Additionality in Payments for Environmental Service Contracts with Technology Diffusion

Nicholas J Pates[1] and Nathan P. Hendricks[2]

[1]PhD Student and Graduate Research Assistant, Department of Agricultural Economics, Kansas State University, Manhattan, KS 66506, njpates@ksu.edu

[2]Assistant Professor, Department of Agricultural Economics, Kansas State University, Manhattan, KS 66506, nph@ksu.edu

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1 Introduction

Voluntary incentive payments, also known green subsidies are a popular method to incentivize farmers into adopting environmentally friendly practices. The United State Department of Agriculture's (USDA) latest budget directs over 4.5 billion dollars toward such programs. Notable domestic examples include the Conservation Reserve Program (CRP), the Environmental Quality Incentives Program (EQIP), and the Conservation Stewardship Program (CStP) and which are expected to have 380 million acres enrolled in these programs in 2016 USDA (2015). The prominence of these programs mean both conservationists and taxpayers have a serious stake in their effectiveness. There may be many measures of a policy's effectiveness but but whatever the measure, counter factual concepts such as additionality provides a useful ways of describing the benefits of a program.

Additionality is closely related to causality and is perhaps best explained in the context of an experiment. Additional benefits occur when a treatment (a green subsidy) encourages a subject (a farmer) to act in an intended way that creates benefits (environmental benefits) that would not have occurred in the control group (the same farmers not subjected to the policy). Pattanayak, Wunder, and Ferraro (2010) explain that asymmetric information and missing markets lead to non-additionality. Problems from asymmetric information can manifest as adverse selection on the part of the government or moral hazard on the part of applicants (Pattanayak et al. (2010), Claassen et al. (2014)). Although these problems are normally associated with insurance policies and not green payments, both stem from the same source, asymmetric information. The policy may suffer from adverse selection when the government offers payments to farmers that do not need financial incentives to generate environmental benefits or when these payments are higher than necessary. Moral hazard is rooted in rent-seeking behavior from farmers and can become a problem if program monitoring is sufficiently difficult or costly. A common example of moral hazard in environmental subsidies occurs in carbon emissions markets when farmers raise their baseline emissions before entering a carbon credit market in order to gain more sell-able credits.

To our knowledge, every study on additionality has framed the problem in a static settings. Our paper adds to the literature by examining additionality in a dynamic setting. This is an important contribution since environmental benefits are rarely earned during a single point in time but accrue over time through continuous stewardship. This assertion implies that a policy's impact on the *timing* of decisions is an important determinant of the policy's true environmental impact. Using a dynamic model allows us to consider a form of additionality that has not yet formally discussed or studied, additional periods of technology use. Policies that encourage individuals to adopt green technology earlier are generally preferred because it produces environmental benefits in the intervening periods between the assisted adoption period and the free market adoption period. In this paper, we will study additionality through a discrete-choice threshold model for a set of forward-looking, heterogeneous farmers considering when to adopt a 'green' (conservation) technology. Using comparative statics, we can show how changes to a policy affect the additionality of a policy.

2 Literature Review

Despite the promise of new sustainable technology, the benefits from these innovations only start to accrue after they are put into practice. Technology diffusion is especially important in environmental practices because environmental benefits generally accrue over time when green technology and stewardship are consistently put into practice. Jaffe et al. (2005) argue that because environmental cost are not internalized in the farmer's adoption decision, green subsidies could be used to hasten adoption of green technology and improve social welfare (Jaffe et al. (2005)). Kurkalova et al. (2006) examined green subsidies for conservation tillage in Iowa. They empirically separated the profitability of conservation tilling into a pure profit and a risk premium associated with adopting a new technology. Although actual profits from conservation tillage were *higher* than conventional tilling, only 36% of farmers had adopted the practice. They argue that subsidies are needed to overcome the risk premium associated with conservation tilling (Kurkalova et al. (2006)).

The effectiveness of environmental payment programs have been scrutinized in the recent literature. In particular, slippage has received notable attention. A policy may have slippage problems when its payments expand the a farmer's set of profitable choices. When these new choices undermine the environmental benefits of the policy, slippage occurs. In 2000, Wu estimated that set-aside payments from CRP program encourages expansion of farms. These farm expansions effectively reduced set-aside acres by 20% (Wu (2000)). In a 2011 paper, Lichtenberg and Ramirez also found evidence of slippage in the state of Maryland's cost-share programs. They showed that farmers participating in cost-share programs brought more marginal land into production. In that same paper they found that factors that were likely to improve the environmental benefits of the program such as the farm's proximately to bodies of water had little if any impact a farmer's probability of receiving payments (Lichtenberg and Smith-Ramirez (2011)). In a 2014 Choices article, Lichtenberg found similar evidence of poorly targeted policies across states. He found the share of EQIP spending was generally portioned to states by the number of farmers in each state and not by the state's impaired waters (Lichtenberg (2014)).

An issue related to slippage is additionality, the additional benefits the policy generates that would not have occurred had the policy not been in place. Generally the problem of non-additionality is thought of as an information problem between the policy maker/implementer and the farmer. Specifically, researchers claim that adverse selection on the part of the government is the underlying cause of non-additionality problems through either imperfect targeting of the subsidy or unnecessarily high payments (Mason and Plantinga (2013), Horowitz and Just (2013)). A relative few articles have brought up moral hazard in green payment policies. Moral hazard differs from slippage since slippage is usually associated with a program's payments leading more profitable choices that undermine environmental benefits. Moral hazard, on the other hand, is associated with rent-seeking actions on the part of the farmer. Pattanayak et al. (2010) briefly mentions that moral hazard behavior on the part of farmers could increase the costs of monitoring compliance of Payment for Ecosystem Services (PES) contracts (Pattanayak et al. (2010)). Claasen et al. (2014) identify moral hazard behavior in offset markets where farmers, in uncovered agricultural sectors, increase their baseline emissions before they enter the market to be eligible to sell more credits (Claassen et al. (2014)).

The literature on additionality is relatively sparse, especially in agricultural. Much of the literature approaches additionality with quasi-experimental designs to estimate additional benefits of programs

(Mezzatesta et al. (2013), Claassen et al. (2014), Czarnitzki and Licht (2006)) or through numerical simulation and theoretical models (Horowitz and Just (2013), Mason and Plantinga (2013), Khanna et al. (2002)). Propensity score matching seems to be an especially popular way of overcoming the counterfactual hurdles of additionality studies.

The literature suggests that non-additionality arises through several avenues. Pattanayak et al. (2010) summarizes four ways in which non-additionality enters Payments for Environmental Services (PES) contracts. Firstly, since the government does not have the counterfactual knowledge of what a program participant would do absent the program, it is difficult to say that any of the benefits are additional. Secondly, ill-defined policies could encourage adverse problems outside of the stipulation of the contract. For instance, payments given to farmers for their current practices are not considered additional since they were already in place before the policy. Lastly, farmers with foreknowledge of the program could change their behavior to maximize the benefits of the program as opposed to the economic or environmental benefits they would have received without the program, for instance increasing the baseline values as a way of maximizing program payoffs (Pattanayak et al. (2010)). Although Pattanayak et al. does not explicitly mention the dynamic problem of non-additionlity, the last point comes closest to our study as it concerns the moral hazard reaction of forward-looking farmers to current and future policy.

Claasen et al. 2014 found that non-additionality could arise in offset markets when the government is not able to ascertain whether uncovered farmers would reduce carbon emissions without an allocation of trade-able permits, any emissions reductions from farmers that received permits would be considered non-additional to the program. They found that additional reductions could be as low as 23% of the total offsets in the marketClaassen et al. (2014). Mason and Plantinga (2013) explicitly stated the costs of asymmetric information as 'information rents' in their study on forestation incentive policies. From their simulations, they concluded that a contracting system versus a uniform subsidy could reduce government for reaching forestation targets by half or more (Mason and Plantinga (2013)).

Horowitz and Just (2013) provided a more theoretical analysis of additionality and showed that the counterfactual profits need to be considered in policy design. They highlighted that in voluntary programs there will be a trade-off to the policy maker of avoiding non-additional payments and generating an attractive program to farmers and provided a framework for designing effective policies for offset programs. An ideal policy will provide enough compensation to *just* incent a positive environmental change Horowitz and Just (2013).

3 Conceptual Model

In this section, we introduce our conceptual model and begin with a simple version with a single farmer making a decision on when best to adopt a green technology under free-market and subsidized scenarios. Our model is largely influenced by the technology diffusion literature. In particular, we use what is known as a threshold model, a standard among economists analyzing diffusion (Sunding and Zilberman (2001)).

Suppose some farmer (f), using conventional technology is faced with a problem in period 0. The farmer, planning according to a time horizon in period T, needs to decide the optimal time to adopt a green technology. Suppose further that the green technology is too costly to remove once it is installed so we assume that the farmer cannot switch back to conventional technology after he chooses to adopt the green technology. Upon adopting the green technology, he incurs a one-time installation cost c_τ. This cost is assumed to decline over time as the technology becomes cheaper and easier to install $\frac{\partial c_\tau}{\partial \tau} < 0$ and these cost improvements decline over time as the technology matures $\frac{\partial^2 c_\tau}{\partial \tau^2} > 0$. If the government does not subsidize adoption at any future period, the problem for the forward-looking farmer f becomes:

$$(1) \quad \max_{\tau} \Pi(\tau) = \sum_{t=1}^{\tau-1} \beta^t \pi_{f,S} + \sum_{t=\tau}^{T} \beta^t \pi_{f,C} - \beta^\tau c_\tau$$

where $\pi_{f,S}$ and $\pi_{f,C}$ are the one-period profit terms for farm (f) using standard technology, and conservation technology respectively, $\beta < 1$ is the discount factor.

