M and −\$.45M, respectively. It would, however, alter the optimal public policy because the social net benefit of the full project at \$2M now exceeds that of the pilot at \$1.95M. Hence a full project subsidy would be warranted in this case. Moreover, it is tempting to think that the subsidy required to induce the full project is \$1M, because that is the expected loss to the private sector from undertaking the full project. But a full project subsidy of this amount on the cost of doing the project would instead induce the private sector to suboptimally undertake the pilot project first. This follows because the private net benefit of undertaking the pilot given a \$1M subsidy is $0.5(0.8 \times 20 - 11 + 1) - 2.95 = 0.05$, which exceeds the zero net benefit of undertaking the full project right away. A further insight of our more general analysis that follows is that full project subsidies must often include a premium to discourage the private sector from seeking information through a pilot that may be private beneficial but socially detrimental.

3. Model setup

We now develop a more general model to help illuminate why pilots may be advantageous and to identify circumstances when public climate finance should focus on subsidizing pilot projects or full projects; we are also interested in the magnitude of the subsidies that are required for each. Let $\$X > 0$ denote the cost to implement a full project. If successful, the project will generate revenue $\$V > 0$ and non-market social benefits $\$H > 0$. If the project fails, both the revenue and non-market social benefits will be zero. The probability of success is $p \in (0, 1)$, and the probability of failure is $(1 - p)$. Importantly, there exists the opportunity to run a pilot, the value of which is primarily further information about the probability of success or failure. Running the pilot has a net cost of $\$Y > 0$, and a pilot returns either a "good" or a "bad" outcome. A good outcome from a pilot allows the decision-maker to update the probability of success from p to g, and a bad outcome updates from p to b, so without loss of generality $g \geq b$. Note that a bad outcome is a lower probability of success and therefore a higher probability of failure. The probability of a good outcome from the pilot is $q \in (0, 1)$, and the probability of a bad outcome is $(1 - q)$.

The unconditional probability of success from the pilot, with the subsequent project option, must match that for the project itself, requiring

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

It is clear from this expression that the good and bad probabilities must satisfy $g \geq p \geq b$. Note further how the general formulation here does not require that the probability of a successful project p be the same as the probability of a successful pilot q.[2]

We begin by calculating the expected values of the project and pilot from a private sector perspective. Letting the subscript *FP* stand for the full project, the expected value of carrying out the full project itself from the private sector perspective can be written as

$$E_{FP}(V) = \max\{pV - X, 0\}. \tag{4}$$

Equation (4) reflects how projects with a negative expected value would not be undertaken and therefore have $E_{FP}(V) = 0$. Notice that the non-market social benefits H are not taken into account from the private sector perspective.

The pilot project, denoted with subscript *PP*, with the subsequent full project option has an expected private value of

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

With probability q the agent obtains $\max\{gV - X, 0\}$, and with probability $(1 - q)$ she obtains $\max\{bV - X, 0\}$. The expression also accounts for the pilot's up-front cost Y. The outer max operator reflects how the pilot combined with the project option would occur only if it has a positive expected value.

The private sector perspective in expressions (4) and (5) are equivalent to those in Nanda and Rhodes-Kropf's (2016) model of entrepreneurial experimentation. In what follows, we highlight some new insights applicable to the private sector perspective, but the novel aspect here is the inclusion of social, non-market benefits and a focus on the public rather than private perspective. Hence, in order to provide a potential role for efficient intervention in the form of public climate finance, we focus on cases where the private sector would *not* undertake the full project or pilot project on its own. Specifically, we assume the expected values to the private sector of both the full project and the pilot project are zero. The following imposes this condition.

The Private Sector Assumption: $pV - X < 0$ and $q(gV - X) - Y < 0$.

Under the Private Sector Assumption, a private agent would rather walk away than undertake either a full project or a pilot project.

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

$$E_{FP}(W) = \max\{pW - X, 0\}. \tag{6}$$

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

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

The only difference with these public sector expressions is inclusion of the non-market social benefits H in addition to V. Notice that we denote the different perspectives with the corresponding argument V or W in $E_{FP}(\cdot)$ and $E_{PP}(\cdot)$.

A key feature of the model's setup is that even if the private sector assumption holds, it is still possible for either $E_{FP}(W) > 0$ or $E_{PP}(W) > 0$, or both. This admits the possibility for a socially beneficial subsidy to encourage either a pilot or a full project. Hence, to further maintain this possibility and focus on the interesting case, we make a further assumption.

The Public Sector Assumption: $gW - X > 0$.

This condition ensures that conditional on the good outcome of a pilot, the social planner would always find the full project socially beneficial. Without this assumption, and using the previous observation that $g \geq p \geq b$, it is straightforward to verify that $E_{FP}(W) = E_{PP}(W) = 0$, and this would imply no potential scope for a socially beneficial project or pilot. Importantly, the public sector assumption does not predetermine the signs of (6) or (7), or their relative magnitudes. This follows because it is still possible for $pW - X \lesseqgtr 0$ in (6), and the magnitude of the pilot project's cost Y renders (7) indeterminate. In other words, the Public Sector Assumption opens the possibility that a pilot (or full) project will be socially beneficial, even though neither is desired by the private sector (by the Private Sector Assumption). Indeed, we now turn to evaluating these relative magnitudes and what they imply about when pilot projects may be socially beneficial.

[2] Later in the paper, when extending the model to include pilots of varying (and endogenous) size, we work with the intuitive case in which $p = q$. In that case, there is a probability distribution over prior beliefs on p, and pilot-project outcomes are treated as draws from the distribution that enable Bayesian updating.

