Teaching and Educational Methods

# Seeds of Learning: Uncertainty and Technology Adoption in an Ecosystem-Based Adaptation Game

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**Abstract**
We introduce an interactive game exploring ecosystem-based adaptation (EBA) to climate change, with a focus on technology adoption and uncertainty. The game is useful in academic classes and training sessions for policy makers and stakeholders. Participants play the role of small-scale farmers in a developing country where their farming practices cause erosion that pollutes waterways, while at the same time climate change is making farmers more vulnerable to natural threats like flooding. The game gives participants a series of opportunities to adopt EBA practices: for example, a riparian buffer strip, low-till farming, and agroforestry. The practices differ in the uncertainty surrounding their effects on yields. The game deploys three policies to encourage adoption: a flat payment, a conservation auction, and a flat payment with a pilot bonus for early adoption. Players observe each other's choices and outcomes, which allows for social learning. Participants get a hands-on understanding of climate change's impacts, adaptation, ecosystem services, payment for ecosystem service programs, choice under uncertainty, social learning, adoption of new technology, learning spillovers, cost-effective conservation, and conservation auctions. We provide all materials necessary to run the game, a list of suggested readings, and ideas for discussions and assignments.

## 1 Introduction

Climate change is already affecting ecosystems worldwide (IPCC, 2014) and the people whose farming and livelihoods are supported by those ecosystems (e.g., Hoegh-Guldberg and Bruno, 2010). Low-income households in tropical developing countries are particularly vulnerable (Barbier, 2010, Barbier and Hochard, 2018). Some technologies and practices that can help reduce these vulnerabilities are referred to as ecosystem-based adaptation (EBA) practices, and use ecosystems to make human and natural systems more resilient (IPCC, 2014, USGCRP, 2018, World Health Organization, 2018). For example, buffer strips of preserved natural ecosystems alongside waterways and roads can fight erosion and protect water quality in the face of increasingly unpredictable precipitation patterns. EBA projects, including watershed management, forest restoration, and mangrove protection, are currently underway in almost sixty countries (Rizvi, et al., 2015). However, people are often hesitant to adopt these practices because adoption is typically costly. This hesitation is greater because many benefits are external to the adopter, and practices' effects on yields are uncertain from the adopter's perspective and, in some cases, not well understood by science.

In this paper, we present an interactive game that explores the adoption of EBA practices. Putting participants in the shoes of decision makers through games like this one, as discussed in Holt (1999), can help build a strong and nuanced understanding of economic models and the systems they represent. The key contributions of the game are to help participants understand how agents choose whether to adopt EBA practices and the hurdles these practices encounter, and to more generally to help participants explore topics surrounding adoption and diffusion of technology with uncertain net benefits. In the game, participants play the role of small-scale farmers in a developing country where policy makers are trying to promote EBA practices. In this role, they must decide, through a series of scenarios in which the policy incentives and the inherent types of uncertainty they face vary, whether to adopt an EBA practice. The structure of the game can easily be adapted to different contexts, such as water quality improvements in developed countries. This paper provides all the information and materials needed to play the game as we present it or to customize it.

This game is well suited to undergraduate and graduate classes in environmental economics, public economics, agricultural economics, environmental policy, environmental studies, international development, and public policy. The game can be used in classes on microeconomics, uncertainty, and information, as well.[1] It also works well in training and capacity-building workshops for policy makers, extension workers, and stakeholders. While it would be helpful for participants to have taken an introductory economics course, the game can be used with participants who have no economics training, including students in introductory and non-economics classes and non-academic stakeholders; in supplementary material we suggest accessible readings to help such participants engage with the game. This type of game may particularly benefit participants who have less economics background or who are intimidated by the mathematics in which economics is often expressed. This is because it allows them to learn about the incentives embedded in scenarios in an intuitive and experiential way. On the other hand, participants who have advanced economics training can use the game to explore and model interesting decision-making contexts in more technical detail. We have, to date, run this game with undergraduate students (who have taken principles of microeconomics), graduate students (with advanced economics backgrounds), and policy makers and stakeholders (with little to no economics background). While the time it takes to play the game has an opportunity cost, it covers many topics, and its immersive and interactive nature may increase the depth of learning, as interactive experiences often do (e.g., Ball, et al., 2006), potentially providing a favorable pedagogical benefit-cost ratio.

The game works best with ten to sixty participants. If played in one sitting, it could last from fifty minutes to two hours depending on how many periods the instructor runs and the intensity of the discussion during the game; alternatively, different treatments of the game can be spread across the semester to match the treatments to the course subject matter, in which case the game would take a small amount of time across each of multiple class sessions.[2] We provide a set of treatments that can be mixed and matched and repeated to the instructor's taste, providing active learning of topics including climate change adaptation, ecosystem services, decision making under uncertainty and (Knightian) ambiguity, payment for ecosystem service programs, cost-effective program deployment, conservation auctions, technology adoption and diffusion, information as a public good, social learning, and learning in a noisy environment. We also provide participant instructions (Appendix I) and, in supplementary material available for download, an Excel sheet for conducting the game, an instructor guide, two handouts with topical background for participants at different levels of technical detail and assumed knowledge, a list of readings that can be shared with different kinds of participants, a list of ways in which the game can be extended or modified, and slides for use with the game.

The paper proceeds as follows. In Section 2, we describe the game and treatments in narrative detail, though we leave the practical details to the instructor guide (supplementary material). In Section 3, we discuss the economic and policy context of the game. In Section 4, we present suggestions that can form the basis for class discussions or assignments. In Section 5, we discuss our experiences with the game. Finally, in Section 6, we conclude.

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[1] While economics graduate courses typically do not devote time to interactive exercises like this, we feel that is a missed opportunity, because games like this have many complexities that can be explored with rigor. This game may also be particularly useful in interdisciplinary master's degree programs because it can let policy-focused students learn from experience how incentives work without having to unravel complex mathematical derivations.

[2] This is reminiscent of Secchi and Banerjee (2019); we thank an anonymous reviewer for suggesting this.

# 2 The Game

In this game, participants learn firsthand about EBA programs and the challenges in deploying adaptation technology and methods, and about how uncertainty in outcomes can affect the adoption of new technologies. Each participant plays the role of a farmer whose livelihood depends on a harvest that is subject to climate risk and who can participate in EBA programs. Participants make decisions over a series of rounds, called "contract periods." We present six treatments that can be mixed and matched, with the option of repeating any treatment if desired. Each treatment introduces an element that renders the game more realistic, and thus more complex; the treatments generally build on each other. Table 1 outlines the treatments; the following sections explain the elements in more detail. The treatments are also described in the standalone participant instructions (Appendix I).

Our preferred way to conduct the game is to play each of the first four treatments for one round and the remaining two treatments in two repeated rounds each, as we describe in the following. That configuration requires about ninety minutes of total class time.[3]

If possible, we suggest that the instructor pay one or more participants an amount of money proportional to their earnings.[4] Real payment heightens attention and creates a lively atmosphere. Further, the incentive compatibility of payment-relevant decisions helps participants gain a stronger understanding of the underlying decision context and the incentives it creates, since they have "skin in the game." Holt (1999) provides a useful discussion of the benefits of using incentives in classroom games. We discuss payment mechanics in detail later on.

In what follows, we give a narrative explanation of the game and how to play it. Recall that we list some suggested ways to modify the game to explore different topics or shift the focus in supplementary material. We explain in extensive detail the practical elements of precisely how to conduct the game, with hints about how to prevent challenging situations and how to make the game go as smoothly as possible, in the instructor guide (in supplementary material).

## 2.1 Setup and General Conduct

Each participant plays the role of a small-scale farmer in a developing country where climate change is increasing the risks to agriculture from both drought and heavy rains. The periods vary in the policy being implemented and the type of uncertainty explored. In each period, each participant decides whether to adopt the EBA practice available that period, and has some resulting earnings (denominated in shillings, ⫛) that represent net income for that period. The costs to adopt a practice are private and comprise explicit costs of adoption and an (often uncertain) opportunity cost in foregone yields. The benefits of adoption are public in that everyone in the community benefits from decreased erosion, which improves water quality.