Because the choice of τ is not a continuous one, taking the derivative of (1) with respect to τ is not appropriate. Instead we use differentials to compare the profit from adopting at time τ and time $\tau + x$ where $x \geqslant 1$:

$$(2) \quad \Pi(\tau + x) - \Pi(\tau) = -\sum_{t=\tau}^{\tau+x-1} \beta^t \Delta_f + \beta^\tau c_\tau - \beta^{\tau+x} c_{\tau+x} \ : \ x \geqslant 1$$

where $\Delta_f = \pi_{f,C} - \pi_{f,S}$ is the relative revenue of the conservation technology over the standard technology farm f receives every period it uses the green technology. We assume that Δ_f is positive for all farmers, that is the green technology generates more revenue than the standard technology. If (2) is positive, then it is more profitable to adopt the green technology in period $\tau + x$ relative to τ and the farmer will wait to adopt the technology for at least another period.

Rearranging (2) and expressing it as an inequality, we get:

$$(3) \quad \psi(\tau, x) = \frac{c_\tau - \beta^x c_{\tau+x}}{\sum_{t=0}^{x-1} \beta^t \Delta_f} \gtreqless 1$$

Expression (3) reveals a fundamental trait of adoption when Δ_f is constant over time. Close inspection of ψ reveals that when the farmer adopts in period τ instead of $\tau + x$ it is akin to purchasing an annuity, an investment with periodic payments that remain constant over time. The "purchase price" of this annuity is the increased cost of adopting in period τ relative to $\tau + x$, represented in the numerator. The annuity's "payment value" is Δ_f, paid out over the intervening x periods between τ and $\tau + x$. When ψ is less than one it is more profitable for the farmer to adopt in period τ relative to $\tau + x$ because the cost of the annuity is less than the value of the annuity. When ψ is less than one for all $x \in [1, T - \tau]$, the farmer will adopt the green technology in τ.

We can now demonstrate how the temporal context influences adoption. We will first show that the conceptual model conforms with the diffusion literature by taking the derivative $\frac{\partial \psi}{\partial \tau}$:

$$(4) \quad \frac{\partial \psi}{\partial \tau} = \frac{\frac{\partial c_\tau}{\partial \tau} - \beta^x \frac{\partial c_{\tau+x}}{\partial \tau}}{\sum_{t=0}^{x-1} \beta^t \Delta_f} < 0$$

The inequality holds because of the convexity of c_τ and from $\beta < 1$. This means that as time passes, farmers with smaller values of Δ will find it profitable to adopt the green technology. Technological diffusion will occur over time with $\frac{\partial c_\tau}{\partial \tau} < 0$ and $\frac{\partial^2 c_\tau}{\partial \tau^2} > 0$ as a sufficient condition.

Dynamic models are considerably more complex than static models because farmers not only consider whether to adopt but also when to adopt. An important concept that arises in this context is the *imminence* of an adoption decision. Imminence describes how far farmers look into the into the future when they make their adoption decisions. In other words, do farmers look to more imminent periods or more distant periods when they consider adopting? Recall that when a farmer finds it profitable to adopt in τ over any other future period the following inequality must hold for all x:

$$(5) \quad \psi = \frac{c_\tau - \beta^x c_{\tau+x}}{\sum_{t=0}^{x-1} \beta^t \Delta_f} < 1$$

This inequality will be most binding for larger values of ψ. When ψ decreases with x, farmers will use more imminent periods to inform their decisions and when ψ increases with x, farmers will look to more distant periods. Taking the derivative of ψ with respect to x we get:

$$(6) \quad \frac{\partial \psi}{\partial x} = -\frac{1}{\sum_{t=0}^{x-1} \beta^t \Delta_f} \left[\frac{\partial \beta^x c_{\tau+x}}{\partial x} + \beta^x \Delta_f \psi \right] \gtreqless 0$$

Because the first term in brackets is negative and the second term is positive, we are unable to definitively sign this term. To understand the ambiguity of the sign, it is useful to again think about the adoption decisions as the purchase of an annuity. The first term can be thought of as the change in the "purchase price" of the annuity. Since costs decline over time, farmers consider paying a higher price when they look to adopting in more distant periods. However, longer lasting annuities generate more income through more annuity payments. This effectively dilutes the purchase price over more periods. The second term represents this dilution effect. To see this we write out the second term:

$$(7)\quad \beta^x \Delta_f \psi = \frac{c_\tau - \beta^x c_{\tau+x}}{\sum_{t=1}^{x} \beta^{-t}}$$

When the dilution effect on the "purchase price"outweighs the increase in the purchase price, $\frac{\partial \psi}{\partial x} < 0$ which means that farmers will look to more imminent periods when they make their purchasing decisions. Based upon the first term in brackets in (6), this will occur when costs are declining sufficiently slowly. In other words, if farmers don't see the future purchase price of the adoption annuity changing very much in future periods, they will tend to look at the current price to inform their decisions. To simplify the remaining discussion of the conceptual model, we will assume that this is the case, that $\frac{\partial \psi}{\partial x} < 0$ so that we need only address period comparisons where $x = 1$.

$$(8)\quad \Pi(\tau + 1) - \Pi(\tau) = -\beta^\tau \Delta_f - \beta^{\tau+1} c_{\tau+1} + \beta^\tau c_\tau \gtreqless 0$$

Stated earlier in the generic comparison, when (8) is positive, farmers will decide to delay adoption for at least another period.

$$(9)\quad c_\tau - \beta c_{\tau+1} \geqslant \Delta_f$$

That is, if the relative profit from adopting the technology in period τ is less than the discounted cost of adopting the technology one period in the future, the farmer will choose to delay adoption by at least one period. However, if (9) holds for all periods from 1 to $\tau - 1$, but through declining costs, the inequality reverses (10), then the farmer will choose to adopt the technology in period τ.

$$(10) \quad c_\tau - \beta c_{\tau+1} < \Delta_f$$

We will use (9) and (10) as baseline equations to illustrate how subsidies or even the expectation of subsidies impact farmers' adoption decisions. We can interpret the left hand side of both of these inequalities as the cost savings from delaying adoption by one period and right hand side as the increase in revenue from adopting the technology in the current period versus the next period.

Consider now that the government, offers a one-time adoption subsidy s to farmers, given out by lottery to farmers expressing interest in the program. The government can observe past practices and, to avoid non-additionality, will only award a subsidy to farmers that have not adopted the green technology in the past. Consider that (9) holds but farmer f is informed that if he adopts the technology, he will receive a subsidy of s. The introduction of this subsidy increases the cost of delaying adoption by s. If the subsidy dissuades the farmer from delaying adoption then:

$$(11) \quad c_\tau - \beta c_{\tau+1} < \Delta_f + s$$

Although it may seem unrealistic to assume a subsidy is only offered in one period, this example parsimoniously demonstrates that for the subsidy to work, the subsidy, combined with the relative revenue, must be large enough to overcome the difference in the cost savings from delaying adoption by one period. It also shows that so long as s is positive, if (10) holds, (11) always holds. That is, farmers that find adopting profitable without a subsidy will also find it profitable to adopt with a subsidy. This point not only makes simulations more efficient it also introduces the first instance of non-additionality that is frequently cited in static analysis of subsidies. The government cannot distinguish between farmers that would consider technology profitable without the subsidy and the farmers that would need a subsidy in order to adopt the technology in a given period.

We continue to add complexity by supposing that the farmer is faced with the uncertain prospect of future subsidies. Consider that if the farmer waits, he will, due to the level of demand for subsidies and the program's budget have a probability of $\phi_{\tau+1}$ of receiving the subsidy in the next period. The prospect of future subsidies decreases the cost of delaying adoption, and has a slowing effect on technology diffusion. If the current subsidy is effective, it will not look as attractive as it did in equation (11) due to the extra opportunity cost of accepting the subsidy in period τ.

(12) $c_\tau - \beta\left[c_{\tau+1} - \phi_{\tau+1}s\right] < \Delta_f + s$

We define individuals where both (9) and (12) hold for a given subsidy as τ^{th} *period marginal free-market non-adopters* (MFN). These individuals have relatively weak free-market justification for not adopting the technology in period τ but if a subsidy were offered, would accept the offer. These are the farmers that the government is targeting with the subsidy.