4. The social value of a pilot

Whether a full project has positive social value depends on whether (6) is greater than zero, keeping in mind that the private sector assumption implies (4) equals zero.[3] Having established the full project as a baseline, it follows that whether a pilot project has positive social value depends on two conditions: it must yield benefits that are greater than those for the full project itself and greater than zero. The second condition is necessary to allow for the possibility that the pilot may have positive net benefits even though the full project does not. In short, a pilot project will have positive social value if (7) is strictly greater than (6).

What is required for the pilot to be the preferred option? We can immediately prove four necessary and intuitive conditions for a pilot project to have positive social benefits. The first relates to the difference between good and bad outcomes from the pilot.

Necessary Condition 1: $g > b$ is necessary for $E_{PP}(W) > E_{FP}(W)$.

We have already shown that $g \geq b$. To prove the desired result, we will show that if $g = b$, it is not possible that $E_{PP}(W) > E_{FP}(W)$. Suppose that $g = b$, which immediately implies $p = g = b$. Substituting this equality into (7) and rearranging yields the following social value of a pilot project:

$$\begin{aligned} E_{PP}(W) &= \max\left\{\max\{pW - X, 0\} - Y, 0\right\} \\ &= \max\left\{E_{FP}(W) - Y, 0\right\}. \end{aligned}$$

This result implies that if $g = b$, then $E_{PP}(W) \leq E_{FP}(W)$. Thus, for $E_{PP}(W) > E_{FP}(W)$, it is necessary that $g > b$ which proves the result. The result emphasizes that there must be something beneficial to learn from the pilot in order for it to have value. If not, there is no difference between the good and bad outcomes, nor the probability of a project's success when viewed through learning from the pilot or through the project itself. Hence there is no potential benefit of the pilot to justify its additional cost.

The second condition requires the pilot's bad outcome to be sufficiently bad.

Necessary Condition 2: $bW - X < 0$ is necessary for $E_{PP}(W) > E_{FP}(W)$.

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

$$\begin{aligned} E_{PP}(W) &= \max\left\{q(gW - X) + (1 - q)(bW - X) - Y, 0\right\} \\ &= \max\left\{(pW - X) - Y, 0\right\} \\ &= \max\left\{E_{FP}(W) - Y, 0\right\}, \end{aligned}$$

where the second equality follows from (3) and the third from recognizing that $bW - X \geq 0$ implies $pW - X \geq 0$. This means that if $bW - X \geq 0$, then $E_{PP}(W) < E_{FP}(W)$. Hence the pilot will provide no additional value if, conditional on the bad outcome, the project would still have positive net benefits. The reason is that the full 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. Thus, for $E_{PP}(W) > E_{FP}(W)$ it is necessary that $bW - X < 0$.

Combining the two previous necessary conditions with (7) immediately yields a third.

Necessary Condition 3: $E_{PP}(W) = \max\left\{q(gW - X) - Y, 0\right\}$ is necessary for $E_{PP}(W) > E_{FP}(W)$.

Necessary Condition 2 already shows that a pilot can only have positive social value if the project would not be beneficial conditional on the bad outcome. Thus, the term $(1 - q)\max\{bW - X, 0\}$ in equation (7) equals zero (by Necessary Condition 2). This immediately implies that $E_{PP}(W) = \max\left\{q(gW - X) - Y, 0\right\}$. Indeed, a key intuition is that the value of the pilot arises because the project can be abandoned without having to ever invest X if the outcome is bad. In this way, the pilot project creates an opportunity for quasi-option value (Arrow and Fisher, 1974).[4] The project investment decision can be delayed while potentially valuable information is revealed, and the question we are building toward is when the information is worth obtaining given the pilot cost of Y.[5]

The final condition follows from recognizing that a pilot will have social value above and beyond a full project if and only if $E_{PP}(W) > E_{FP}(W)$. A necessary condition is therefore $q(gW - X) - Y > pW - X$. Rearranging this inequality yields

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

[4] For more recent contributions and expanded intuition see Fisher (2000), Mensink and Requate (2005), and Traeger (2014).

[5] Throughout the paper we do not consider discounting between the pilot and subsequent project phase. We do this for simplicity, but it is straightforward to modify all conditions to account for discounting in settings where the time lag may be important. Clearly, the longer the time lag, the more disadvantageous a pilot project would become. In doing so, however, the setting might also require the inclusion of discounting between the timing of a full project's costs X and realization of its benefits V.

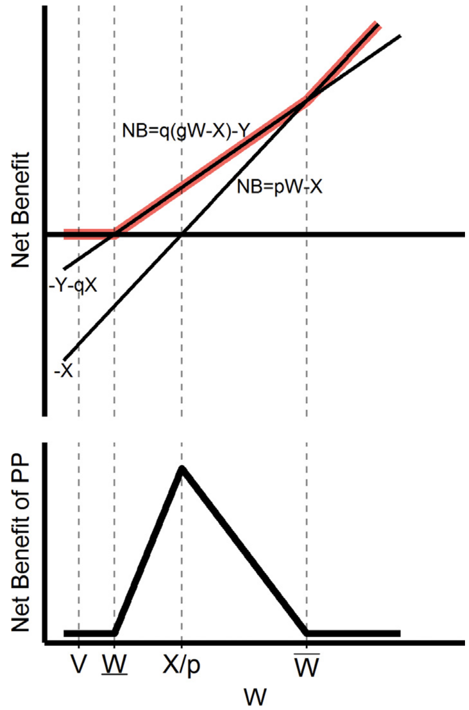

Fig. 1. Social benefits of the pilot and full project at different levels of *V* or *W* (upper panel); social net benefits of the pilot relative to nothing and the full project at different levels of *V* or *W* (lower panel).