A participant's earnings in each period depend on their decisions, the decisions of others, and chance, and their total earnings for the game are the sum of their earnings in each period. Specifically, at the start of the game, each person is given a randomly selected number from one to ten (we use playing cards) that determines their baseline returns from agriculture. Their Farming Value, used for earnings calculations, is the number they receive times 1,000⫛. Their earnings, in a general sense, are given in Equation 1.

$$\text{Earnings} = \text{Farming Earnings} + \text{Government Payments} \quad (1)$$

Government payments vary from treatment to treatment. If present, they consist of a base adoption incentive (either a fixed 1,500⫛, or an amount depending on participants' bids in the auction

[3] For shorter sessions we recommend playing the first two treatments and either following up with a detailed discussion or playing treatment 3 or treatment 4, depending on the desired focus.
[4] At some institutions, the instructor may need to seek permission to pay participants.

**Table 1. Treatments and Learning Objectives**

| Period | EBA Practice | Incentive/Policy | Brief Description | Learning Objectives |
|---|---|---|---|---|
| 1 | Riparian buffer strips | No government involvement | Participants decide whether to adopt EBA[a] with no uncertainty about costs or benefits and no policy incentive to adopt | • Impacts of climate change<br>• EBA<br>• Subsistence agriculture in developing countries<br>• Erosion and water quality<br>• Provision of local public goods |
| 2 | Riparian buffer strips | Flat adoption subsidy | A fixed payment is offered for EBA adoption | • Payment for ecosystem services programs<br>• Cost-effectiveness in pollution abatement |
| 3 | Riparian buffer strips | Conservation auction | Participation in the EBA program is determined by an auction | • Conservation and procurement auctions<br>• Incentive compatible auction design |
| 4 | Low-till or no-till farming | Flat adoption subsidy; uncertain direct impact | Direct impact to the EBA adopter is uncertain; fixed payment for adoption | • Decision making under uncertainty |
| 5 | Agroforestry (border) | Flat adoption subsidy; uncertain but correlated direct impact | Direct impact to the EBA adopter is uncertain, but those impacts are correlated across participants; fixed payment for adoption | • Different forms of uncertainty<br>• Learning spillovers in the adoption of new technology |
| 6 | Agroforestry (intercropped) | Flat adoption subsidy plus pilot bonus; uncertain but correlated direct impact | Direct impact to the EBA adopter is uncertain, but those impacts are correlated across participants; fixed payment for adoption plus bonus for early adoption | • Incentivizing learning about new technology |

[a]EBA stands for ecosystem-based adaptation.

treatment) as well as, in the final treatment, a bonus for early adopters (a pilot bonus).

Farming earnings depend on the participant's Farming Value and are affected by whether the participant adopts the EBA practice as well as externalities from other farmers who do not adopt the EBA practice. Equation 2 shows how Farming Earnings are calculated:

$$\text{Farming Earnings} = \text{Farming Value} * (1 + \text{\# Adopters} * 5\%) - (\text{Adopt}) * \text{Direct Costs} \qquad (2)$$

where Adopt is a dummy equal to one if the participant themselves adopted the practice, and "# Adopters" is the number of participants in total who adopted it this period.

The Farming Value represents the basic suitability of this farmer's land to agriculture. The land's productivity is increased by every farmer's adoption of the EBA practice. The instructor can use examples to explain how such spillovers might arise. The story we tell is that these practices limit the impact of erosion on water quality in shared waterways in the face of the increase in intense rainstorms that comes from climate change.[5] In the game, for each farmer that adopts the EBA practice, the yield of every farmer in the group (including themselves) increases by 5 percent as the negative externality of nutrient runoff is abated. In reality, this ecosystem benefit will vary across different practices and will also be subject to uncertainty, but for simplicity, we keep it constant. Because these benefits are mostly external to the decision maker, the Nash equilibrium for most players in most situations in the game is to not adopt the EBA practice even though it will often be socially beneficial for everyone to adopt it. This divergence occurs because many benefits are external.

Direct Costs of adoption always include an explicit cost of 1,000₼ in the game. Additional direct costs arise because each practice also comes with an opportunity cost in the form of a yield reduction. With some EBA practices, this yield loss results from surrendering some land to filter strips; with other practices, it comes from increased weed growth or need for herbicides; and in some cases, it comes from interactions between the crops and trees used for agroforestry. In the first periods, this is a loss of 10 percent of base farming earnings. However, later periods demonstrate various kinds of uncertainty, as we will describe when we describe the treatments.

We summarize the payoff function's components in Table 2.

In advance of the game, we suggest sharing the instructions (Appendix I) and one of the handouts in the supplementary material as well as any additional desired readings (see supplementary material) with the participants. Before the game session, instructors should take time to familiarize themselves with the spreadsheet and the steps in the instructor guide (supplementary material), which includes instructions for modifying the spreadsheet to run treatments more or fewer times or to accommodate more or fewer participants.

**Table 2. Elements of the Payoff Function**

| Name/Description | Value or Range | Description |
|---|---|---|
| Farming Value | Card number (1-10) times 1,000₼ | Base earnings from farming if no one adopts the EBA[a] |
| # Adopters | 0-$N$, where $N$ is the number of participants | Number of people adopting the EBA including self |
| Yield improvement from reduced water pollution externality | 1 + # Adopters * 5% | The amount by which yield is improved from everyone's adoption of the EBA |
| EBA practice adoption cost | 1,000₼ | The flat cost to adopt an EBA |
| Additional farming earnings reduction from adopting the EBA practice | Farming Value times: 10% for Treatments 1, 2, & 3; Weather Yield Effect for Treatment 4; Unknown Yield Effect for Treatments 5 & 6 | How much the EBA reduces (or, if negative, increases) farming earnings, e.g., through land not planted or increased/reduced yield |
| Adoption incentive | 1,500₼ in Treatments 2, 4, 5, and 6; depends on auction outcome in Treatment 3 | The amount the government will pay to those who adopt the EBA |
| Pilot bonus | 500₼ | The added payment (in Treatment 6) for being an early adopter of the EBA |

[a]EBA stands for ecosystem-based adaptation.

[5] You might need to explain to participants that while climate change will cause some places to be drier (and others to be wetter), a sudden rainstorm in a dry ecosystem can be quite damaging.

In the game session, in each period, the instructor should explain the decision environment, and then verbally elicit every participant's decision for that period. After each period, they should summarize to the participants how many people chose to adopt an EBA practice and show them the implications for participants' earnings that period.

After all of the periods, as we discussed, we suggest paying at least one participant. The spreadsheet is set up to choose 10 percent of participants randomly and to convert earnings into dollar amounts on the order of $2 to $10 (though the conversion rate to dollars can be changed in the spreadsheet if your game configuration would yield an undesirable pay range). Participants can also be paid in other ways if that is preferred; some alternatives are shared in the instructor guide (in supplementary material). Even if there are no payments for participation, participants tend to enjoy looking at everyone's earnings at the end of the game.

The game can be preceded by, interspersed with, or followed by discussions or assignments. When we play the game, we lead short discussions to debrief after each treatment and a more substantial discussion after the game is complete, linked to readings assigned before class and written assignments that follow the class.

## 2.2 Treatments

As discussed, the treatments are independent from each other, but they are mostly progressive in the sense that many build on each other. In particular, the fifth and sixth treatments are more intuitive if run together.

The first three treatments use riparian buffer strips (Hill, 1996) as their EBA technique. Farmers who adopt this practice leave a stretch of land unfarmed at the edge of the waterway, and turn that land into a quasi-natural ecosystem to provide a variety of ecosystem services such as habitat for species. However, the primary benefit of this practice to the community is that it reduces runoff into the waterway by filtering soil that is eroded by rainfall and filtering many chemicals that would otherwise pollute the water. Its primary cost is a reduction in the land available to farm. This land is often the farmer's most fertile land because of its location next to the water. In the game, the adoption of riparian buffers leads to a 10 percent decrease in yields, which is the opportunity cost of participating.