There are a few details worth mentioning before we move on to scenarios where the farmer does not receive the subsidy but has the prospect of future subsidies. Firstly, the prospect of a future subsidy can keep farmers that would have adopted with a one-time-offered subsidy from adopting the technology. This is especially true when the probability of a subsidy is high. This paradoxically means that the subsidy will be most effective at avoiding non-additional payments when the probability of receiving it in the future is low. Secondly, if the discount factor β is less than 1, the effective current effective subsidy $s^e_\tau = s - \beta\phi_{\tau+1}s$ will be positive. This means that even with the prospect of future subsidies, farmers that would have adopted the technology in period t under free-market conditions, would adopt the technology in the first period it would be offered the subsidy. Lastly, the effective current subsidy, s^e_τ *increases* with the magnitude of the subsidy s. This means that increasing s will increase the level of additional benefits from free-market non-adopting farmers and, together with our second point, will not encourage waiting by the free-market adopters *provided that they are offered the subsidy.*

If we could stop here, we could say that the best way to encourage additional payments would be to offer a subsidy that maximizes the probability of choosing a sufficiently large pool of free-market non-adopters. In fact, survival analysis would be the literature of interest as the government could adjust the subsidy level according to the probability of the current applicant pool adopting in the current period, which is akin to the hazard function. However, the last scenario presents the true challenge of designing these green subsidy programs. Consider farmer f *does not receive* the subsidy in the current period but *has the prospect* of receiving it in the future. Suppose f is a free-market adopter where (10) holds and f is *not* offered the subsidy in period τ but has the *prospect* of receiving it in period $\tau + 1$. This prospect could be attractive enough to *delay* his adoption relative to his free market decision. A farmer that does not receive a subsidy finds it optimal to delay adoption by at least one period if the following condition holds:

$$(13) \quad c_{\tau} - \beta\left[c_{\tau+1} - \phi_{\tau+1}s\right] \geqslant \Delta_f$$

We define individuals where both (10) and (13) hold for a given subsidy as τ^{th} *period marginal free-market adopters* (MFA). These are that farmers have relatively weak justification *for* adopting in period τ in the free-market. This implication means that every period that these farmers do not receive a subsidy, they will continue to wait as long as (13) holds. The inequality shows that groups of farmers that are especially close to adopting a technology without the government's help are not the best candidates for subsidies. Farmers that are close to adopting under free-market conditions will not provide much additional benefits, and those that are marginal free-market adopters will wait until they receive a subsidy. This delaying effect will be worse when the subsidy's magnitude and the probability of receiving the subsidy in the future are high.

These scenarios demonstrate that, due to asymmetric information problems, any subsidy program can and probably will suffer from one problem or another. Any farmer that will adopt in the free market will accept a subsidy, and, by doing so, contribute non-additional benefits, increasing the cost of the program. However, by not awarding a subsidy to MFA farmers, results in adoption delay. Table 1 provides a summary of the potential types of farmers by using the inequalities[1]. The first two rows signify free market adopters (FA) and FMA farmers respectively. These inequalities were derived from (13). Since both FA and MFA would adopt in the free market (10) will be positive however the inequality (13) reverses between FA and MFA. Because FA and MFA are farmers that would have adopted the technology in the τ^{th} period in the free market they would both adopt the technology if a subsidy were offered to them in the τ^{th} period. However MFA would change their decision and delay adoption if they did not receive the subsidy in the τ^{th} period. The last two rows of the table represent MFN and free-market non-adopters FN respectively. The relations for these farmers come from (9) and (12). Both FN and MFN would not adopt in the free market in period τ. However, if the MFN were given a subsidy in the τ^{th} period, they would accept it and adopt the technology earlier. We will define the term *temporal additionality* as the additional number of periods of technology use that would not have occurred without the policy. Awarding the subsidy to FA and MFA will generate non-additional benefits. Only by awarding subsidies to MFN does the policy generate temporal additionality. However, without subsidies, MFA will delay their adoption.

[1]The relation to 0 differentiates between the adoption decisions in the free market.

Famer Type	Profit Relation	Adopts in Free Market	Free-Market Justification	Adopts With Subsidy	Adopts Without Subsidy
FA	$\beta\phi_{\tau+1}s < \Delta_f + \beta c_{\tau+1} - c_\tau$	Yes	Strong	Yes	Yes
MFA	$0 < \Delta_f + \beta c_{\tau+1} - c_\tau < \beta\phi_{\tau+1}s$	Yes	Weak	Yes	No
MFN	$\beta\phi_{\tau+1}s - s < \Delta_f + \beta c_{\tau+1} - c_\tau < 0$	No	Weak	Yes	No
FN	$\Delta_f + \beta c_{\tau+1} - c_\tau < \beta\phi_{\tau+1}s - s$	No	Strong	No	No

Table 1: Relation Summary of Adoption

We conclude this section by summarizing the effects of changes to each of the policy characteristics. The effect of subsidy level is largely determined by whether or not the government offers the subsidy to the farmer. If a farmer is offered a subsidy, raising the value of the subsidy will quicken adoption because it raises the cost of waiting to adopt. If the government does not offer a subsidy to the farmer, larger subsidies will delay adoption because they present higher potential profits if the framer decides to delay adoption by at least one period. We should therefore see more linear diffusion curves in policies with larger subsidies. High probabilities of receiving a subsidy encourage delay. This is because there is a smaller penalty for waiting, even if the government offers the farmer a subsidy in a given period.

4 Simulation

In the conceptual model section, we outlined how different farmers would react depending upon their characteristics captured in their relative profit Δ_f. To specify how this term varies over our set of farmers, we will use tie Δ_f to a heterogeneity term θ_f. This heterogeneity term is associated with characteristics that make the green technology relatively more profitable or easier to implement including managerial characteristics, farm characteristics etc. We assume that $\Delta_f = \Delta_f(\theta)$, where $\frac{\partial\Delta}{\partial\theta_f} < 0$ and $\frac{\partial^2\Delta}{\partial^2\theta_f} < 0$ (Figure 1). Individuals with smaller θ_f will be more likely to adopt early as they have a relatively larger green technology profit premium in each period. The simulation version of the model considers that there are N heterogeneous farmers where θ_f is distributed logistically. We chose this distribution since it is relatively easy to program and it is unimodal. This means that we should see the commonly observed S-shaped diffusion curve under free-market conditions (Sunding and Zilberman (2001)). As before, all farmers are forward-looking, and maximize profits over periods 0 to T. Like the conceptual model, we assume that once farmers adopt the green technology, they are not able to switch back to the traditional technology. Installation costs are assumed to decline over time and this is what drives diffusion of the green technology in the free-market.

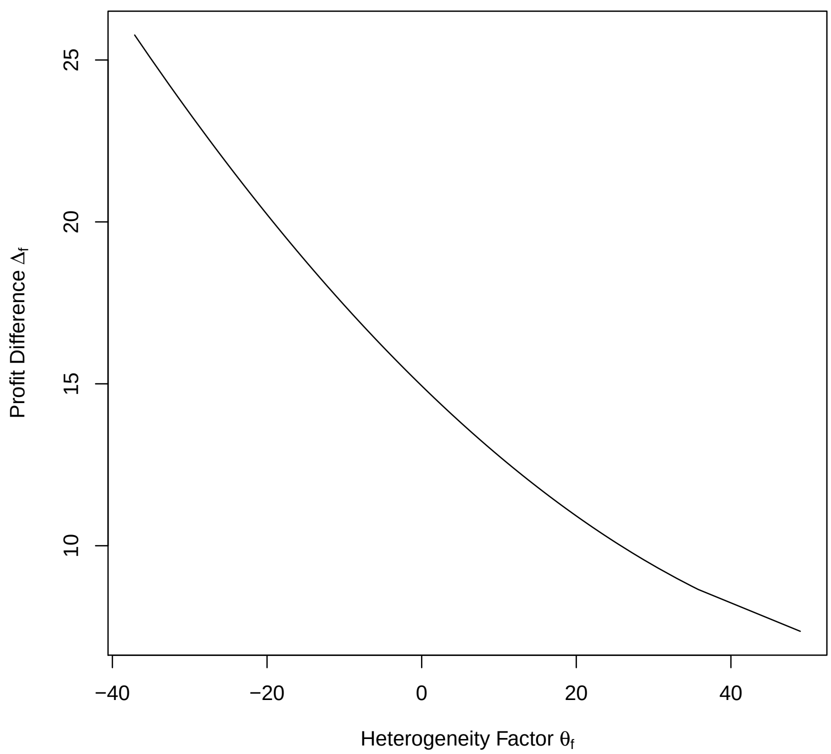

Figure 1: Relative Profit Over Heterogeneity Factor

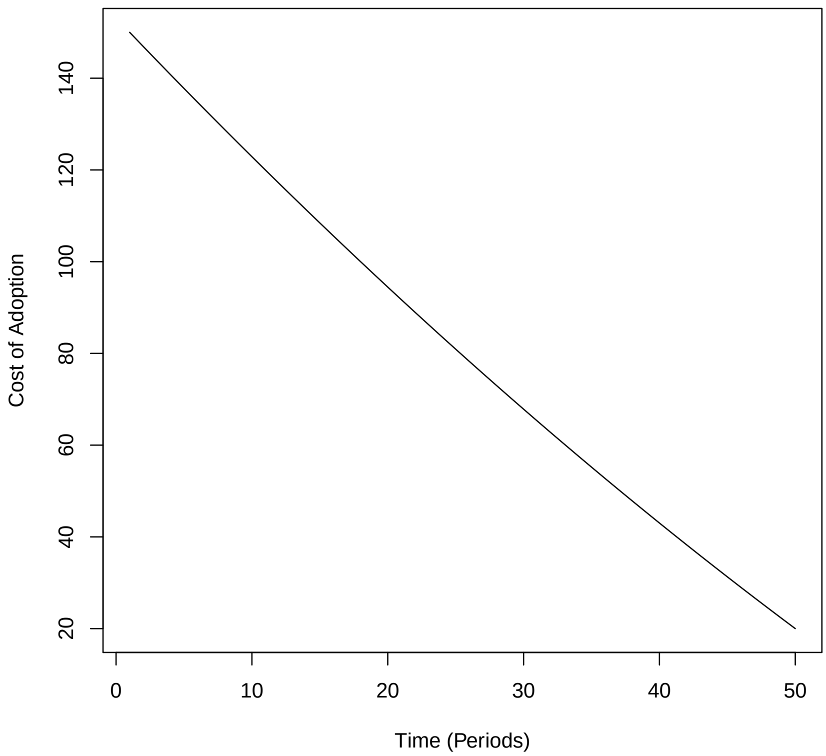

Figure 2: Cost of Adoption Over Time

We model each farmers' problem in terms of a longest path problem using a directional network graph. Figure 3 shows a 4-period version of the model[2]. Following the conventional operations research notation, farmers start at node s and solve for a path from node s to node t that maximizes the sum of the path's arc lengths which represent periodic profit. The blue nodes indicate periods where the farmer is using the standard technology and the green nodes indicate periods where the farmer is using the conservation (or green) technology. To solve the problem for each farmer, we use Dijkstra's algorithm. Although the Bellman-Ford algorithm is more popular among economists for solving discrete dynamic problems, Dijkstra's algorithm is faster and produces an identical solution if there are no negative weights Weber (2003). Because the graph is acyclic and flows in one direction, we can re-establish the profit weights by adding the absolute value of the smallest arc weight to all of the arcs without changing the problem.