$W(qg - p) > Y + qX - X$, where the left-hand side is negative, so the following must hold.

Necessary Condition 4: $Y + qX < X$ is necessary for $E_{PP}(W) > E_{FP}(W)$.

This implies quite simply that the expected costs of the pilot with the project option must be less than the costs of the project itself. The 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. This also implies that the pilot cost must be less than the full project cost.

We illustrate much of the analysis thus far in the upper panel of Fig. 1. We show how payoffs change at different levels of the project benefits while satisfying the necessary conditions. We consider changes to either the private or public components, *V* or *H*, nesting the insights into the study of *W*, while ensuring the private sector assumption continues to hold. The upper panel shows the net benefits (labeled NB in the figure) of undertaking the project or the pilot, as reflected in the functions $pW - X$ and $q(gW - X) - Y$, respectively. The social planner would prefer doing nothing to negative net benefits and would prefer choosing the project or pilot depending on which has higher net benefits. The benefits of the optimal policy are therefore shown as the upper envelope, highlighted in bold. Neither the pilot nor the full project have positive, social value if $W \leq \underline{W}$, keeping in mind that satisfying the private sector assumption requires that $V < \underline{W}$. The pilot is preferable to the full project if $W \in (\underline{W}, \overline{W})$, but the full project itself is preferable with sufficiently high public benefits of $W > \overline{W}$.[6]

We summarize the main findings depicted in Fig. 1 with the following result:

Result 1. *The pilot project has positive, net social value if and only if*

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

The proof requires showing both that condition (8) implies $E_{PP}(W) > E_{FP}(W)$ and that $E_{PP}(W) > E_{FP}(W)$ implies condition (8). To show the latter, we note that $E_{PP}(W) > E_{FP}(W)$ implies condition (8) directly from Necessary Condition 3 and the definition of $E_{FP}(W)$ in equation (6). To show the former, note from its definition in equation (7), that $E_{PP}(W) \geq q(gW - x) - Y$, and by equation (6), $E_{FP}(W) = \max\{pW - X, 0\}$. Therefore, condition (8) implies $E_{PP}(W) > E_{FP}(W)$. Result 1 clarifies how the value of a pilot project depends on a comparison of (*i*) its expected value conditional on the good outcome, and (*ii*) the expected value of doing the full project immediately or nothing at all.

[6] It is straightforward to solve for $\underline{W} = \frac{Y+qX}{qg}$ and $\overline{W} = \frac{X(1-q)-Y}{p-qg}$.

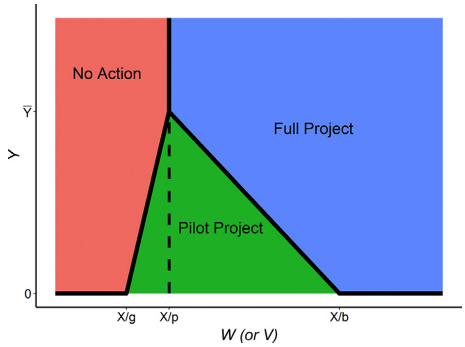

Fig. 2. Optimal policy—no action, full project, or pilot project—for different combinations of Y and W (or V).

Turning now to the lower panel of Fig. 1, we show the net social benefit of the pilot at different levels of W (this is the vertical distance between the two lines in the upper panel). The interesting result is how the net benefit of the pilot is not monotonic. It is initially increasing in W, yet sharply decreases when the full project begins to have positive net social benefits. Over the interval $W \in (\frac{X}{p}, \overline{W})$, the net benefit of the pilot is only the additional increment above that for the full project. 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 additional value within a specific range of non-market benefits. Of particular interest is the region where full projects themselves do not have positive, net social benefits; that is, when $W \in (\underline{W}, \frac{X}{p})$. Under these circumstances, conducting a pilot project can be pivotal for making a project socially desirable. The second insight is that for projects with sufficiently high social benefits, pilots add no additional value to already beneficial projects.

While Fig. 1 emphasizes that the desirability of a pilot hinges on the total benefits W, it also depends on the cost of the pilot Y. Fig. 2 shows how the optimal policy (no action, pilot project, or full project) depends on different values of W and Y. The borders between regions trace out the locus of (W, Y) combinations that generate indifference between the two adjacent policies.[7] Sufficiently high W and Y always favors the full project. For lower values of Y, increases in W move the optimal policy from no action to the pilot project and ultimately the full project. For all $Y > \overline{Y}$, the pilot project is too costly and never optimal for any level of W.[8] Finally, note that Fig. 2 can apply equally to the private sector if the horizontal axis is interpreted as V rather than W, which assumes implicitly that $H = 0$. Hence the private sector assumption can be understood as assuming only cases where (V, Y) lie within the region of no action.