### 2.2.1 Treatment 1: No Government Involvement

This treatment is the simplest, and both sets a baseline and provides participants with experience in the decision environment. Earnings are as shown in Equation 3.

$$\text{Earnings} = \text{Farming Value} * (1 + \#\ \text{Adopters} * 5\%) - (\text{Adopt}) * [\text{Farming Value} * 10\% - 1{,}000\pitchfork] \qquad (3)$$

If we denote Farming Value (1,000⋔ times the person's card) as $FV$, the private cost of taking a contract is $1{,}000 + 0.1 * FV$ ⋔, while the private benefit is $0.05 * FV$ ⋔; as a result, the net private cost is $1{,}000 + 0.05 * FV$ ⋔, so profit-maximizing people will not adopt the practice. However, the external public benefit is 5 percent times the sum of all other Farming Values in the room. If cards are uniformly distributed from 1 to 10, then this is $5.5 * 1{,}000 * 5\% * (N-1)\pitchfork = 275(N-1)\pitchfork$. Thus, it is socially beneficial for someone to adopt as long as $275(N-1)\pitchfork \geq 1{,}000 + 0.05FV\pitchfork$. If cards are uniformly distributed, then it will be socially beneficial for everyone to adopt if $N - 1 \geq \frac{1{,}000+50}{275}\pitchfork$, which requires $N > 4$. In this treatment, participants can learn about the negative externality caused by agricultural activity and can grapple with ideas about public good provision and ecosystem services.

It is worth pausing after this treatment to discuss why people made the choices they made. This can help clear up any confusion participants have about the game.

### 2.2.2 Treatment 2: Flat Adoption Subsidy

This treatment introduces the payment for ecosystem services scheme, using a flat payment of 1,500₼. Earnings for this treatment are as shown in Equation 4.

$$\text{Earnings} = \text{Farming Value} * (1 + \#\ \text{Adopters} * 5\%) - (\text{Adopt}) * [\text{Farming Value} * 10\% + 500₼] \tag{4}$$

The payment makes it privately optimal for a participant to take the contract if 1,500₼ ≥ $1{,}000 + 0.05 * FV$ ₼. In other words, adoption is strictly optimal for everyone except those with a card of 10, and weakly optimal for them. We find it useful to have a payment that encourages full participation in this treatment, since later treatments that add uncertainty will decrease participation from this level. If the instructor prefers only partial participation, they can reduce the payment.

Is a flat payment realistic? In practice, some payment for ecosystem services schemes use flat payments. The prices are typically exogenous to the local decision makers because they are derived from national or global valuation estimates.

This treatment provides an opportunity to talk about the dual goals of efficiency and cost-effectiveness before introducing more complicating factors.

### 2.2.3 Treatment 3: Conservation Auction

In this treatment, payments and participation are based on a procurement auction. Auctions are common in conservation programs, including the United States Conservation Reserve Program (Hellerstein, 2017). In this treatment, participants submit bids for desired payment amounts, and the lowest 50 percent of the bids are accepted into contracts. All contracts are paid the value of the lowest bid *not* accepted. Earnings are therefore as given in Equation 5.

$$\begin{aligned}\text{Earnings} = \text{Farming Value} * (1 + \#\ \text{Adopters} * 5\%) - (\text{Adopt}) * [&\text{Farming Value} * 10\% \\ &+ \text{Auction Payment}]\end{aligned} \tag{5}$$

Since this is incentive-compatible, everyone should bid their true cost of adoption. If participants are purely self-interested, this is $1{,}000 + 0.1 * FV$ ₼. (The same amount of ecosystem services is always provided regardless of whether an individual takes up the contract since there is a set number of contracts; therefore, adoption no longer yields an added $0.05 * FV$ private benefit from increased ecosystem services.)[6]

Bidding in the auction is engaging and students enjoy it, but it is more complex than flat payments. It is possible to run all of the remaining treatments with auctions (which requires modifying the spreadsheet), but for simplicity, our materials implement them with flat payments.

### 2.2.4 Treatment 4: Uncertain Direct Effect

This treatment introduces a new EBA practice: low-till or no-till farming (Montgomery, 2007).[7] Low-till and no-till farming disturb the soil less than conventional tilling, and as a result, the soil is less erodible and requires less fertilizer as more nutrients stay in the soil. However, the undisturbed soil is more prone to weed growth. This treatment can be modified to represent weed growth as a flat cost (representing more time and effort spent weeding or more herbicides purchased), but we express it as a reduction in yield, which is likely as weeds crowd out the crop. Of course, weed growth depends on many factors, and in a good year, the net private effect of the reduced tilling and the weed growth can even be positive.

Therefore, we use this treatment to introduce uncertainty. The uncertainty in this treatment is

[6] If some bids are tied, depending on how ties are resolved, the number of contracts and thus the amount of ecosystem services may vary after all. The instructor guide discusses this in detail.

[7] It is possible to use the same EBA practice for all treatments and ask the participants to assume they are independent. We suggest using different practices to reduce behavioral spillovers across treatments and to introduce more examples of EBA practices.

simple: everyone in the community faces a common weather shock that determines how vigorous weed growth will be that year. That common shock, which we call the Weather Yield Adjustment, is equally likely to be -30 percent or +10 percent, which is a mean-preserving spread from the yield impact in the earlier treatments, but provides two possible outcomes that are quite different from each other. Earnings are given by Equation 6.

$$\text{Earnings} = \text{Farming Value} * (1 + \#\text{ Adopters} * 5\%) +/- (\text{Adopt}) * [\text{Farming Value} * (\text{Weather Yield Adjustment}) + 500⋔] \quad (6)$$

On average, low-till farming and the riparian buffer strip have the same impact on yield: a decrease of 10 percent. Thus, risk-neutral agents will always take up contracts because the payment equals the expected cost of participating. However, as most people are risk-averse, some will not participate, especially those with higher cards.

**2.2.5 Treatment 5: Uncertain but Correlated Direct Effect**

In this and the next treatment, the EBA practices are forms of agroforestry (Branca, et al., 2011, Jose, 2009, Kiptot, et al., 2007).[8] In this treatment, trees are to be planted around crop fields as a border. In the sixth treatment, trees are to be interspersed throughout the crop field, a practice known as intercropping. In each case, the trees are native species and provide ecosystem benefits by reducing runoff into waterways. In addition, they may yield net positive or negative effects on crop yields. The negative effects occur because the trees take some land, water, and nutrients away from the crops. On the positive side, however, they provide a windbreak (reducing erosion), can hold soil, nutrients, and water in place (reducing runoff) so that crops can use them, and may also provide local cooling.

Farmers may be uncertain about how agroforestry will perform in their context. Treatments five and six both showcase two elements of this uncertainty: systemic and idiosyncratic. The total yield impact is the sum of these effects. Figure 1 shows these two elements, which we describe in detail next.