[2]For the sake of readability, the discount factors are omitted from the figure.

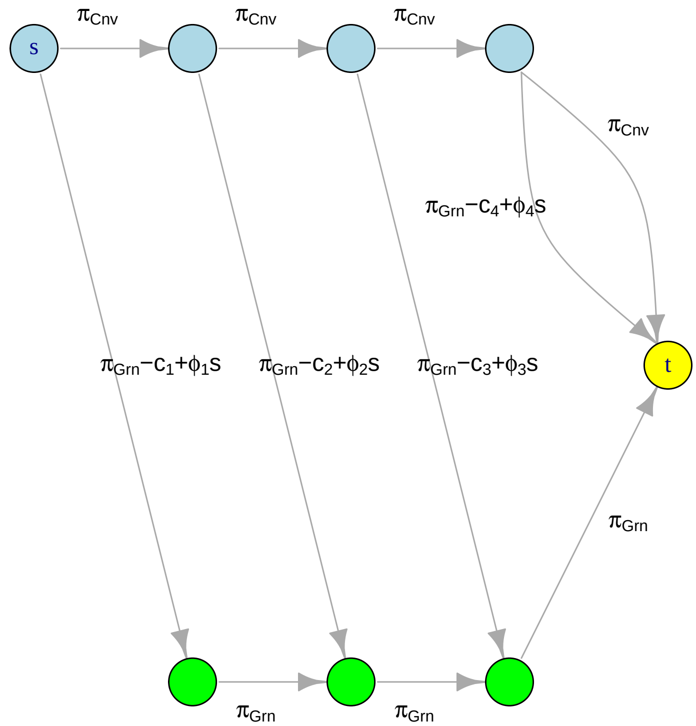

Figure 3: Discrete Dynamic Adoption Problem

It may be tempting at first to calculate diffusion analytically with the conceptual model. However throughout most of the section we assumed that $\frac{\partial \psi}{\partial x} < 0$ to simplify the discussion. We cannot assume this generally holds. Using the longest path problem,farmers consider every pairwise path comparison and get around the imminence problem. Diagraphs are a useful way to perform these simulations. In addition to producing an illustration, they easily allows for changes in the profit path structure and help avoid the complications of working with the analytical model. Initially we ran the model under free-market conditions. In this case the probability of receiving a subsidy in every period is, and is perceived to be zero. We examine how different policies impact different farmers by adjusting the arc weights in the diagraph, changing $\boldsymbol{\phi}$, π_{Cnv}, π_{Grn}, and s.

We define the policy in terms of four characteristics, the announcement period, the active period, the subsidy size (s), and the program's periodic budget (B). The announcement period is the period the government discloses the policy details to the public. The active period is the period when the policy first becomes active, that is, it is the first period a farmer could potentially receive a subsidy. We start out each simulation by running the optimization routine on all of the farmers in a free-market environment. Any farmer that adopts between the first period and the announcement period is taken out of the pool of farmers in further simulations.

We continue by simulating decisions between the announcement period and the active period. In this step of the simulation we include the expected value of the subsidies for periods after the active period but free-market profits assigned between the disclosure and the active period. Because farmers, like the government, are unable to observe the characteristics (θ_f) of the other farmers, they base their expectations on the farmers that the policy could conceivably subsidize in each period $\left(\frac{B}{s}\right)$ and the number of farmers that are eligible to receive a subsidy in a given period. This is not necessarily an unreasonable assumption as many of the several US incentives programs such as EQIP and CStP are run at the county-level (Lichtenberg (2014)). Any farmers that adopt between the announcement period and the active period are again removed from the pool of eligible farmers.

In the final simulation, illustrated in figure 4, we model the decisions of farmers after the policy becomes active. This simulation runs two optimization routines for each of the remaining farmers. The first routine adjusts the probability of receiving a subsidy in the current period to 100% for all of the remaining eligible farmers. Farmers that chose to adopt the technology in the current period are considered applicants to the subsidy program because, as we showed in the conceptual model, farmers adopting in the free market in period τ would also accept a subsidy in the τ^{th} period. The government takes a random sample of size $\left(\frac{B}{s}\right)$ to subsidize and the sampled farmers are removed from the pool of eligible farmers. The remaining eligible farmers then enter the second routine of the simulation.

The diagraphs for these farmers are adjusted, removing the subsidy in current period while keeping the expectations of subsidies in future periods. Any farmer that chose to adopt without the subsidy but with the expectation of future subsidies are removed from the pool of eligible farmers and the simulation moves forward by one period.

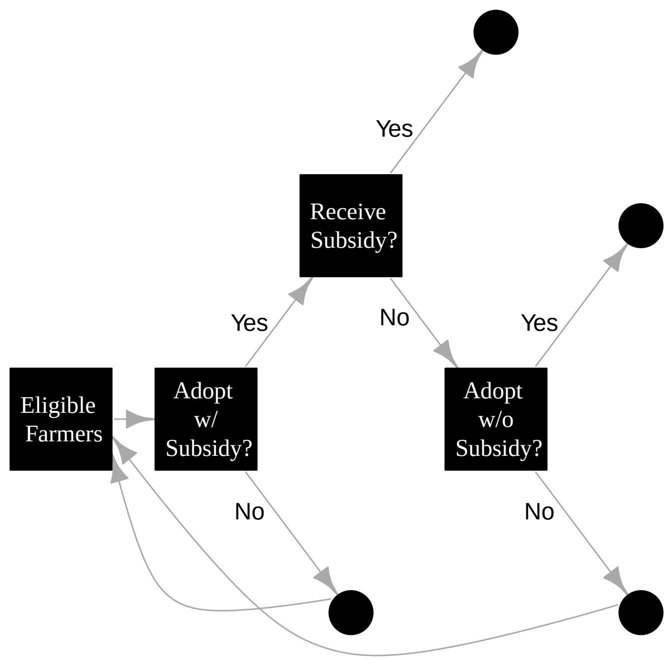

Figure 4: Post-Active-Period Simulation Schematic

In the conceptual model, farmers expectations of receiving a subsidy in the future is very important in the diffusion process. For this reason, we conclude this section with a detailed explanation of how these expectations are determined in the simulations. This will be determined in part by the number of farmers delaying adoption We assume that farmers have at least as much information as the government. For instance, they know the number farmers that are eligible for subsidies in each period. Another way of putting this is farmers know how many farmers have adopted the technology in each period. We also assume that the policy characteristics are all public knowledge. This includes knowledge of the budget and subsidy levels and, consequently, the number of potential subsidies that can be given out in each period. We also assume, like the government, farmers do not know the underlying characteristics of other farmers (θ). Because of this, it is unreasonable to assume that farmers expectations will match the observed probability of receiving a subsidy. These observed probabilities are influenced by the choices of the other farmers and in turn these choices are influenced by their characteristics. The random choices of the government further complicate calculating the observed probabilities of subsidization.

With information alone, we could generate farmers' expected probabilities of a recieving subsidies as:

$$(14) \quad E_t\left[\phi_{t+s}\right] = \frac{\frac{Budget}{Subsidy}}{(No.\ Eligible\ Farmers)_t - s \times \frac{Budget}{Subsidy}}$$

Where $E_t\left[\phi_{t+s}\right]$ is the expected probability of recieving a subsidy at time $t+s$ with information at time t. While this is a simple method of calculating expectations it is also naive. Under this framework, farmers could assume that a one time, one cent subsidy would encourage a laggard farmer to adopt many periods earlier than they would have in the free market. For this reason, we make an additional assumption that will allow us to generate a more reasonable expectations. We assume that farmers know the *distribution* of the heterogeneity factor $f(\theta)$. With this knowledge, farmers know how attractive a subsidy will be. Before each policy simulation, we run a series of other simulations that gives the entire set of farmers a subsidy in each of the active periods. From this, farmers will have a more reasonable assumption of the largest number of applicants to the policy in each period.

With this, we calculate the expected probability of receiving a subsidy in period t as:

$$(15)\quad E_t\left[\phi_{t+s}\right] = \frac{\frac{Budget}{Subsidy}}{(Eligible\ Farmers)_t - (Max.\ No.\ Expected\ Applicants)_{t+s} - s \times \frac{Budget}{Subsidy}}$$

While these expectations probabilities still will not correspond to the observed probabilities, they will be closer and relies on a set of reasonable assumptions. Delayed adoption from other farmers as well as the random dispensation of subsidies will still keep observations from matching expectations. It should be noted however, for small values of s the difference will be small and through the discount factor, expectations of subsidies further into the future are less important.