5. Subsidizing pilots or projects

Fig. 2 clarifies the optimal policy choice for a private agent (by viewing the horizontal axis as V), and the optimal choice for society (by viewing the horizontal axis as W). We now solve for the minimum necessary subsidy to induce a private agent to undertake a socially desirable pilot or full project. We employ the standard, public finance assumption that the planner seeks to maximize social net benefits and treats the subsidy payment as a transfer. The results from the previous section therefore identify the optimal subsidy policy: the planner would prefer no subsidy for sufficiently low levels of W (because the socially optimal outcome is no action), a subsidy to induce the pilot for intermediate levels of W, and a subsidy to induce the project itself for sufficiently high levels of W. As part of solving for the minimum subsidy to induce the socially desirable behavior, we must pay careful attention to the private agent's incentives. In particular, we now show that a critical part of solving for the required subsidies is accounting for whether the private agent will follow through on a socially desirable project after conducting a subsidized pilot, and whether the private agent may be induced to suboptimally conduct a pilot when given a full project subsidy.

5.1. Pilot project subsidies

We begin with cases where the pilot project is socially optimal, so the subsidy attempts to induce the private agent to undertake a pilot project. The private sector assumption implies $q(gV - X) - Y < 0$, yet the private net benefits must be non-negative to induce the private agent to undertake the pilot project. The inequality suggests three possible ways to offer a subsidy: lower Y, lower X, or increase V. In each case, we solve for the minimum subsidy required for indifference between doing the pilot or the next best alternative, which includes either nothing or the full project. We must also carefully attend to the incentives for

[7] The upward sloping line satisfies $q(gW - X) - Y = 0$, and the downward sloping line satisfies $q(gW - X) - Y - (pW - X) = 0$.

[8] We derive $\overline{Y}$ as follows: If $W = \frac{X}{p}$, Proposition 1 implies the pilot is not optimal if $Y \geq qX(\frac{g}{p} - 1) = \overline{Y}$. It is then straightforward to verify using (8) that if $Y \geq \overline{Y}$, then the pilot remains not optimal for all smaller and larger values of W.

efficient behavior after the pilot has been undertaken.

Let $s_{PP} = Y - q(gV - X)$ denote the expected private sector loss without a subsidy. Clearly an up-front subsidy on Y of $s_{PP}^{Y} = s_{PP}$ will cause the private agent to break-even with the pilot. Offering a subsidy on the cost of doing the pilot also has no implication on the net benefit of doing the full project (instead of the pilot), which is itself negative by the private sector assumption. There is, however, a need for some qualification in this case to ensure incentive compatibility at the next stage with the full project. If $gV - X \geq 0$, the subsidy is (weakly) less than the cost of the pilot. This also means that carrying out the full project conditional on the pilot's good outcome, which is by assumption socially optimal, is incentive compatible for the private agent. In contrast, if the inequality does not hold, the expected subsidy is greater than Y, and the private agent would prefer to keep the subsidy and not follow through on the full project. In this case, ensuring the private agent follows through on the socially optimal project can be accomplished in at least two ways. The first is an enforceable contract requiring the full project conditional on the good outcome of the pilot. The second is splitting the subsidy in two parts: Y for doing the pilot, and $X - gV$ conditional on g, which occurs with probability q. This two-part subsidy induces the socially desirable pilot and the socially desirable follow-through contingent on the pilot's outcome.

Instead of a subsidy on the cost of a pilot, consider a subsidy to increase the value of a successful full project, V. Consider a V-subsidy of $s_{PP}^{V} = \frac{s_{PP}}{qg}$. Note that the *ex ante* expected value of this subsidy is qgs_{PP}^{V} which equals s_{PP}, and this is exactly the same as that for the subsidy on Y. While this implies a *ex ante* net benefit of zero for the pilot, we must verify that offering the subsidy on V does not suboptimally induce the private agent to skip the pilot and do the full project immediately (which would be socially undesirable). It is straightforward to show that $p(V + s_{PP}^{V}) - X \leq 0$ for all $Y \leq \overline{Y}$, and we know the latter condition holds by the assumption that the pilot project is socially optimal.[9] Hence an expected subsidy on V equal to s_{PP} will induce the private agent to follow a socially optimal plan that entails the pilot project initially and the full project conditional on the pilot's good outcome.

The third subsidy to consider is one that reduces the cost of doing the project X. The subsidy that produces a private net benefit of zero for the pilot is $s_{PP}^{X} = \frac{s_{PP}}{q}$. But how does offering this subsidy affect the private agent's incentive with respect to the full project? With a bit of rearranging it is easy to show that $pV - (X - s_{PP}^{X}) \leq 0$ only if Y is sufficiently small ($Y \leq qV(g - p) \equiv \tilde{Y}$). This means that the proposed subsidy on X implements the socially optimal plan if and only if $Y \leq \tilde{Y}$. Interestingly, this result is somewhat limited because $\widetilde{Y} < \overline{Y}$. A consequence is that for values of $Y \in (\widetilde{Y}, \overline{Y})$ offering the subsidy on X would induce the private the agent to suboptimally do the full project immediately rather than the pilot.[10] Intuition for this result follows from recognizing that a lower cost of doing the project makes the pilot less beneficial, so offering the subsidy on X to the private agent when Y is sufficiently high causes the flip to the full project rather than inducing the pilot.[11]

The following result summarizes our findings on subsidies when the pilot project is socially optimal.

Result 2. *Consider scenarios where conducting the pilot project is socially optimal, and consider the three possible subsidies of: lowering Y, increasing V, or lowering X. It follows that*

a. *The minimum ex ante expected subsidy is the same for all three instruments and equal to* $s_{PP} = s_{PP}^{Y} = qgs_{PP}^{V} = qs_{PP}^{X}$;
b. *The subsidy on Y will always induce the optimal plan, but may require a contract or some conditionality of the payment to ensure follow through on the full project;*
c. *The subsidy on V will always induce the optimal plan;*
d. *The subsidy on X will induce the optimal plan if Y is sufficiently low, otherwise it will suboptimally induce the private agent to (inefficiently) skip the pilot in favor of the full project immediately.*

5.2. Full project subsidies

Now consider scenarios where skipping the pilot and conducting the full project immediately is socially optimal. If the pilot project is not viable at any cost, the problem is trivial and an expected subsidy equal to the private sector loss of $s_{FP} = X - pV > 0$ will induce the optimal behavior. To maintain the interesting case, therefore, we assume $Y < \overline{Y}$. We consider two types of subsidies: One that increases V and one that decreases X.

