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 to climate change, with a focus on technology adoption and uncertainty. The game is useful in academic classes and trainings for policymakers 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 ecosystem-based adaptation 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 impact and 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, plus suggested readings and suggestions for discussions and assignments.

Keywords: classroom game, climate change adaptation, ecosystem-based adaptation, learning, payment for environmental services, technology adoption, uncertainty

JEL Codes: A20, D80, Q16, Q54, Q56, Q58

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We love to get feedback on the game, so please let us know how it works for you!

1. Introduction

Climate change is already affecting ecosystems (IPCC, 2014a), and the people whose farming and livelihoods are supported by those ecosystems (e.g., Hoegh-Guldberg and Bruno, 2010), worldwide. Low-income households in tropical developing countries are particularly vulnerable (Barbier, 2010; Barbier and Hochard, 2018). Some of the technologies and practices that help reduce these vulnerabilities are referred to as ecosystem-based adaptation practices, and operate by using ecosystems to make human and natural systems more resilient (IPCC, 2014a; USGCRP, 2018; World Health Organization, 2018). For example, strips of preserved natural ecosystems alongside waterways and roads can fight erosion and protect water quality in the face of increasingly unpredictable precipitation patterns. Ecosystem-based adaptation projects, including watershed management, forest restoration, and mangrove protection, are currently underway in almost 60 countries (Rizvi et al., 2015). However, people are often hesitant to adopt these practices because they typically impose an additional cost to the adopter. This hesitation is exacerbated by the facts that many benefits are external to the adopter, and the practices' effects on yields are uncertain and, in some cases, not well understood.

In this paper, we present an interactive game that explores the adoption of ecosystem-based adaptation 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. The key contributions of the game are to help participants understand, in the specific context of ecosystem-based adaptation, how people decide whether to adopt these practices and the hurdles for policy implementation, and to more generally 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 policymakers are trying different policies to promote the adoption of ecosystem-based adaptation practices. The structure of the game can also easily be adapted to different contexts, including for water quality improvements in developed countries. This paper provides all the information and materials needed to play the game and to customize it as needed.

This game is well suited to undergraduate and graduate classes in environmental economics, environmental policy, public economics, agricultural economics, environmental studies, international development, and public policy, and could also be used in classes on microeconomics, uncertainty, and information. While it would be helpful for students to have taken an introductory economics course, the game can also be used in settings where participants have no economics training. If students have advanced economics training, the game lets them explore behavioral decisions making contexts in more technical detail. The game also works well in training and capacity building workshops for policymakers, extension workers, and stakeholders. We have to date run it with undergraduate students (who have taken principles of microeconomics), graduate students (with advanced economics background), and with policymakers and stakeholders (with little economics background).

The game works best in a group of ten to sixty participants and could last from fifty minutes to two hours depending on how many rounds the trainer runs and the intensity of the discussion allowed while playing the game. 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 true (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 an instructor's guide (Appendix I), participant instructions (Appendix II), a handout with topical background for participants (Appendix III), a list of readings that can be distributed to different kinds of participants (Appendix IV), an Excel sheet (available for download) for conducting the game, and slides for use with the game (available for download).[2]

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 Instructors' Guide. In Section 3, we provide deeper discussion of 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. In Section 6, we present a non-exhaustive set of ways the game can be modified to meet different learning objectives or shift the focus of the game. Finally, in Section 7, we conclude.

2. The Game

In this game, participants learn firsthand about ecosystem-based adaptation programs, the challenges in deploying adaptation technology and methods, and 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 ecosystem-based adaptation 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 each treatment as many times as needed for pedagogical ends, and we share

[2] We also attach printouts of the slides as a reviewers' appendix.

ideas about ways the game can be altered and customized. Each treatment introduces an element that renders the game more exciting and realistic, and as such, more complex, and in most cases, the treatments build on each other. Table 1 outlines the treatments and the main learning objectives associated with them. Our preferred way to play the game is to play the first four treatments once each and the remaining two twice each, as we describe below. That configuration requires at least ninety minutes of total class time.[3]

Table 1: Treatments and Learning Objectives

Treatment	**Learning Objectives**
1: Baseline (No Government Involvement)	Impacts of climate change; ecosystem-based adaptation, subsistence agriculture in developing countries; erosion and water quality; provision of local public goods
2: Flat Adoption Subsidy	Payments for ecosystem services programs; cost-effectiveness in pollution abatement
3: Conservation Auction	Conservation and procurement auctions; incentive compatible bidding
4: Uncertain Direct Effect	Decision-making under uncertainty
5: Uncertain but Correlated Direct Effect	Different forms of uncertainty; learning spillovers in adoption of new technology
6: Uncertain but Correlated Direct Effect, with Pilot Bonus	Incentivizing learning about new technology

If possible, we suggest that the instructor pay one or more participants an amount of money proportional to their earnings to encourage participants to take the game's incentives seriously. The incentive is helpful since the goal is not only to learn about the desired policy outcomes but also to understand how individuals are likely to behave in the situation modeled by these incentives. Real payment also heightens attention and creates a lively atmosphere. Holt (1999) provides a useful discussion of the use of incentives in classroom games. We discuss payment mechanics in detail below.