The baseline policy that we will use in our simulations is announced in the 20^{th} period, becomes active in the 25^{th} period, provides a subsidy of \$60 and is budgeted \$3000 in each period. These are the characteristics of the policy unless otherwise stated. We consider the decisions of 1,000 farmers over the course of 50 periods ($N = 1,000$, $T = 50$). With the aid of the conceptual model, the heterogeneity factor and adoption cost function were calibrated so that free-market diffusion at period 25 is approximately 50% and that costs reach approximately \$100 at period 25. We made these calibrations so that at the baseline active period the policy will resemble a 60% cost share, corresponding to average EQIP figures from 2004 to 2013 USDA (2014).

5 Results

In this section, we run the simulation model described in the previous section and vary the characteristics of the subsidy policy to see the impact on the aggregate adoption of the green technology. We run five batches of simulations changing the active period, the announcement period, the subsidy level, the budget level and a final batch where we proportionally change both the subsidy and budget. For each of these batches we also plot the free-market diffusion and the baseline policy. These benchmarks are important since illustrate how each of the policy characteristics impact additionality, non-additionality and delay. The results from each batch are shown in a series of three graphs. The first shows the green-technology diffusion curves under each of the policies as well as the free-market diffusion. As a contextual aid for the diffusion graph, we plot second graph showing the observed probability of receiving a subsidy over time was also included. These probabilities were calculated using the number of eligible farmers that would have accepted a subsidy in each period. Because diffusion curves do not highlight the choices of individual farmers, we also included a density plot showing the proportion of farmers that changed their periodic use relative to the free market for each policy. In addition to the graphs, we present a table for each batch showing summary statistics for 10 separate policies.

Varying Policy by Active Period

We start our simulations by comparing policies varying the period the active period. We present our results with a series of graphs and a summary table. The first graph shows the diffusion path of four scenarios. The black line corresponds to a free-market (no-policy) simulation. The colored lines correspond to policy simulations the red line corresponds to the diffusion of small-active-period policy where the policy becomes active in period 5. The blue line plots diffusion of the baseline policy. One thing to keep in mind is that the elements correspond to the same policy but we would not expect to see identical results due to the random selections from the government. Finally, the green line plots diffusion for a policy with a high active period, the policy becomes active in period 45. The second line graph plots the observed probabilities of receiving a subsidy in each period for each policy. The probability of subsidization was calculated by “offering” a subsidy to every farmer that did not choose to adopt in previous periods. Any farmer that chose to adopt in the offer period is considered an applicant. Because the budget and subsidy level are fixed in each simulation, divided the number of farmers the government could potentially subsidize by the number of adopters in each period. While the diffusion plot and the probability plots offer information on diffusion, they do not give information on the relative choices individual farmers.

The last graph shows relative-periods-of-use densities from the same policies. By subtracting each farmer's free market adoption period from the policy's free market adoption period, we can compare how the policy hastened or hindered adoption for individual farmers farmers. In the context of the density plot (-1) can be interpreted as the policy delaying adoption for the farmer by one period and a (+1) can be interpreted as the policy hastened a farmer's adoption by one period. Since the decisions of farmers in the periods before the policy is announced are not impacted by the policy, and when free-market adopters are subsidized, differencing their adoption period choices register as a (0). We therefore we only include decisions of farmers that adopted after the policy's announcement period in these plots.

The table presents the results of 10 simulations, varying the active period from period 5 to 50. The first row of the table shows the total temporal additionality of the policy. This is the total number of additional periods of green technology-use the policy generates relative to the free-market simulation. The second row of the table shows the total number periods that the policy delayed adoption relative to the free-market simulation. In the third row we add the second row to the first, we get the net number of periods of green technology-use that the policy generated. The numbers from the third row correspond to the density plot. The fourth and fifth rows show the highest number of additional periods of technology-use and longest delay observed from an individual farmer. For example, a policy that first becomes active in the 5th in period encouraged at least one farmer to adopt 32 periods before its free-market adoption period and led to another farmer to delay adoption by 8 periods. The next four rows of the table are measures of the cost of the program. The sixth row shows the total cost of the program, the seventh row shows the total expenditures given to farmers that hastened there adoption, the 8th row shows the total expenditure to farmers that either delayed adoption or were non-additional and the 9th row shows the proportion of total expenditure given to farmers that either delayed adoption or did not change their adoption period relative to their free-market decision. In the last row of the table we calculate the total number of periods that all of the farmers used the green technology and divided it by the total number of periods of green technology-use from the policy. This gives us a relative measure of how effective the policy is at encouraging earlier adoption.

The first thing to note about the diffusion graph (Figure 5) is the black free-market diffusion curve follows the familiar "S" shape that we see in the literature. We expect this result because θ is distributed as a unimodal logistic distribution. The diffusion graph also shows that under each of the policies, green technology diffusion practically halts between the announcement period and the initial active period. This reflects rent-seeking behavior on the part of farmers because after the announcement period farmers can take into account the expected value of the subsidy once the policy becomes active. We will call this slow down in adoption the policy's *initial delay*. Once the policy becomes active, diffusion accelerates faster than free-market diffusion as subsidies are given out. The policy that became active in period 5 saw a much faster diffusion than the baseline policy and the policy becoming active in period 45. When the policy becomes active in period 5, universal adoption occurs around period 19, period 30 when the policy becomes active in period 25, and period 45 when the policy becomes active in period 45. There is also less curvature in the policy diffusion curves relative to free-market diffusion. Using the probability line graph in conjunction with the diffusion graph, we see that the initial probability of adoption for the policy starting in period 5 was lower than the initial subsidization probabilities for the other policies. Because the policy starting in period 5 begins earlier in the diffusion process, there are more eligible farmers and the subsidy is high enough so that many of these farmers apply earlier than they would have in the free-market. We see an almost linear diffusion path in the period 5 policy. This is because the subsidy, as opposed to cost of adoption becomes primary driver of diffusion.

It may seem strange that the base policy diffusion curve has more curvature than the

Active 5 policy. Although the Active 5 policy attracts more applicants initially, there are also fewer initial applicants that had the opportunity to delay adoption because the Active 5 policy began early in the diffusion process. This meant, for a given year, there was a lower probability of the government choosing a farmer that is delaying adoption. Table 2 shows that the spending on non-additional farmers for an Active 5 policy made up only 9% of total expenditures, a smaller proportion than all of the other simulations in the table. Based upon the implications of the conceptual model the larger probability of subsidization in the base policy also suggests that we should see slower diffusion rate relative to the Active 5 policy. The larger probability of future subsidization means that more farms are willing to delay adoption when they do not receive a subsidy. We therefore the density plot reveals that more farmers delay adoption in the base policy than in the Active 5 policy.

The active 45 policy barely registers in the diffusion graph. This is because there are few eligible farms left in the diffusion process. While the smaller pool of eligible farmers limits the damage of the program in terms of delayed adoption and total expenditures it also means that there will be a higher initial probability of receiving the subsidy which means that most if not all of the farmers will apply and receive the subsidy. Due to the concavity of the diffusion curve later in the diffusion process, this means that the policy will experience more delayed adoption. This is shown in both the density plot and proportion of total expenditures given to non-additional adopters in the table.

The descriptive example shows that the government should be targeting subsidies to cutting-edge technologies as opposed to trying to convert laggard farmers to established industry standards. Subsidy policies create 'bubbles' in the diffusion curve when rent-seeking farmers delay adoption relative to their free-market decisions. The larger the pool of rent-seeking farmers is relative to the total applicant pool, the less likely legitimate applicants will receive a subsidy creating the potential for even more rent-seeking from the farmers that were denied subsidies. There are trade-offs to this strategy. Table 2 shows that while wasted funds are lower, overall program costs are higher when the policy begins earlier.

By the active 30 policy, the program actually causes environmental damage and becomes unjustifiable to environmental stakeholders despite the smaller overall cost to taxpayers.

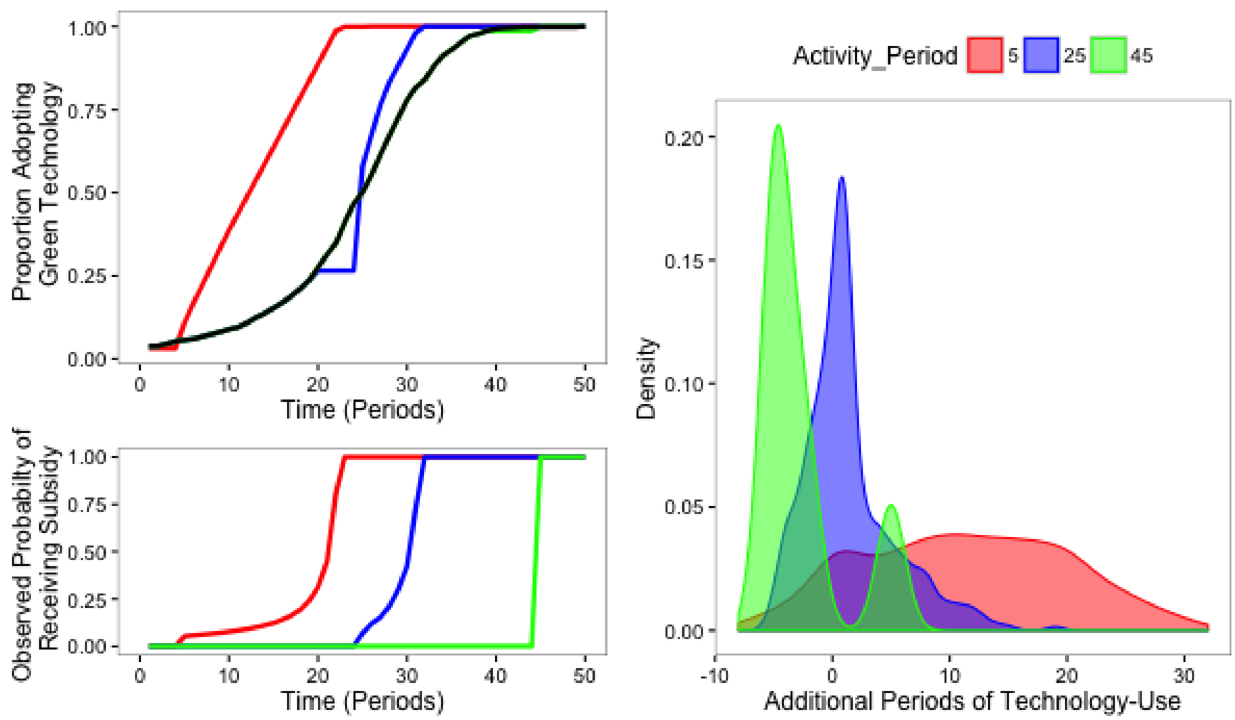

Figure 5: Diffusion, Probability of Subsidization and Relative Technology-Use Density by Activity Period