It is useful to first consider a subsidy on V equal to $\frac{s_{FP}}{p}$, which by definition satisfies $p(V + \frac{s_{FP}}{p}) - X = 0$. Although break-even for the project, it turns out that offering this subsidy will instead cause the private agent to (suboptimally) undertake the pilot first, knowing the subsidy of $\frac{s_{FP}}{p}$ exists on V for a successful project. The reason is that $q(g(V + \frac{s_{FP}}{p}) - X) - Y > 0$ for all $Y < \overline{Y}$.[12]

[9] See Fig. 2 and the derivation of $\overline{Y} = qX(\frac{g}{p} - 1)$ in footnote 8.

[10] We can also verify that offering a higher subsidy on X would not change the outcome. This follows because the private marginal benefit of a higher subsidy is $q < 1$ for the pilot and unity for the project.

[11] It is natural to question why there is not symmetry between subsidies on X and V? The reason is that the two subsidies have different consequences on the expected values of the pilot's "good" and "bad" outcomes. Lowering X has a private marginal benefit of q and $(1 - q)$, respectively; whereas, increasing V has a marginal benefit of qg and $(1 - q)b$, respectively. Hence subsidizing V is relatively more favorable to the pilot because it further differentiates between the good and bad outcomes. In the case considered here, with the subsidy on X, it is more likely to make the project privately beneficial even under the bad outcome, and this has the consequence of eliminating the value of doing the pilot and switching to the project.

[12] For the pilot to be preferred, the private sector analog of necessary condition 3 must hold, and it does because $b(V + \frac{s_{FP}}{p}) - X < 0$ with $b < p$.

But what about offering a larger subsidy? A marginal increase in the subsidy on V benefits the full project by p and the pilot by the lesser qg. It follows that the minimum possible subsidy, denoted s_{FP}^{V}, to induce the full project will solve

$$p(V + s_{FP}^{V}) - X = q(g(V + s_{FP}^{V}) - X) - Y,$$

and this yields

$$s_{PP}^{V} = \frac{s_{FP}}{p} + \frac{\overline{Y} - Y}{(p - qg)}.$$

This means that the *ex ante* expected subsidy ps_{PP}^{V} requires a premium equal to $\frac{p(\overline{Y}-Y)}{(p-qg)}$ beyond the break-even point for the project.[13] The premium is needed to discourage the pilot, and its magnitude is greater with a lower cost of the pilot.[14]

Turning now to a subsidy on the project's cost X, consider the same starting point of offering s_{FP}, which is break-even for the full project. The *ex ante* net benefit of doing the pilot instead is $q(gV - (X - s_{FP})) - Y$, and this condition is less than or equal to the zero only if $Y > \tilde{Y}$. Otherwise a premium is again necessary, and we use the same approach to solve for the s_{FP}^{X} that satisfies:

$$pV - (X - s_{FP}^{X}) = q(gV - (X - s_{FP}^{X})) - Y.$$

Combining the two cases, we find the minimum required subsidy on X is

$$s_{FP}^{X} = \begin{cases} s_{FP} & \text{if } Y \geq \widetilde{Y} \\ s_{FP} + \dfrac{\widetilde{Y} - Y}{1 - q} & \text{if } Y < \widetilde{Y} \end{cases},$$

and s_{FP}^{X} also represents the *ex ante* expected value.[15] In this case, therefore, the premium to induce the project is not necessary with a sufficiently high pilot cost, as this is precisely when the pilot is less beneficial.

Unlike the subsidy results for the pilot, we find that when subsidizing the full project, the *ex ante* expected value of the two subsidies ps_{PP}^{V} and s_{FP}^{X} are not equal. This raises the question of relative magnitudes between full project subsidies on V or X. That is, might one be more cost effective than the other? It follows immediately that the expected subsidy on X is smaller if $Y \geq \tilde{Y}$ because there is no required premium in this case. For lower values of Y, the expected subsidy on X will still be smaller if its premium is lower. With a bit of rearranging, it turns out that showing $ps_{PP}^{V} > s_{FP}^{X}$ is equivalent to showing

$$\frac{p - qp}{p - qg} > \frac{\widetilde{Y} - Y}{\overline{Y} - Y},$$

and we know this holds because $g > p$ means the left-hand side is greater than 1, and $\overline{Y} > \widetilde{Y}$ means the right-hand side is less than one. Thus, we conclude that the X-subsidy is always a cheaper way to induce a full project. Intuition for why the X subsidy is always less costly builds on our previous observation that it is relatively less favorable to the pilot (see footnote 11). Then, because discouraging the pilot from the private sector perspective is the reason for the subsidy premium, the expected X subsidy is always less costly.

We summarize our findings for full project subsidies with the following result.