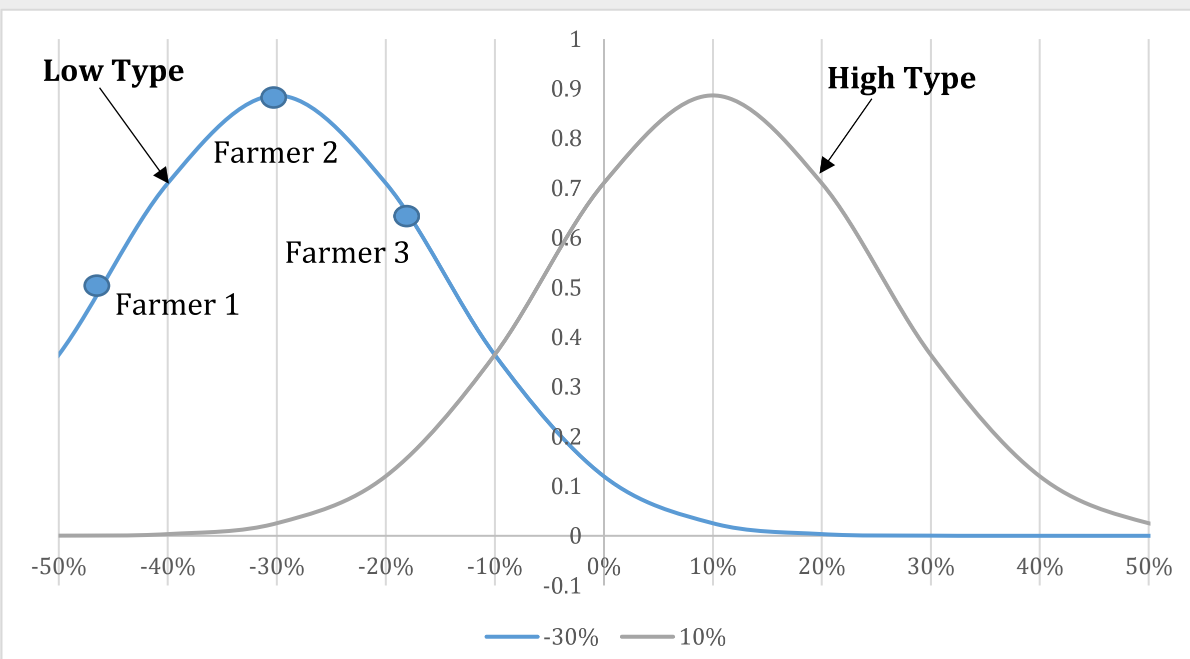


**Figure 1. Systemic and Idiosyncratic Uncertainty in Yield Impacts**

[8] Branca, et al. (2011) define agroforestry as "land use practices in which woody perennials are deliberately integrated with agricultural crops" and describe the ways in which such practices can improve land productivity.

Systemic uncertainty is represented in Figure 1 by whether a community is on the Low Type or High Type curve, which each represent a distribution of effects across participants that is equally likely, as each community is equally likely to be a Low Type or High Type in terms of yield impact. There is systemic uncertainty about the fundamental performance of agroforestry, particularly in any local area. Studies have found mixed evidence of agroforestry's impacts (Branca, et al., 2011, Kiptot, et al., 2007), depending on the trees used, how they are planted, and the local climate. In the game, the systemic uncertainty is equally likely to be -30 (Low) or +10 (High) percent.

Idiosyncratic uncertainty is represented in Figure 1 by the location of any given farmer on their community's distribution curve, as exemplified by Farmer 1, Farmer 2, and Farmer 3. The idiosyncratic uncertainty in agroforestry performance arises because land, soil, and microclimate properties can vary quite a bit even within a local area, causing agroforestry to perform differently on different plots of land. The practice's effect on yield, therefore, is an idiosyncratic disturbance (drawn from a normal distribution) away from the mean systemic effect (which is equally likely to be -30 percent or +10 percent). The idiosyncratic risk has characteristics of risk because participants know the shape of the distribution from which the disturbance is drawn, but also has characteristics of Knightian uncertainty (i.e., ambiguity) because participants do not know the probability of any particular disturbance since they do not know the standard deviation of the distribution, and further may have a hard time understanding a normal distribution. Earnings from Treatment 5 are given by Equation 7.

$$\text{Earnings} = \text{Farming Value} * (1 + \#\text{ Adopters} * 5\%) +/- (\text{Adopt}) * [\text{Farming Value} * (\text{Unknown Yield Effect}) + 500₼] \qquad (7)$$

Because most people are risk averse and ambiguity averse, participants, especially those with higher card values, should become even less inclined to adopt a contract.

Because of the systemic element of risk, participants can learn from each other's experience with agroforestry, but because of the idiosyncratic element, any individual's outcome is imperfectly informative of any other individual's outcome. These concepts are difficult and require thorough explanation, especially with participants with less quantitative background. To enable social learning, we recommend playing this treatment twice, reminding participants that the same draws for both the systemic and idiosyncratic elements of risk will be used both times.

Because the agroforestry implementations differ, the mean and idiosyncratic effects may be different between this treatment and the following treatment, so they are separate independent draws for the two treatments, though they are the same for different rounds within a treatment.

#### 2.2.6 Treatment 6: Uncertain but Correlated Direct Effect, with Pilot Bonus

This treatment, which uses intercropped agroforestry (described previously), builds on Treatment 5 by introducing a pilot bonus. This is an additional payment of 500₼ for people to adopt the practice in the first of the two paired rounds. Importantly, the same realizations for systematic and idiosyncratic risk hold for both of the paired rounds. Earnings from Treatment 6 are given by Equation 8.

$$\text{Earnings} = \text{Farming Value} * (1 + \#\text{ Adopters} * 5\%) +/- (\text{Adopt}) * [\text{Farming Value} * (\text{Unknown Yield Effect}) + 500₼ + (\text{First Round}) * 500₼] \qquad (8)$$

where First Round is a dummy equal to one if this is the first round of this treatment.

Risk aversion and ambiguity aversion should again drive participants away from agroforestry. However, revelation of adopters' yield realizations provides information about the systemic element of risk that is valuable to everyone since the more adopters have been observed, the better everyone can guess what the systemic element is; information acts as a public good because yields are publicly visible. Because of this public good element, "experimentation" with the practice by community members is underprovided relative to what is optimal, and thus a subsidy for early adopters may be efficiency enhancing.

As with Treatment 5, we recommend running this treatment twice to allow for social learning. Participants' attention should be called to the fact that this treatment introduces a different practice that will have a different and independent draw for the systemic element of risk for any rounds done in this treatment rather than the same value as in Treatment 5.

# 3 Policy Context and Economic Underpinnings

In this section, we provide a general economics-based discussion of the topics addressed in the game, with instructors conducting the game as the target audience. Participants can learn from the handouts and additional readings (both of which can be found in supplementary material).

## 3.1 Climate Change

Climate change is a dramatic public goods problem. Greenhouse gases emitted anywhere in the world generate physical impacts that are already affecting the world and that are predicted to intensify over time (IPCC, 2014, USGCRP, 2018). According to the Intergovernmental Panel on Climate Change, "Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability" (IPCC, 2014). The human cost of climate change's impacts will be most significant in tropical and low-lying areas (IPCC, 2014), and low-income populations are particularly vulnerable (Barbier and Hochard, 2018).

While climate change's progression can be reduced by mitigation (abatement) of global net greenhouse gas emissions, there is general agreement that some impacts of climate change are now unavoidable, and thus communities and individuals must take action to lessen the damages from those impacts. These actions are broadly referred to as adaptation.

## 3.2 Adaptation and EBA

Adaptation comprises large-scale projects undertaken or funded by governments as well as actions taken by households or firms. Adaptation modes can be categorized into "hard adaptation," also known as grey adaptation, which includes the construction of flood barriers and other infrastructure (McGeehan and Hu, 2017), or "soft adaptation," which comprises social initiatives, policy initiatives, and EBA (also known as green adaptation).

EBA relies on natural features to reduce the impacts of climate change. For example, wetlands can buffer coastal areas to reduce flood risk during storm surges (Burley, et al., 2012). Restored or natural ecosystems alongside waterways or roads, particularly instead of development, can reduce vulnerability to the erosion and flooding that are rendered more likely by increased variability in precipitation, improving water quality.

Individual EBA projects (e.g., Rijal and Yansanjav, 2017, Twinomuhangi, 2017) have been developed by several United Nations initiatives, especially by the United Nations Environment Programme and the United Nations Development Programme. This work advances Sustainable Development Goal #13: "Take urgent action to combat climate change and its impacts." EBA projects, including watershed management, forest restoration, and mangrove protection, are underway in almost sixty countries (Rizvi, et al., 2015). Many EBA projects also provide other local and global ecosystem services; for example, agroforestry may reduce erosion from extreme weather while also absorbing carbon dioxide. Table 3 describes examples of EBA from the United Nations Development Programme's EBA Programme.

**Table 3. Examples of EBA Projects**

| Nepal | Peru | Uganda |
|---|---|---|
| • Maintaining and restoring ecosystems along roads to reduce landslides<br>• Restoring wetlands, springs, and ponds to ensure year-long drinking water supply<br>• Soil nutrient management to increase soil moisture during dry periods | • Restoring water channels and reservoirs to support micro-watersheds and wetlands to secure provision of water for the reserve communities and downstream users<br>• Grassland management to enhance pastoral livelihoods and increase resilience to drought and frost<br>• Vicuña management to produce animal fiber for livelihoods and communal livestock management in natural grasslands | • Improved water retention through roadside drainage bunds and runoff retention drains<br>• A gravity flow engineered irrigation scheme, combined with reforestation and soil and water conservation<br>• Riverbank restoration to create a hybrid grey-green solution to catchment-scale water management<br>• Tree planting using agroforestry to stabilize soil to reduce landslides |

Source: (UNDP, 2015).