	Activity Period									
	5	10	15	20	25	30	35	40	45	50
Tot. Temp. Add.	11514	7934	5090	3049	1592	469	112	27	10	0
Tot. Delay	−267	−342	−359	−309	−517	−1090	−1127	−292	−45	0
Temp. Add. Minus Delay	11247	7592	4731	2740	1075	−621	−1015	−265	−35	0
Largest Tem. Add.	32	29	34	25	19	20	13	10	5	0
Longest Delay	−8	−9	−6	−5	−5	−7	−10	−6	−5	0
Total Policy Cost (Dollars)	54780	51000	43560	33180	22080	19920	16500	5280	780	120
Additional Spending (Dollars)	49920	44160	36120	26640	17040	6600	2100	240	0	0
Non-Additional Spending (Dollars)	4860	6840	7440	6540	5040	13320	14400	5040	780	120
Non-Add. Spending / Total Policy Cost	0.089	0.134	0.171	0.197	0.228	0.669	0.873	0.955	1	1
Pct. Increase in Periodic Use	0.434	0.325	0.213	0.137	0.064	−0.06	−0.225	−0.239	−0.35	NA

Table 2: Effects From Changing the Activity Period

Varying Policy by Announcement Period

In our next set of simulations we vary policies by the number of periods of notice farmers receive before the policy becomes active. The line graph in the results plots are constrained to the earliest announcement periods to best show the differences between the policies. The first difference we see between the policies is the initial slowdown is more pronounced as the number of periods of notice rises. This is because when the level of notice is reduced farmers that would have adopted between the announcement period and the active period is relatively small. There is a limit to this however. Although the Notice 9 policy has four more periods of notice relative to the baseline policy, the level of initial delay in the Notice 9 policy is comparable to the baseline even slightly smaller. This is partly from the earlier adopters forgoing the prospect of a subsidy to generate larger profits and partly from the way that farmers generate their initial expected subsidy. Because farmers are not able to estimate the number of initial applicants, they instead use the total number of adopters if every farmer were given a one-time subsidy in the inital active period and subtract cumulative adoption between period 1 and the announcement period. This means that when policies give more notice to farmers, they perceive they will initially have a smaller probability of receiving a subsidy. This reduces the delay from farmers that do not receive the subsidy leading to more rapid diffusion.

Another result we see is that the diffusion path of the Notice 1 policy is more linear and closer to the free-market diffusion curve. This is because the initial probability of subsidization is larger. The higher probability attracts more applicants which means that more applicants will delay adoption if they do not receive the subsidy. In turn this causes a linear diffusion curve, a longer path to full diffusion, and is evidenced by the higher initial probability and less steep probability curve. The density curves between the simulations look very similar but policies with more notification tend to lead to cause less extreme delays. This is further reflected in the table when we compare more announcement simulations. Total program expenditures when the periods of notification increase. The cost reduction is driven by the expenditures to non-additional adopters.

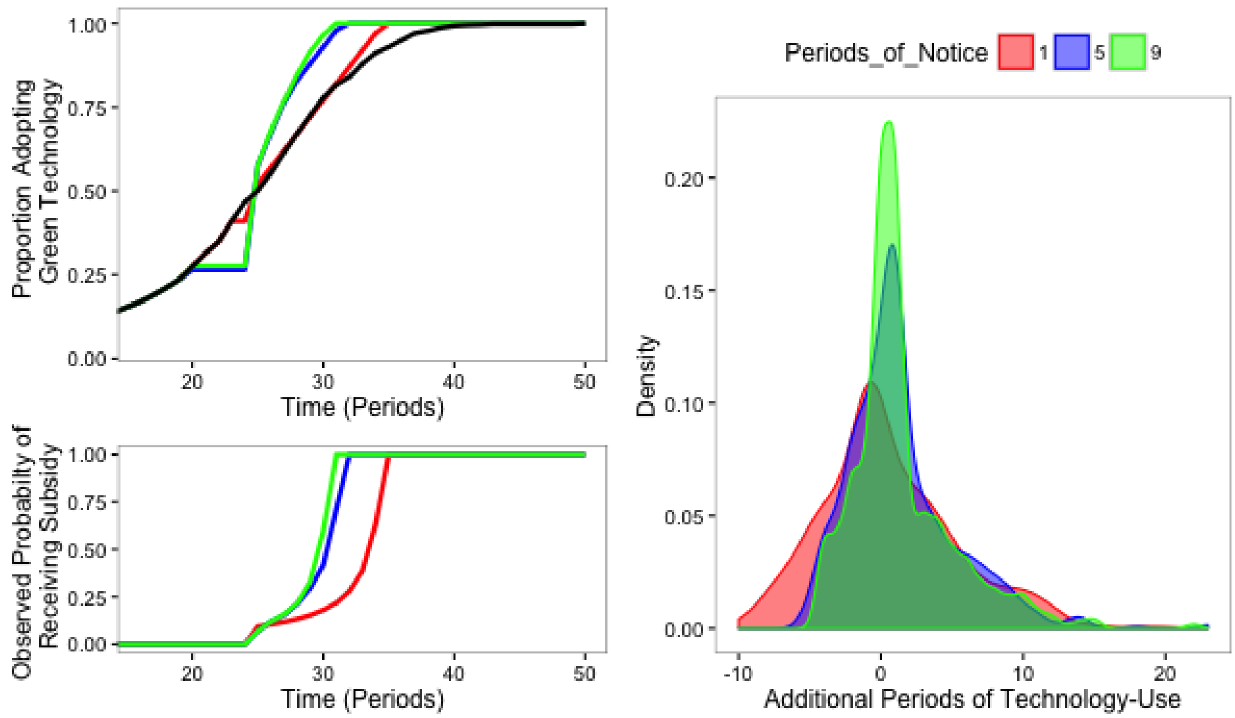

Figure 6: Diffusion, Probability of Subsidization and Relative Technology-Use Density by Notification Periods

	Notificaiton Periods									
	1	2	3	4	5	6	7	8	9	10
Tot. Temp. Add.	1221	1387	1423	1518	1597	1605	1640	1643	1678	1691
Tot. Delay	−897	−699	−572	−555	−532	−504	−452	−440	−437	−435
Temp. Add. Minus Delay	324	688	851	963	1065	1101	1188	1203	1241	1256
Largest Tem. Add.	20	22	23	23	23	22	22	24	22	23
Longest Delay	−10	−8	−6	−4	−5	−5	−5	−4	−4	−4
Total Policy Cost (Dollars)	31740	28680	26700	24120	22200	22020	20580	20580	20040	19560
Additional Spending (Dollars)	15060	15660	16860	16800	16980	17100	16980	16800	16800	16320
Non-Additional Spending (Dollars)	16680	13020	9840	7320	5220	4920	3600	3780	3240	3240
Non-Add. Spending / Total Policy Cost	0.526	0.454	0.369	0.303	0.235	0.223	0.175	0.184	0.162	0.166
Pct. Increase in Periodic Use	0.027	0.051	0.059	0.062	0.063	0.063	0.065	0.063	0.064	0.063

Table 3: Effects From Changing the Periods of Notice

Varying Policy by Subsidy Level

We next compare policies by their subsidy level. Increasing the subsidy will have two effects. Higher subsidies will be more attractive to farmers so it will encourage farmers that receive the subsidy to adopt but will also encourage delay among farmers that do not receive the subsidy. This in turn will cause the probability of recieving a subsidy to fall as the subsidy level itself increases. Figure 7 shows that the Subsidy 12 policy gives farmers a far higher probability of receiving a subsidy against the baseline and the Subsidy 108 policy. In spite of the higher probability of subsidization, the Subsidy 12 policy diffusion has more curvature, implying that the subsidy is not large enough to encourage earlier adoption for many farmers, even after subsidization is certain. The baseline policy and the Subsidy 108 policy the most similar in terms of diffusion and probability of subsidization. The diffusion curves of both policies exhibit an almost piecewise linear shape although the baseline policy has slightly more curvature. Under the baseline and the Subsidy 108 policy, subsidies are large enough so that the policy as opposed to the cost is the main driver of diffusion. Roughly speaking, the slope of the diffusion curve under the baseline is higher than the Subsidy 108 policy. This is a consequence of the probability of subsidization being larger under the baseline policy. Simply put, a smaller subsidy level means the government can subsidize more farmers in each period with the same budget.