Result 3. *Consider scenarios where conducting the full project immediately is socially optimal and the cost of the pilot is sufficiently low ($Y < \overline{Y}$). Consider two possible subsidies: increasing Vor lowering X. It follows that:*

a. *The minimum ex ante expected subsidy on X is strictly less than the subsidy on V, that is,* $s_{FP}^{X} < ps_{FP}^{V}$.
b. *The subsidy on V that induces the full project will result in expected private net benefits greater than zero.*
c. *The subsidy on X that induces the full project will result in expected private net benefits greater than zero only if Y is sufficiently small.*

A key result here is that when pilot projects are a viable option, a planner seeking to induce a full project will find it more cost effective to subsidize project costs rather than project benefits. Moreover, it is worth emphasizing how the subsidy premiums to discourage the pilot project are somewhat of a counterintuitive result. The value of information is usually positive, or at least non-negative. In this case, however, there is a difference between the public and private perspectives, and this means that the optimal subsidies will, in general, induce the private agent to avoid seeking information that would otherwise be privately valuable.

[13] It is straightforward to verify further that the expected value of the project conditional on the pilot's bad outcome remains negative with this subsidy, i.e., $b(V + s_{FP}^{V}) - X < 0$. This confirms that a lower subsidy would not eliminate net benefits from the pilot.

[14] An alternative policy instrument that we do not consider, but that can have an equivalent effect, is a tax on the pilot.

[15] To confirm that a lower premium would not sufficiently discourage the pilot, we must verify that $bV - X + s_{FP}^{X} < 0$. Clearly, the inequality is satisfied if $s_{FP}^{X} = s_{FP}$. With the premium, however, a few lines of substitution and rearranging can simplify the expression requiring only that $Y > 0$.

6. Extension to an endogenous pilot size

Our analysis has thus far focused on the decision of whether to undertake a pilot project or a full project, where the former is assumed to have a fixed and exogenous size. In practice, however, pilot projects can take many different forms. For example, an alternative energy pilot can often be scaled, where larger pilots are more costly to conduct, but reveal more information about the likelihood of a full project's ultimate success. In such cases, the planner, along with potential private agents, must decide not only on whether to undertake a pilot, but also on the optimal size of a pilot. In this section, we generalize the model to account for pilot projects of an endogenous size, that is, we allow the extent of the pilot project to be a choice variable. The purpose is to consider how the results about when pilot projects are preferred generalize to such cases.

To formalize the notion of a pilot project's size, we need to specify the process by which a more extensive pilot generates more information and opportunities for learning. We take a Bayesian approach. Assume the decision-maker has initial uncertainty over the probability of a full project's success p.[16] The uncertainty is captured by a Beta distribution with parameters α and β, which we denote $B(\alpha, \beta)$. Accordingly, the initial expectation of the success probability is $\frac{\alpha}{\alpha+\beta}$. Pilot projects can be scaled to the extent $N = 1, 2, \ldots$,. For simplicity, we assume a constant marginal cost, such that the cost of a pilot of extent N is YN. We assume further that the expectation of a full project's success is updated after a pilot according to the Beta-Binomial conjugacy. This means that with a pilot of size N, which includes s successes and $N - s$ failures, the updated distribution is $B(\alpha\prime, \beta\prime)$, where $\alpha\prime = \alpha + s$ and $\beta\prime = \beta + N - s$, and therefore $p' = \frac{\alpha+s}{\alpha+\beta+N}$.[17]

Now consider the expected social payoffs of each option with the modified setup. No action still yields a payoff of zero. The payoff of undertaking the full project immediately is $\mathbb{E}pW - X$, where the only difference is that p is uncertain, with an expectation based on the Beta distribution. The payoff of undertaking a pilot project of size N, which includes the second stage option of conducting the full project, is $\mathbb{E}\max(p'W - X, 0) - YN$. In this case, the probability of success is uncertain for the additional reason that the number of success s is uncertain for any given N. We can therefore write

$$\mathbb{E}\max(p'W - X, 0) - YN = \sum_{s=0}^{N} F(s,N)\max\left(\frac{\alpha+s}{\alpha+\beta+N}W - X, 0\right) - YN, \tag{9}$$

where $F(s, N)$ is the probability of s successes in N trials. Note that if p is known with certainty, $F(s, N)$ is the probability mass function of the binomial distribution. But because p is uncertain, we must integrate over the full Beta distribution, and we can solve for

$$F(s,N) = \begin{pmatrix} N \\ s \end{pmatrix} \frac{\mathbf{B}(\alpha+s, \beta+N-s)}{\mathbf{B}(\alpha,\beta)},$$

where $\mathbf{B}(a, b)$ is the Beta function.[18]

Now that we have an explicit expression for the expected net benefits of a pilot project of any size, we can explore conditions under which pilots of different sizes are preferred. Intuition suggests that adding flexibility about a pilot's size can only increase the parameter space over which a pilot project might be preferred. The simplest way to see the mechanism at work is to consider the special case where $Y = 0$. Despite a pilot having no cost, there are still circumstances under which conducting one adds no value. Fig. 2 shows this for the previous setup with sufficiently low and high W. A costless pilot adds no value if the full project is not worthwhile even conditional on the pilot's good outcome (i.e., when $W < X/g$). Similarly, a costless pilot adds no value if the full project is worthwhile even conditional on the pilot's bad outcome (i.e., when $W > X/b$).