Adaptation typically provides benefits by reducing damage costs, though EBA may provide additional benefits through other ecosystem services such as the water quality benefits that appear in this game. Adaptation, including EBA, generally has costs as well; if it did not, the agent would have theoretically already taken the adaptation action.[9] Some costs are explicit, such as labor and resources used to restore an ecosystem that can buffer rainfall. However, some costs are opportunity costs: benefits foregone by taking action. For example, the opportunity cost of establishing a filter strip on a waterway is the crop yield that strip of land could have borne.

Are EBA decisions chosen by individuals likely to be economically efficient in the sense of maximizing net social benefits? It is efficient to take an adaptation action if the costs of the action are less than the benefits it provides, or if the marginal benefit of the last marginal adaptation step (e.g., the last inch of riverbank turned into a filter strip) just equals the marginal cost of that step. Thus we must consider whether the decision-making agent appropriately weighs all marginal costs and benefits. Some EBA is undertaken on public lands. In those cases, policy makers can evaluate total costs and total benefits and make the efficient decision.

Some adaptation actions require individuals or firms to change their behaviors. Some of the people most exposed to climate risks and thus most in need of adaptation are farmers, whose adaptation decisions this game focuses on. Farmers are already changing farming practices in response to climate change (Reed, et al., 2017), presumably because the benefits in mitigating yield losses outweigh the adaptation costs. However, farmers' EBA provides positive externalities to others inside and outside their communities. These benefits come in the form of ecosystem services (MEA, 2005) such as habitat provision, water filtration, limiting erosion, and local climate regulation. These are public goods or common pool resources because they are non-rival (e.g., a person can benefit from increased biodiversity without detracting from others' benefits) or congestible (e.g., a groundwater source that can be degraded by excessive extraction), and they are nonexcludable (e.g., no one can be stopped from enjoying reduced

[9] Some agents, particularly in markets with limited access to credit, may not have the capital to make up-front investments that would be privately optimal. Other policies, like grant programs, can help ease such constraints.

flooding). Because ecosystem services are positive externalities (modeled in our game by other farmers' improved crop yields), without policy intervention, people's tendency to focus on their own costs and benefits will cause them to do less EBA than would be efficient.

## 3.3 Policies to Promote Ecosystem Service Provision

Economists and policy analysts argue that policies like mandates, supports, or incentives are needed to achieve the efficient provision of public goods like ecosystem services.

Many such initiatives are payment for ecosystem service programs (Forest Trends, et al., 2008). Payments for ecosystem services monetize externalities by paying the providers of ecosystem services. These payments may be orchestrated by global organizations like the United Nations, private nonprofits like The Nature Conservancy, or directly by governments.

Theoretically, the size of the externality is calculated, and payment in the amount of the estimated externality is offered to the provider of the ecosystem services. This is a Pigouvian solution and should be both efficient and cost-effective. As noted previously, efficiency requires provision of the social welfare maximizing amount of ecosystem service (here, EBA). Cost-effectiveness requires that the costs of providing this amount of ecosystem service are as low as possible. A flat payment of the size of the externality is efficient and cost-effective because only, and all of, the land parcels for which adoption costs are low enough for adoption to be socially beneficial will adopt the practice. However, sometimes a target amount of ecosystem provision is chosen based on other factors, such as the wishes of stakeholders, and payments are set to achieve that amount. Alternatively, a flat payment may be determined based on the budget available. Either of these may not be efficient, but is still cost-effective.

The advantage of opt-in payment for ecosystem services systems over mandates that specify which parcels should adopt practices is that they let policy makers be ignorant of the true costs of participation for any individual since individuals make choices based on their private knowledge of their costs. If the policy maker knew the distribution of costs but couldn't attribute costs to individual parcels, mandates could achieve efficiency but not cost-effectiveness.

If policy makers have a fixed budget, or participation costs are so uncertain that they could not effectively target a flat payment, a conservation auction can achieve a cost-effective ecosystem service provision while eliciting information about participants' costs. Landholders submit bids consisting of a proposed action and payment. If all land would provide the same ecosystem benefits, the policy body can accept bids starting from the lowest until they meet the desired number of contracts or budget (if benefits vary, a weighting scheme can be used). If the auction is incentive compatible, bidders should bid their true participation costs, assuring cost-effectiveness. Conservation auctions are widely used worldwide, including in the United States Conservation Reserve Program and projects under the United Nations REDD+ Programme.

In the context of EBA, Wertz-Kanounnikoff, et al. (2011) demonstrate that a well-designed payment for ecosystem services system can address some of the key elements necessary to be successful, and that it can be cost-effective and equitable, but only in some situations, and even then, complementary policies must be used.

## 3.4 Uncertainty and Technology Diffusion

Many agricultural EBA practices are new. The effects these practices may have on yields may be uncertain (Doswald, et al., 2014), and the results from past research may leave it unclear how well they will work in local conditions. Worse yet, the changing climate makes past results a limited predictor of future performance. Information about how a technology works is essential to spreading new agricultural technologies in developing countries (Caeiro, 2019, Jack and Tobias, 2017, Pates and Hendricks, 2020), but the best available information still leaves farmers with uncertainty. People are generally averse to risk, and especially to what economists call ambiguity or true (Knightian) uncertainty, in which the odds of the outcomes cannot be quantified. New technology presents this more challenging kind of uncertainty, and thus people may refuse to adopt it. However, if people adopt it, their experience would let others learn about the technology's performance, so the information generated from experimentation is a public good. People, therefore, do not have the incentive to adopt the new technology as much as would be optimal, as shown in lab experiments (Raeburn, et al., 2016).

Therefore, if policy makers want households and firms to take the risky act of adopting a new technology so society can benefit from learning about the technology, policy makers must encourage that adoption. One possible solution is an adoption bonus: an additional payment, on top of the base payment for ecosystem services, to reward risk-taking by early adopters.

# 4 Discussions and Assignments Related to the Game

We prefer to conduct some discussion interspersed between treatments, followed by a robust discussion after the game. Alternatively, if the time for the game is short, participants can engage in conversations through online forums after the game. They can also be assigned writing or analytical exercises before or after the game session. Because the game has many features, the instructor can tune the discussion or assignments to complement the desired focus. In what follows, we provide suggestions for leading discussions and designing assignments, organized by topic.

## 4.1 General Prompts

We always like to start discussions by asking, "How did you make your decisions? How *should* people make their decisions?" If answers are public, participants can learn from each other, and these answers may open doors to the other topics described next.

Another broad prompt is, "What is missing from this game?" Ask for real-life complicating features, and discuss whether these features have policy implications. This is particularly fruitful if participants are policy makers or stakeholders, as it can help them envision how payments for ecosystem services or EBA might work in their setting.

We also like to ask, "What policy do you think is best to achieve the goals in this kind of setting?" Participants can identify policies from the game, real-life policies, or their own ideas.

## 4.2 Climate Change, Ecosystems, and Ecosystem Services

Ecosystem service provision and the fight against climate change can be understood through theories of public goods and externalities. If participants are analytically inclined (e.g., in a higher-level economics class), ask them to derive the equilibrium with self-interested agents and the socially optimal outcome. More generally, participants can discuss the *homo economicus* assumption of rational self-interest and why people might deviate from it, including mistakes, other-regarding preferences, and preferences for environmental stewardship.

More concretely, participants can discuss ecosystems and agriculture and how they interact, especially subject to climate change. Participants can brainstorm locally relevant examples of ecosystem services that affect agriculture and how human action can diminish or bolster those services. They can reflect on whether ecosystems should be valued beyond their instrumental value, and this discussion can cover alternative foundations for social decision making such as rights-based and obligation-based systems.