Table 4 also reflects the two effects of raising the subsidy. Total delayed periods tends to decline as the subsidy level rises. Although many of the variables rise and fall with the subsidy, spending on total additionality rises with the subsidy level. We would additional spending to increase as both the subsidy rises and the probability of subsidization falls. As the subsidy level rises, there is a smaller chance that a farmer that delays adoption will be subsidized and each subsidized farmer receives more funding as the subsidy level rises. While spending on additional adopters increases, the simulations suggest that the Subsidy 72 policy achieves the higher net periods of technology use, a greater overall percentage increase in technology use with less total expenditures.

The results give important information for policy makers as well as lobbying groups. It may be tempting to generously subsidize farmers for adopting green technology but this undermines the benefits generated earlier in the diffusion process. Unsubsidized farmers that would have been earlier adopters under smaller subsidies will delay adoption when the government offers larger ones. The rise and fall of the policy's environmental impact as subsidies rise clearly demonstrate policy makers must take rent seeking on the part of farmers into account during the design. When subsidies are set high enough, they tends to dictate diffusion rates more than the actual adoption costs. When this is the case, policy makers should subsidies should be set at their lowest possible level while maintaining the linear relationship. This will ensure farmers that are waiting for a subsidy do not have to wait too long.

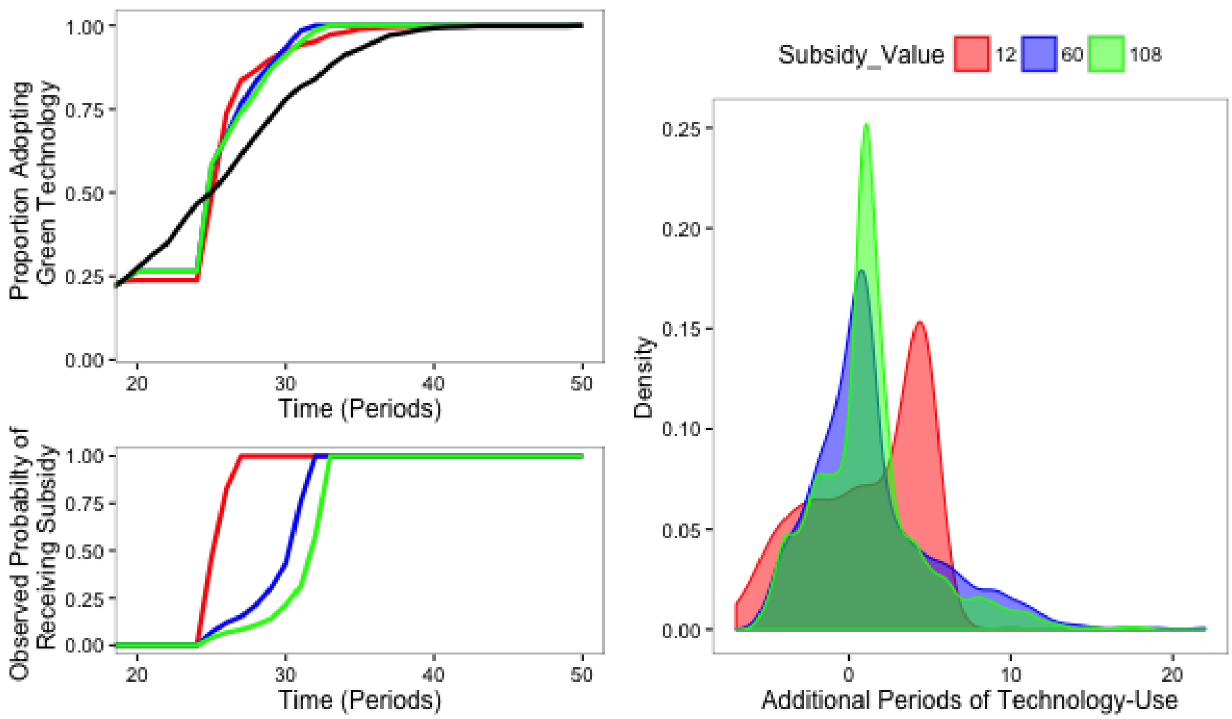

Figure 7: Diffusion, Probability of Subsidization and Relative Technology-Use Density by Subsidy Level

	Subsidy Level									
	12	24	36	48	60	72	84	96	108	120
Tot. Temp. Add.	1681	1781	1651	1568	1604	1636	1525	1473	1433	1378
Tot. Delay	−813	−1106	−942	−699	−521	−489	−489	−489	−489	−489
Temp. Add. Minus Delay	868	675	709	869	1083	1147	1036	984	944	889
Largest Tem. Add.	10	15	19	22	22	23	23	20	18	21
Longest Delay	−7	−8	−7	−5	−5	−5	−5	−5	−5	−5
Total Policy Cost (Dollars)	9084	17208	20844	22632	21960	21000	23436	25056	25620	27000
Additional Spending (Dollars)	3360	8616	12168	15312	16860	17928	18900	19872	19872	20040
Non-Additional Spending (Dollars)	5724	8592	8676	7320	5100	3072	4536	5184	5748	6960
Non-Add. Spending / Total Policy Cost	0.63	0.499	0.416	0.323	0.232	0.146	0.194	0.207	0.224	0.258
Pct. Increase in Periodic Use	0.052	0.04	0.042	0.052	0.064	0.068	0.062	0.059	0.056	0.053

Table 4: Effects From Changing the Subsidy Level

Varying Policy by Budget Level

Varying the policy by the budget level produces similar results to varying the policy by the subsidy and largely for same reason. Increasing the budget will also increase the probability of receiving a subsidy. Higher probability in turn, encourages delay. Smaller budgets mean fewer farmers can actually be subsidized and will restrict the potential benefits of the policy. Figure 8 shows the diffusion rate for the Budget 600 policy produces less initial delay and closely follows free-market diffusion beyond the active period. The technological-period change density shows that the most of the Budget 600 period changes came from farmers either slowing or hastening adoption by two periods or less. Under a larger budget as in the Budget 5400 policy, the incentive to delay great enough to cause linear diffusion. The larger budget also causes more initial delay.

Table 5 shows the effect of budget changes in greater detail. Policies with budgets between $600 and $3000 tended to increase benefit from budgetary increases. Net periodic technology tended to rise over this interval and sharply fell at a budget $3600. At this point, damage from delaying adoption begins to work against the benefits of the policy. The table also shows what happens when the subsidy gets especially large. In the last two columns the policy subsidizes every farmer that did not adopt before the announcement period, 764 farmers. When budgets are increased beyond this point, the damage from delay goes down because the government can subsidize the remaining farmers more quickly. While extremely large budgets can potentially lead to higher periodic use increases, such policies are less politically feasible since more funds need to be set-aside. Over the budget interval in our study, net period use was largest under the Budget 2400 policy. This yeilded a 6.6% increase in periodic use relative to the free-market.

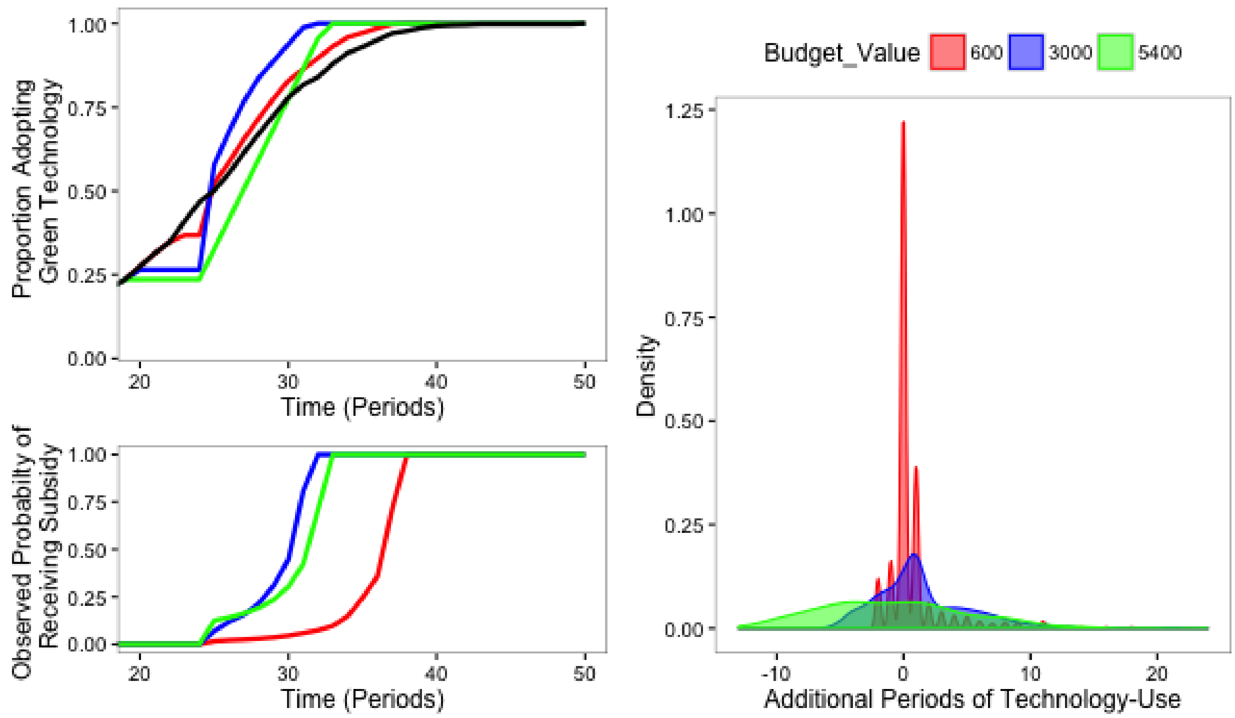

Figure 8: Diffusion, Probability of Subsidization and Relative Technology-Use Density by Budget Level