More generally, we can solve for the analogous total benefit thresholds with $Y = 0$ for a pilot of any size N. We derive W^{Min} as the minimum total benefits such that the project just breaks even in the second stage, but only when the best pilot outcome is revealed, i.e., $s = N$. Below this threshold, the full project would never be beneficial, so the pilot itself adds no potential value. The threshold must satisfy $\frac{\alpha+N}{\alpha+\beta+N}W^{\text{Min}} - X = 0$, which implies

$$W^{\text{Min}}|_{Y=0} = \frac{X(\alpha+\beta+N)}{\alpha+N}. \tag{10}$$

The important observation is that the threshold is decreasing in N, thereby lowering the total benefits at which a pilot project is beneficial. Intuitively, the threshold is also decreasing in the prior mean p, and increasing in X. Note further that the threshold is always greater than X, because the project benefits must always exceed its costs.

We derive W^{Max} at $Y = 0$ by solving for the minimum total benefits such that the project just breaks even in the second stage, but only when the worst pilot outcome is revealed, i.e., $s = 0$. Below this threshold, the pilot will certainly have value because

[16] Note that this differs from earlier in the paper, where we assumed p was a known parameter.

[17] As a point of clarification, we are considering a case where the pilot's size N must be chosen before conducting the pilot. That is, the setup in this section is not a sequence of additional decisions about when to stop conducting a pilot after one has been initiated.

[18] In particular, the Beta function is $\mathbf{B}(a, b) = \int_0^1 x^{a-1}(1-x)^{b-1}dx$.

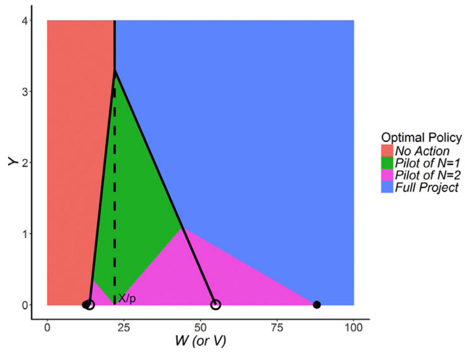

Fig. 3. Optimal policy—no action, full project, or endogenous pilot project size with $N = 1$ or $N = 2$—for different combinations of Y and W (or V).

there is a chance the planer would abandon the full project in the second stage, yet above this threshold, the incentive to carry-out the full project is there regardless of any other pilot outcome. In this case, the threshold must satisfy $W^{\text{Max}} \frac{\alpha}{\alpha+\beta+N} - X = 0$, and we have

$$W^{\text{Max}}|_{Y=0} = \frac{X(\alpha+\beta+N)}{\alpha} \tag{11}$$

Here we see that the threshold is increasing in N, once again broadening the range over total benefits at which a pilot project is preferable. Indeed, the threshold is increasing linearly in N. It is also decreasing in the prior mean p, and increasing in X.

To provide further insight, we now consider a numerical example. In particular, we extend the motivating example in Section 2 to allow a pilot project of different sizes. The example includes initial parameter values of $p = 0.5$, $b = 0.2$, $g = 0.8$, and $X = 11$. These correspond to $\alpha = \beta = 1/3$, and a pilot size of $N = 1$. Using these values, along with equations (10) and (11), we obtain the result that, as $Y \to 0$, a pilot project of size $N = 1$ is preferred to no action and the full project immediately provided that $W \in (13.75, 55.0)$. Yet, as shown above, the range expands with the size of the pilot. For example, $N = 2$ implies a range of $(12.57, 88.01)$, and $N = 10$ implies $(11.35, 352.03)$.

Fig. 3 further illustrates the parameter space over which pilots of different sizes are preferable. In particular, we replicate the procedure underlying Fig. 2 allowing the possibility for a pilot project of size $N = 1$ and $N = 2$.[19] We first calculate the expected payoffs from no action, the full project immediately, and pilot projects of both sizes. Note that the latter require implementation of equation (9). We then choose the policy that returns the largest payoff, and plot the regions in Fig. 3. The bold lines outline the region over which a pilot of size $N = 1$ is optimal, mirroring the results from Fig. 2.

Several results are worth noting in Fig. 3. First is the increased range of W over which a pilot project is preferable, especially at the upper end, where the pilot of $N = 2$ is preferred to the full project. When the pilot cost is sufficiently low, there is an incentive to obtain more information in the event that it might induce the planner to abandon what initially seemed like a beneficial project. Second is how the range narrows with an increase in Y. There exists a sufficiently high pilot cost such that only the pilot of $N = 1$ is a viable alternative. Third is the way that the smaller pilot is preferred over a greater area when W is near X/p. Intuition for this result follows from recognizing that when $W = X/p$ it takes very little information—one way or the other—about an updated p to tip the planner towards follow-through or abandonment of the full project. In this case, there is little value of additional information, which is furthered because the cost of making the wrong decision is relatively small. When moving away from this break-even point, however, it takes more information to change a decision, and the costs of making the wrong decision are greater. The result is greater preference for a larger pilot given a sufficiently low cost. A further consequence is that the optimal endogenous size of a pilot project is often non-monotonic in the full project benefits W.

7. Conclusion

International efforts to address climate change are growing increasingly reliant on climate finance. Indeed 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.

This paper considers how to maximize the impact of publicly provided climate finance to leverage the private sector. The conceptual underpinning of publicly-funded climate finance is that many projects, if successful, will have distinct public and private benefits. When the public benefits are significant, and the privately optimal investment decisions do not reflect this, then public subsidies may be warranted. In such cases, subsidies need to finance only the “incremental cost” necessary to get efficiently-

[19] We consider the possibility for pilot projects of size $N = 1, 2$ to simply focus on the underlying intuition distinguishing pilots of a different size. It is nevertheless straightforward to extend the analysis to $N > 2$, in which case all of the general insights that we highlight here continue to hold.

scaled projects off the ground.[20] While this seems straightforward and intuitive, we find that many important nuances arise. The most fundamental question is one that many agencies already face: Should they target subsidies towards pilot projects or full projects, where the later provides better information about a full project's likely success?