To begin discussions of climate change, participants can use the Intergovernmental Panel on Climate Change's latest Assessment Report (IPCC, 2014) to learn what impacts they can expect in their home country or region. Participants can be prompted to think about interactions between adaptation decisions and the amount of greenhouse gas mitigation that is optimal or expected. They can research the forms of adaptation that are available in different contexts and explore the potential for feedbacks between climate change and ecosystem service provision.

## 4.3 Payments for Ecosystem Services

Participants can link the incentive payments in the game to the externalities provided by adoption, and discuss whether this might be an efficient payment for ecosystem services scheme. Similarly, they can discuss cost-effectiveness in this setting and whether it was achieved when they played the game. Participants can identify sources of implementation costs and discuss whether universal adoption is efficient. They can compare the game's incentive-based payment for ecosystem services system to an alternative command and control policy. A discussion of how non-self-interested preferences may affect cost-effectiveness can also be fruitful.

It is useful to point out that the payments themselves do not enter into efficiency calculations, as they are a transfer. However, participants can discuss where the payment money comes from, such as taxation, which may generate inefficiencies through distorted incentives or administrative costs, as well as the potential redistributional (i.e., equity) effect of these transfers.

The game also provides room to discuss the contract payment mechanism. We like to ask, "What are the benefits of a flat payment versus an auction?" It's important to identify the potential informational advantage of the auction. In advanced academic settings, students can prove that *n*th-price procurement auctions are incentive compatible; in less technical settings, participants can discuss the intuition for this by noting that one's bid influences whether one wins the auction, but not how much one pays, as noted in the instructor guide (in supplementary material).

This game does not cover all issues regarding payment for ecosystem services programs. Dissanayake and Jacobson (2021) describe another game that focuses on additionality, verifiability, and community governance in the context of tropical deforestation. Alternatively, Dissanayake and Jacobson (2016) uses a game modeled on the United States Conservation Reserve Program to explore how ecosystem service costs and benefits may vary spatially.

## 4.4 Uncertainty, Information, and Technology

This game emphasizes risk and uncertainty and offers entry points to these topics from theoretical, behavioral, and policy-focused perspectives. In upper-level economics classes, students can discuss expected value, expected utility (and risk aversion), prospect theory (and loss aversion), and subjective expected utility (and ambiguity aversion) and how they would guide behavior here. Which of these theories best describe how people actually behave? Are there other biases we should consider? How should society make choices facing risk and ambiguity? It is also useful to discuss the merit of judging decisions ex ante rather than ex post.

It can also be productive to consider upside and downside risk separately since, in this game, information can unlock upside risk. The precautionary principle is also relevant. From an individual perspective, it might be precautionary to wait to observe others' outcomes. In the game, society has no reason to follow the precautionary principle, but if technologies (like gene modification) have substantial downside risks, then some would prescribe a precautionary approach of limiting adoption. Distribution of risk within society is also relevant: in the agroforestry treatments, each farmer naturally focuses on their own outcome, while society encompasses a portfolio of people with different outcomes. Social risk is lower than individual risk because of diversification, and individual risk-taking has positive social externalities.

The game can also spur discussion about the role of information. As noted, distributed information about costs is an argument for incentive-based systems over mandates, and for auctions over flat payments. Participants can also discuss how people learn new information; in higher-level economics classes, Bayesian learning and the formation and updating of priors can be discussed. Most centrally, participants can discuss information revelation and diffusion of a new technology, and how that feeds into efficiency in adoption and innovation. In the agroforestry treatments, information about a new technology is publicly revealed by adoption, so adoption provides an informational public good. The instructor can ask questions like: "What are the impediments to the diffusion of a technology?" "What are the respective roles of the private and public sectors in innovation and technology diffusion?" "Who captures the benefits of new technology? How do they capture it, and does this increase or decrease inequality?"

# 5 Our Experience with the Game

We have played the game once with a lower-level undergraduate environmental and resource economics class at a liberal arts school in the United States, once with graduate students in agricultural economics at a university in China, once in a seminar with economics faculty, and with policy makers and stakeholders from various countries at capacity-building training sessions held in Zambia and Uganda. Each time we have played the game, we found that participants engaged deeply with decision making and the context of the game. Only the first instance was conducive to a post-game survey. Out of the thirty-two participants, twelve completed an optional online survey. In this section, we discuss our experiences in general and responses from the survey.

Most survey respondents reported that the game helped them somewhat or very much learn about each of the main learning objectives: EBA (100 percent), payment for ecosystem services programs (100 percent), adaptation (92 percent), climate change (67 percent), risk and uncertainty (83 percent), auctions (67 percent), agriculture in developing countries (67 percent), and how agents learn about new technologies (58 percent). Further, all students said they enjoyed the game somewhat or very much and that the game was a good use of time, and they recommended its future use.

When asked what their takeaways were, many students reflected on how incentives drove participants' choices. One student said, "One takeaway was that even though I really wanted to do adaptation because I knew that it would be good environmentally, for most rounds it did not make economic sense to do it so most of the time I did not adopt. Another takeaway was that the people with the lowest cards adopted most of the time, which to me shows that lower-income farmers bear the burden of adaptation, which is not necessarily how I believe it should be."

Participants also reflected in nuanced ways about the considerations they now thought were important in designing payment for ecosystem services programs, with many commenting about equity and fairness, such as this student: "Ethical implications! Why will program participants decide to take part? Is it fair? Also, how can you support lower-income firms/people in the case of bad luck, like in the second half of the game?[10] It seems like it would make sense to encourage participation by offering a safety net for those who need it." When asked if the game changed how the participants think and feel about the kinds of families the participants are playing the roles of, many said the game helped them understand the decision-making scenario but also highlighted issues of fairness, like this student: "Definitely. It shows how directly impacted these rural households in developing countries can be, and how EBA can help them and incentivize them to protect the environment and adapt to challenges from climate change, while also not losing all their returns/money."

This feedback, while only from one session, provides evidence that the game is effective at achieving the learning objectives presented in Table 1. Informal feedback and discussions from the other instances of playing the game, including with the policy makers, reflected similar positive outcomes. Overall, participants felt the game was a good use of time and that it allowed an in-depth exploration of issues surrounding EBA adoption. For the policy makers, for instance, one primary reflection was that the game let them better understand the constraints farmers face when they make environmental decisions. Only a few of them had thought about the trade-offs that farmers and communities face, especially regarding yield uncertainty. Participants were struck by the importance of accounting for risk aversion when trying to implement a program of this type. Participants generated some of the discussion ideas we provide in the preceding section, including questions about the distribution of costs and benefits.

We now provide a few lessons we have learned about playing the game, though we give these and

[10] This time the game was played, the realized common effect was large and negative.

many other tips in the instructor guide (in supplementary material). One lesson is that since the treatments build in complexity, discussions between treatments help participants understand basic concepts before they are used again. This is why we recommend interspersed discussion over a single cumulative final discussion. Another is that the auction is challenging for participants to understand, but can be made clearer by writing some hypothetical bids on the board, stacked vertically in increasing order, and then showing which bids would be accepted and what payment they'd receive. Finally, the nature of the uncertainty in the later treatments can be hard for participants to grasp; indeed, the purpose of the game is to help participants grasp these concepts. We find it useful to build plots on the board to demonstrate the correlated uncertainty: we lay out a bell curve and then demonstrate draws from it (dots on the line) that may represent values of different participants in the room, and then another bell curve with another set of dots that could hold in another scenario, effectively building up a graph like that in the instructions and Figure 1.

# 6 Conclusion

In this paper, we present a game that can be used to engage students and practitioners with the mechanics of environmental policies, the theory that underlies those policies, features of human behavior, and ethical and practical questions that arise in environmental policy. The game puts participants in the role of small-scale farmers in developing countries deciding whether to adopt EBA practices. Participants get a hands-on understanding of climate change and adaptation, ecosystem services, payment for ecosystem service programs, choice under uncertainty, social learning, adoption of a new technology, learning spillovers, cost-effective conservation, and conservation auctions. While the game's application is specific, many concepts demonstrated in the game have broad implications. In our experience with the game, the immersion it provides in a variety of topics renders the use of time well worth it, and our participant feedback supports this assessment. We hope that you find this interactive exercise useful for your teaching, training, and capacity-building activities.