	Budget Level									
	600	1200	1800	2400	3000	3600	4200	4800	5400	6000
Tot. Temp. Add.	615	1011	1328	1505	1627	1432	1410	1437	1518	1632
Tot. Delay	−141	−229	−323	−391	−521	−986	−1547	−1798	−2103	−1893
Temp. Add. Minus Delay	474	782	1005	1114	1106	446	−137	−361	−585	−261
Largest Tem. Add.	18	24	21	24	21	23	18	23	24	25
Longest Delay	−2	−3	−4	−4	−5	−7	−9	−11	−13	−12
Total Policy Cost (Dollars)	7920	12480	15600	18180	21720	30420	37080	41460	45840	45840
Additional Spending (Dollars)	6180	10140	12360	15240	17400	17760	17940	17700	18120	18300
Non-Additional Spending (Dollars)	1740	2340	3240	2940	4320	12660	19140	23760	27720	27540
Non-Add. Spending / Total Policy Cost	0.22	0.188	0.208	0.162	0.199	0.416	0.516	0.573	0.605	0.601
Pct. Increase in Periodic Use	0.028	0.047	0.06	0.066	0.066	0.027	−0.008	−0.021	−0.035	−0.016

Table 5: Effects From Changing the Budget Level

Varying Policy by Both Budget and Subsidy Levels

In our final set of simulations, we proportionally vary the policy's subsidy and budget. We do this to isolate the effect of increasing a subsidy without changing the number of applicants the government can subsidize in a given period. The policy's effects are more neatly stratified by the Budget and Subsidy (BS) level. As expected, figure 9 the observed probability of subsidization increases as the budget and subsidy level decrease. Holding the number of applicants the government can subsidize, constant, the probabilities are determined by the number of applicants the policy attracts. Since higher subsidy levels attract more applicants, the lower BS policies should have higher a probability of subsidization in each period. Like the sets of simulations where we varied the subsidy and budget independently, we see less curvature and more initial delay as the budgets and subsidy increased.

Table 6 shows that when we proportionally increase the budget and subsidy level we see that the total policy cost increases. In general, the percentage change in periodic use and the net periodic technology-use relative to the free-market simulation also decreases. This is because higher subsidies, like higher probabilities, encourages farmers that don't receive a subsidy delay adoption. Taken together, these two results are intriguing as it means that relatively modest sized policies can outperform larger ones. The best policies in terms of net periodic use and percentage increase in periodic use relative to free-market adoption cost around 50% less than the baseline policy.

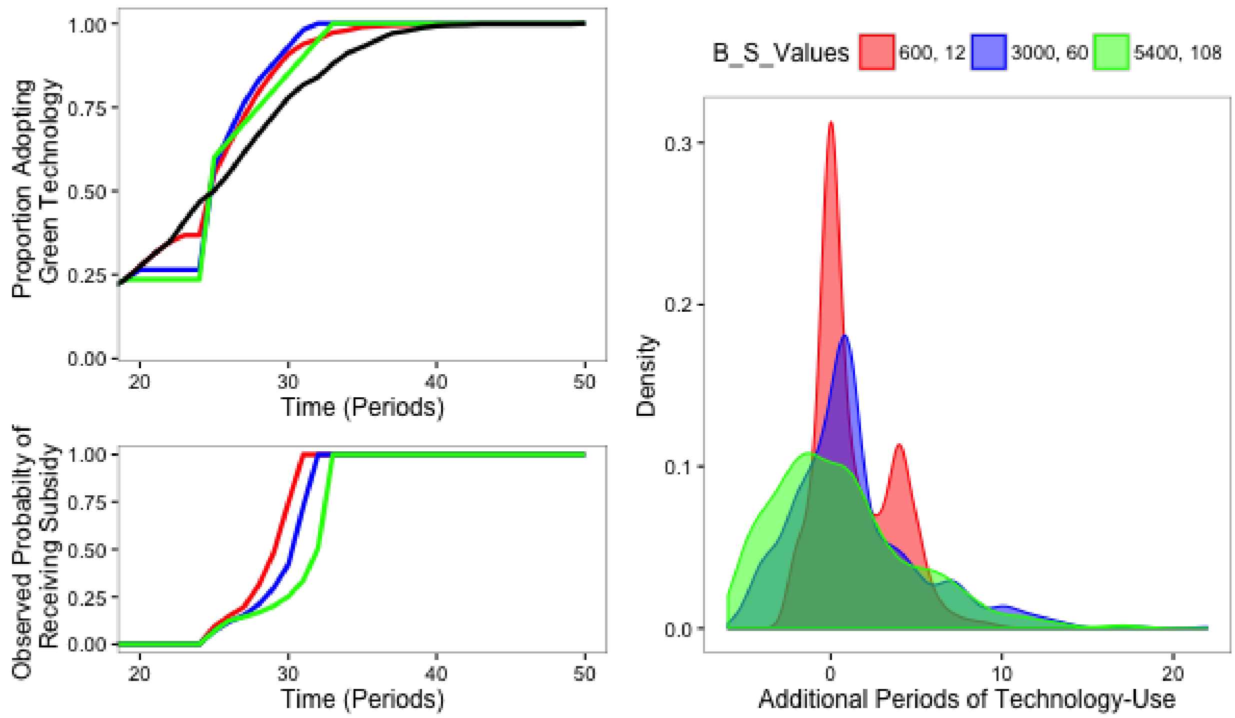

Figure 9: Diffusion, Probability of Subsidization and Relative Technology-Use Density by Budget and Subsidy Level

	Budget and Subsidy Level									
	600, 12	1200, 24	1800, 36	2400, 48	3000, 60	3600, 72	4200, 84	4800, 96	5400, 108	6000, 120
Tot. Temp. Add.	1207	1524	1560	1619	1583	1605	1588	1562	1441	1412
Tot. Delay	−141	−229	−323	−397	−520	−638	−757	−827	−946	−1015
Temp. Add. Minus Delay	1066	1295	1237	1222	1063	967	831	735	495	397
Largest Tem. Add.	10	15	19	21	22	23	24	20	18	20
Longest Delay	−2	−3	−4	−4	−5	−5	−5	−5	−6	−7
Total Policy Cost (Dollars)	4692	8280	12420	16512	22140	27288	33600	39936	48492	55200
Additional Spending (Dollars)	3972	6912	10224	13680	17220	19944	23100	26688	29160	32880
Non-Additional Spending (Dollars)	720	1368	2196	2832	4920	7344	10500	13248	19332	22320
Non-Add. Spending / Total Policy Cost	0.153	0.165	0.177	0.172	0.222	0.269	0.312	0.332	0.399	0.404
Pct. Increase in Periodic Use	0.063	0.077	0.074	0.073	0.063	0.058	0.049	0.044	0.029	0.024

Table 6: Effects From Changing the Budget and Subsidy Level

6 Conclusions

The results from this paper demonstrate that policy makers must be mindful of the policy and the environment that the policy is being introduced into. Ideally, the government should try to identify and collect as much information pertaining the profitability of the green technology as possible. This will help avoid asymmetric information problems. In the face of asymmetric information, payment policies are likely face non-additional expenditures or adoption delay or both. Because environmental benefits accrue over time, these delays can be viewed as environmental damage caused by the policy.

While a degree non-additional payments or adoption delay is inevitable when the government faces asymmetric information problems, their severity can be mitigated with proper policy design. Policymakers need to be aware of new technology and its potential for improving profits and the environment. Our results showed that policies targeted at cutting-edge technology, ones early in their diffusion process, produce more temporally additional benefits, more effectively target funds towards legitimate applicants, but generally have a higher overall cost. Farmer expectations play a large role in the policy's overall effectiveness. When farmers receive more notice, initial delays drive down the probability of a given farmer receiving a subsidy in the future. This ultimately discourages delay, driving down total expenditures and improving periodic use relative to the free-market. Changes to the budget and subsidy levels produced similar results due their effect on the probability of subsidization. The impact of changing either the budget or the subsidy level depends upon the of the original subsidy. What is clear from the simulations is that larger budgets or subsidies do not necessarily produce more additional benefits. This means that larger programs are not necessarily optimal. At extreme budget and subsidy levels, diffusion is driven more by the policy and not the cost of adoption and tend to lead to linear diffusion curves. These indicate that farmers that are denied subsidies will wait to adopt the technology to remain eligible to reapply in future periods. This is a clear demonstration of moral hazard behavior that has been largely ignored by previous literature.

Simulations like the ones carried out in this paper could be a useful tool for policy makers. With proper information on free-market diffusion, the simulations can help specify policy parameters that maximize the policies effectiveness and also adhere to their departmental budget constraints. This style of simulation also shows promise for further studies. Carrying out the simulations with a diagraph gives the researcher a great deal of flexibility. Farmers could apply for a variety of green payment programs and with a few changes to the digraph, these choices could also be incorporated into the decision. The simulations in this paper emphasize, that if environmental benefits accrue over time, the additionality of incentives programs should also have a dynamic component. Viewing the adoption dynamically reveals important information to stakeholders.

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