We show that the opportunity to conduct pilots can expand the set of socially beneficial, climate-related investments. Indeed, it can be worth spending more on a pilot than the expected loss from a project itself. The reason is that pilots create a quasi-option value because the learning that takes place allows for the abandonment of what might emerge as an undesirable project. With respect to subsidizing pilot projects, the expected subsidies are, in general, equal across the options of lowering a pilots cost's or focusing subsidies on the second stage of a project's costs or benefits. We also find that even when full projects are socially optimal, the possibility for conducting a pilot still has important implications. One result is that full project subsidies must include a premium to discourage private agents from suboptimally undertaking a pilot. Another is that subsidizing a full project's certain costs is more cost-effective than subsidizing its expected benefits. This result runs counter to the standard notion in economics favoring the efficiency of subsidizing outputs rather than inputs. Finally, we show that the scope for potentially valuable pilot projects can increase substantially when their size is endogenous.

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 our basic model, other topics that could be accounted for in future extensions include risk aversion and differences between private and public costs of conducting a pilot. Additionally, given the importance of setting subsidies at their minimum (i.e., incremental) cost, further research would be particularly useful on mechanism design in the deployment of climate finance to address problems of asymmetric information and moral hazard between the private and public sectors. The problem applies to full projects themselves, and pilot projects create another dimension over which the issues may arise. How the asymmetries and moral hazard are correlated across these dimensions is likely to affect whether pilot projects have further advantages or disadvantages than those described here.

References

Arrow, K., Fisher, A., 1974. Environmental preservation, uncertainty and irreversibility. Q. J. Econ. 88, 312–319.

Buchner, B.K., Oliver, P., Wang, X., Carswell, C., Meattle, C., Mazza, F., 2017. Global Landscape of Climate Finance 2017. A Climate Policy Initiative Report. San Francisco, California.

Buntaine, M.T., Pizer, W.A., 2015. Encouraging clean energy investment in developing countries: what role for aid? Clim. Pol. 51 (5), 543–564.

Ferraro, P.J., 2008. Asymmetric information and contract design for payments for environmental services. Ecol. Econ. 65 (4), 810–821.

Fischer, C., 2016. Environmental protection for sale: strategic green industrial policy and climate finance. Environ. Resour. Econ., https://doi.org/10.1007/s10640-016-0092-5 Forthcoming.

Fisher, A., 2000. Investment under uncertainty and option value in environmental economics. Resour. Energy Econ. 22 (3), 197–204.

Gompers, P.A., 1995. Optimal investment, monitoring, and the staging of venture capital. J. Finance 50 (5) 1461–1289.

Gompers, P.A., Lerner, J., 2004. The Venture Capital Cycle. MIT Press, Cambridge, MA.

IPCC, 2014. Climate Change 2014: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jack, K., Kousky, C., Sims, K.R.E., 2008. Designing payments for ecosystem services: lessons from previous experience with incentive-based mechanisms. Proc. Natl. Acad. Sci. Unit. States Am. 105 (28), 9465–9470.

Kerr, W.R., Nanda, R., Rhodes-Kropf, M., 2014. Entrepreneurship as experimentation. J. Econ. Perspect. 28 (3), 25–48.

Kotchen, M.J., 2015. A view from the United States. In: Barrett, S., Carraro, C., de Melo, J., ebook, VoxEU. (Eds.), Towards a Workable and Effective Climate Regime.

Kotchen, M.J., Negi, N.K., 2016. Cofinancing in Environment and Development: Evidence from the Global Environment Facility. NBER Working Paper 21139, and forthcoming in *The World Bank Economic Review*.

Mensink, P., Requate, T., 2005. The Dixit–Pindyck and the Arrow–Fisher–Hanemann–Henry option values are not equivalent: a note on Fisher (2000). Resour. Energy Econ. 27 (1), 83–88.

Nanda, R., Rhodes-Kropf, M., 2016. Financing entrepreneurial experimentation. Innovat. Pol. Econ. 16, 1–23.

Polasky, S., Lewis, D.J., Plantinga, A.J., Nelson, E., 2014. Implementing the optimal provision of ecosystem services. Proc. Natl. Acad. Sci. Unit. States Am. 111 (17), 6248–6253.

Sahlman, W.A., 1990. The structure and governance of venture-capital organizations. J. Financ. Econ. 27 (2), 473–521.

Stewart, R.B., Kingbury, B., Rudyk, B., 2009. In: Climate Finance: Regulatory and Funding Strategies for Climate Change and Global Development. New York University Press, New York.

Traeger, C., 2014. On option values in environmental and resource economics. Resour. Energy Econ. 37, 242–252.

UNFCCC, 2009. The Copenhagen Accord, in the Report of the Conference of the Parties on its Fifteenth Session. United Nations Framework Convention on Climate Change, FCC/CP/2009/11/Add.1.

UNFCCC, 2015. Conference of the Parties Twenty-first Session: Adoption of the Paris Agreement. In: United Nations Framework Convention on Climate Change, FCC/CP/2015/L.9.

World Bank, 2015. Funding Boost for Climate Action. The World Bank News. October 10, 2015.

World Economic Forum, 2013. The Green Investment Report: the Ways and Means to Unlock Private Finance for Green Growth. Geneva, Switzerland.

[20] 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 et al. (2008), and Polasky et al. (2014).