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# Appendix I. Participant Instructions

## Seeds of Learning: Ecosystem-Based Adaptation Interactive Game Instructions

You are a small-scale farmer in a rural region of a developing country. You are a subsistence farmer: your crops feed your family, and thus your crop yield is crucial to your family's well-being. Climate change is causing an increase in extreme precipitation and temperature patterns where you live. As a result, the agriculture that you and your neighbors practice is increasingly threatened by hazards such as drought, flooding, and extreme heat.

Your government would therefore like to encourage some people in your community to adopt ecosystem-based adaptation (EBA) practices to reduce erosion and improve water quality, soil quality, and agriculture in your area. EBA practices include changes to landscape configuration (terraces, contours, and bunds), different ways of working the soil (e.g., low-till or no-till), different inputs (improved seeds, mulch, organic fertilizer instead of traditional, and reduced fertilizer use), agroforestry, intercropping, and preservation of small strips of land along waterways to filter runoff (riparian buffer strips). Over a series of periods (each of which represents a growing season), the government will offer conservation contracts; the contract in each period will offer you a payment if you adopt the EBA practice the government proposed for that period.

Each practice requires you to put in a lot of work to implement it. We represent this as an adoption cost of 1,000⋔ (your country's currency, which is known as shillings). Each practice reduces erosion, and each (in ways we will describe) affects your crop yield directly and affects everyone in the community indirectly by improving the ecosystem.

The direct effect on your yield comes from reduced erosion and other features of the practice; for example, some practices reduce the amount of your land you can grow crops on. The net direct effect may be positive or negative, and may be a known amount or may be uncertain. The direct effect depends on the specific practice, and will be described in each contract period.

Your adoption of an EBA practice provides ecosystem services because reduced erosion reduces sedimentation and pollutants in waterways and diminishes the force of flowing water. Thus, if one person adopts any EBA practice, other farms have improved water and soil quality and themselves experience less erosion. Specifically, each person's adoption of any EBA practice increases the yields of everyone in the community by 5%. For example, if 10 farmers adopt a practice, everyone's yields go up by 10*5% = 50%. We'll call this the *ecosystem yield increase rate*. If you are an adopter, this indirect effect is additional to the direct effect the practice has on your yield.

We will play through several contract periods, with specific circumstances changing in ways that we will describe in the following. In each year, your earnings are the sum of your *farming earnings*, your *adoption costs*, and your *government payments*. You were handed a card at the start of today's session. Your *Farming Value*, the value of the crop yield you get if no one adopts an EBA practice, is 1,000⋔ times the value on your card. Your *farming earnings* come from your *Farming Value*, adjusted by direct and indirect effects from the conservation practices you and your neighbors adopt. The *adoption costs* are 1,000⋔ if you adopt the practice and 0⋔ if you do not. The *government payments* vary across contract periods: there is either no government payment, a flat payment for adopters, or a payment based on an auction (which we will describe later).

In each contract period, you must make a decision: whether to adopt the EBA practice (or what bid to make in an auction to determine who adopts the practice). Your earnings for that period depend on your decision and the decisions of the other people in the community.

The table below translates the possible per-period earning ranges in this game into ways a low-income family in a situation like this might experience those levels of earnings.

| Per-Period Earnings | Your Family's Experience |
|---|---|
| Less than 2,000₼ | Family is hungry; it cannot afford basic necessities; health suffers; children are removed from school at a young age. |
| 2,000₼ to 5,000₼ | Basic necessities are met; can afford some schooling for children, but a life shock (e.g., major illness) can push the family into deep need. |
| 5,000₼ to 10,000₼ | Basic necessities and health are covered; children can attend school. |
| Above 10,000₼ | Can save money or start a business; children can attend university. |

Your earnings for the whole session are the sum of your earnings in each period. To ensure that each person makes thoughtful decisions, at the end of the game we will randomly choose one or more people (the instructor will announce how many) and pay them an amount based on their total earnings (the sum of earnings for all periods converted to dollars by dividing by 10,000₼/$).

## Contract Period 1: No Government Involvement

The EBA practice the government would like you to adopt is a riparian buffer strip: keeping an uncultivated buffer of land along river banks. Adoption directly *reduces* your yield by 10%.

The government is offering no payment.

Therefore, if you adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%) – Farming Value * 10% – 1,000₼

If you do not adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%)

## Contract Period 2: Flat Adoption Subsidy

The EBA practice is again a riparian buffer strip, and its direct effect on your yield if you adopt it is to *reduce* your yield by 10%.

The government will pay 1,500₼ to each person who enters a contract to adopt the EBA practice. Since adoption costs 1,000₼, this means that if you adopt, in addition to your farming earnings you get 1,500₼ – 1,000₼ = 500₼.

Therefore, if you adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%) – Farming Value * 10% + 500₼

If you do not adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%)

### Contract Period 3: Conservation Auction

The EBA practice is again a riparian buffer strip, and its direct effect on your yield if you adopt it is to *reduce* your yield by 10%.

The government will pay for adoption of an EBA practice, but now it will choose conservation contract recipients and the subsidy amount based on a conservation auction.

Therefore, if you adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%) – Farming Value * 10%
– 1,000₼ + Government Payment

If you do not adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%)

As noted, contracts will be awarded this period through an auction. Instead of declaring whether you'd like to adopt the adaptation practice, you will instead declare a bid. The government asks you to bid the minimum amount of money you'd be willing to accept to adopt the practice. Once everyone has made a bid, the government will rank the bids and will accept the lower half of them (all bids asking for up to the median bid). The government payment for all accepted bids will be the lowest bid that was *not* accepted. For example, if the bids were 1₼, 2₼, 3₼, 4₼, and 5₼, bids 1₼, 2₼, and 3₼ would be accepted, and the payment for all of them would be 4₼.

## Contract Period 4: Uncertain Direct Effect

The EBA practice is now low-till farming. This practice has different direct effects on your yields in different years because the effects depend on the weather, although it has the same ecosystem-based water and soil quality benefits for everyone in every year (5% increase times the number of adopters in the community). In a good year, the practice will increase yield by 10%, but in a bad year, it will decrease yield by 30%. Good years and bad years are equally likely (50% chance). We call this amount the *Weather Yield Adjustment*. Everyone will have the same *Weather Yield Adjustment* (in percent) in this contract period. We will use the random number generator in Excel to determine the weather this year and thus the effect on everyone's yields, but only after everyone has made their decision.

The government will pay 1,500₼ to each person who enters a contract to adopt the EBA practice. Since adoption costs 1,000₼, this means that if you adopt, in addition to your farming earnings you get 1,500₼ – 1,000₼ = 500₼.

Therefore, if you adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%) +/– Farming Value * (Weather Yield
Adjustment) + 500₼

If you do not adopt the practice, your earnings are:

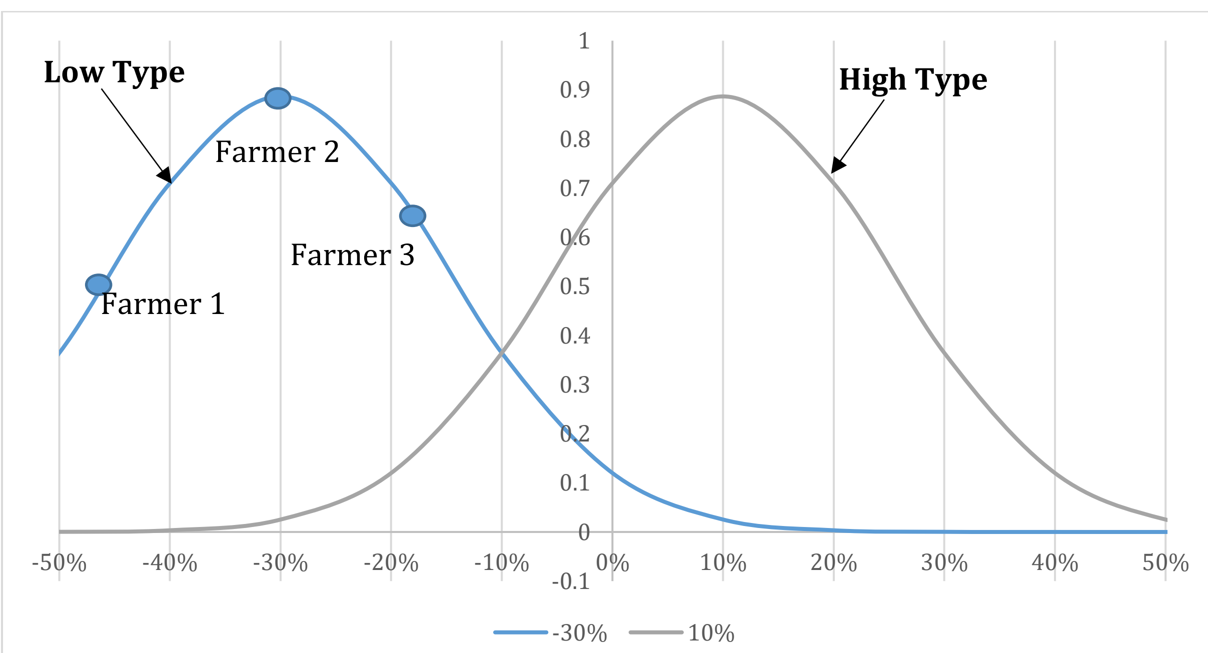
Earnings = Farming Value * (1 + # Adopters * 5%)

## Contract Periods 5A & 5B: Uncertain but Correlated Direct Effect

The EBA practice is now agroforestry, with trees planted in borders surrounding the crops. This practice takes land away from cropping, and the trees will use water and nutrients that the crops would otherwise use. On the other hand, the trees will provide a windbreak and will anchor the soil, and thus reduce erosion. The trees may also provide local cooling and may make water more available to your crops. Studies have found varying effects of these benefits on yields; the results also may depend greatly on factors like the soil type, elevation, and gradient of the land. Scientists do know that agroforestry will generate the same water and soil quality benefits as the other practices (5% increase times the number of adopters in the community), but the direct effect on adopters' yields could be to *increase or decrease* your yield by an amount we will call the *Unknown Yield Effect*.

This Unknown Yield Effect will vary from field to field, but the general tendency will be the same across all fields in a local area. To be precise, the Unknown Yield Effect will be normally distributed around some mean (average) value, and that mean value will be either -30% (Low Type) or +10% (High Type). Both are equally likely; that is, each is 50% likely. This means that there is a high chance of getting values that are close to the mean and a small chance of getting values that are more different. Therefore, if you see someone else's yield effect from agroforestry, that tells you something about how it will work on your land, though your exact effect will probably be different. In other words, you don't know the effect agroforestry will have on your farming until you try it; you don't even know the precise mean value of the distribution of possible effects, but can learn about it from seeing others' yield effects.

The following figure will help you visualize these random effects. There are two lines on the figure (Low Type and High Type); each represents one the way that farmers' values for agroforestry might be distributed in a local area. The height of the line shows how common a value is in the given community. The mean of the distribution is where the line peaks. As you can see, each distribution has a different mean (average) but has some values larger and some smaller than the mean. Everyone in your community will have a value from the same distribution, but you don't know yet which distribution applies in your community. Not only that, you don't know where on the distribution your own personal effect will be. For example, if your community has a Low Type distribution, you could be more like Farmer 2, than Farmer 1, or Farmer 3.



We will use Excel's random number generator to determine the mean effect and each person's individual effect, but both will be hidden; only the Unknown Yield Effect for people who adopt agroforestry will be revealed.[11]

The government will pay 1,500₼ to each person who enters a contract to adopt the EBA practice. Since adoption costs 1,000₼, this means that if you adopt, in addition to your farming earnings you get 1,500₼ – 1,000₼ = 500₼.

We will play this treatment for two periods, and you need <u>not</u> make the same decision in both periods. Your Unknown Yield Effect will stay the same across the two periods! That is, we'll use Excel to come up with random numbers at the beginning of period 5A, and those numbers will apply to both 5A and 5B.

In each period, if you adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%) +/– Farming Value * (Unknown Yield Effect) + 500₼

If you do not, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%)

## <u>Contract Periods 6A & 6B: Uncertain but Correlated Direct Effect, with Pilot Bonus</u>

The EBA practice again uses trees, but in this case through intercropping. That is, you are being encouraged to plant trees at regular intervals within your crop fields. The benefits and costs of intercropping with trees are similar to those of planting tree borders around crop fields. However, the net effects are again uncertain and may be entirely different from the effects of the tree borders: both the costs and benefits are distributed broadly rather than concentrated around the edges of the field. Different plots of land will respond differently to intercropping as compared to agroforestry, because the two systems perform differently in response to different sizes, shapes, and elevation patterns on a plot of land. As a result, there is the same kind of uncertainty about intercropping's effects on yields as there was for border agroforestry. There is some unknown mean effect, which will be either -30% (Low Type) or +10% (High Type). Both are equally likely; that is, each is 50% likely. Again, everyone has a personal difference in effect drawn from a distribution with that mean, and your personal value is your Unknown Yield Effect. We will determine both the mean and the individual effects with Excel's random number generator. Both the mean and the personal difference will be different from the values you saw with border agroforestry.

The government will pay 1,500₼ to each person who enters a contract to adopt the EBA practice in each period. Since adoption costs 1,000₼, this means that if you adopt, in addition to your farming earnings you get 1,500₼ – 1,000₼ = 500₼.

What's different now is that the government is offering an additional pilot bonus of 500₼ to people who adopt the conservation practice *in the first period*. The goal is to help everyone learn more about the effect of this practice.

We will play this treatment for two periods, and you need <u>not</u> make the same decision in both periods.

[11] Don't worry that your earnings might go negative; we are truncating the distribution so that cannot happen.

Your Unknown Yield Effect will stay the same in both periods! That is, we'll use Excel to come up with random numbers at the beginning of period 6A, and those numbers will apply to both 6A and 6B.

In each period, if you adopt the practice, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%) +/− Farming Value * (Unknown Yield Effect) + 500₼ + Pilot Bonus

where the Pilot Bonus is 500₼ in the first period, and 0 in the second period.

If you do not, your earnings are:

Earnings = Farming Value * (1 + # Adopters * 5%)

## Recording Sheet

Name: ____________________________________________

Your Card Value: ____________ Player: ______________

Note: The column references here refer to the columns of this recording sheet, not the earnings spreadsheet we'll use in class!

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Treatment | Farming Value | Bid | Adopt? | Ecosystem boost rate | Ecosystem yield effect | Direct Adoption Effect (%) | Direct Adoption Effect Amount | Farming Income | Adoption Cost | Government Payment | Total Income |
| | | Card value * 1000 ₼ | | Y=1 / N=0 | (from spreadsheet) | C * F | | C * H | C + G + I | 1000 ₼ if adopt | 1500 ₼ or bid if adopt | J - K + L |
| 1 | No government | ₼ | | | % | ₼ | -10% | ₼ | ₼ | ₼ | ₼ | ₼ |
| 2 | Flat subsidy | ₼ | | | % | ₼ | -10% | ₼ | ₼ | ₼ | ₼ | ₼ |
| 3 | Auction | ₼ | ₼ | | % | ₼ | -10% | ₼ | ₼ | ₼ | ₼ | ₼ |
| 4 | Uncertain | ₼ | | | % | ₼ | % | ₼ | ₼ | ₼ | ₼ | ₼ |
| 5A | Uncertain but correlated | ₼ | | | % | ₼ | % | ₼ | ₼ | ₼ | ₼ | ₼ |
| 5B | Uncertain but correlated | ₼ | | | % | ₼ | % | ₼ | ₼ | ₼ | ₼ | ₼ |
| 6A | Pilot bonus 1 | ₼ | | | % | ₼ | % | ₼ | ₼ | ₼ | ₼ | ₼ |
| 6B | Pilot bonus 2 | ₼ | | | % | ₼ | % | ₼ | ₼ | ₼ | ₼ | ₼ |

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