[3] For shorter sessions we recommend playing the first two treatments and following up with a detailed discussion or playing treatment 3 or treatment 4 depending on the desired focus.

In what follows, we give a narrative explanation of the game and how to play it. Recall that more detail is in the Instructor's Guide (Appendix I).

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 flooding caused by heavy rains. Each person is given a randomly selected number from one to ten that determines their baseline returns from agriculture. Earnings and costs are denominated in shillings (₼). Their farming value, used for earnings calculations, is the number they receive times 1,000₼.

The rounds vary by the policy being implemented and the type of uncertainty explored. In each round, each participant decides whether to adopt the ecosystem-based adaptation practice available that round. The costs to adopt a practice are private and comprise explicit costs of adoption, and an (expected) 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 round depend on their decisions, the decisions of others, and chance. We describe the payoff function and its components in Table 2 with more detail in the text that follows. A participant's total earnings are the sum of their earnings in each round.

Table 2: Elements of the Payoff Function

Name	**Value or Range**	**Description**
Farming Value	Card number (1-10) times 1,000₼	Base earnings from farming if no-one adopts the EBA
# 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
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	500₼	The amount the government will pay (in Treatments 2, 4, 5, and 6) those who adopt the EBA
Pilot bonus	500₼	The added payment (in Treatment 6) for being an early adopter of the EBA

Note: EBA stands for ecosystem-based adaptation.

The precise way in which decisions translate into earnings varies from round to round for those who adopt conservation practices. The general framework is that each participant earns money from farming their land, and in addition, if they enter into an ecosystem-based adaptation contract, they pay adoption costs and may gain some government payments. While there are added complications in later treatments, earnings in treatment 1 for those who adopt are thus:

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

For those who do not adopt, earnings are always:

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

Farming earnings depend on the participant's Farming Value and are affected by externalities from other farmers in the group who do not adopt the ecosystem-based adaptation practice. The instructor can use their own examples to explain how there might be such spillovers between farmers; the story we tell is the increased occurrence of storms that cause a great deal of erosion, and where this erosion worsens water quality in the waterways that everyone in the community depends on by adding excessive nutrients to the water.[4] In this game, for each farmer that adopts the ecosystem-based adaptation practice, the yield of every farmer in the group (including themselves) increases by 5%. The increase in return is the abatement of a negative externality. In reality, this ecosystem benefit will vary across different practices and will also be subject to uncertainty, but for simplicity, we keep it constant. The Nash equilibrium for most players in most situations in the game will be to not adopt the ecosystem-based adaptation practice even though it will often be social beneficial for everyone to adopt it; this divergence occurs because many benefits are external.

Our ecosystem-based adaptation practices fight this kind of destructive runoff event. Explicit costs of adopting such a practice are always 1,000₼. In addition, each method also comes with an opportunity cost in the form of a yield reduction. With some ecosystem-based adaptation practices, this yield loss is a function of surrendering of 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 rounds, this is a loss of 10% of the base farming earnings, as shown in the payoff function above. However, later rounds demonstrate various kinds of uncertainty, as we will describe when we describe the treatments.

The government payment for ecosystem-based adaptation is 500₼ in most rounds in which payment is offered, except that the payment in the conservation auction treatment is based on participants' bids, and treatment six includes a pilot bonus for early adopters.

[4] 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 days before playing the game, we suggest sharing the instructions (Appendix II) and handout (Appendix III) and any other reading materials with the participants and encouraging them to read them in advance. Also, choose the desired combination of treatments and prepare the spreadsheet for those treatments and the intended number of participants. Before playing the game with the participants, instructors should take some time to become comfortable with the spreadsheet and the steps laid out in the instructors' guide (Appendix I). The instructor may need to change parameters to adapt the game to the number of participants; this should be done in advance of running the game.

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

After all of the rounds, as we discuss above, we suggest paying at least one participant. The spreadsheet is set up to choose 10% of participants randomly and to convert earnings into dollar amounts on the order of $2 to $10 (though this depends on the number of participants and their decisions; the conversion rate to dollars can be changed by updating a parameter in the Excel sheet). Participants can also be paid in other ways if that is preferred, and some possibilities are shared in the instructors guide (Appendix I). 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 before class and written assignments after class.

2.2 Treatments

As discussed above, the treatments are independent, but they are mostly progressive in the sense that many build on each other. In particular, the fifth and sixth treatments ("Uncertain but Correlated Direct Effect" and "Uncertain but Correlated Direct Effect with Pilot Bonus") are more intuitive if run together.

The first three treatments use riparian buffer strips (Hill, 1996) as their ecosystem-based adaptation technique. Farmers who adopt this practice leave a stretch of land unfarmed at the edge of the waterway, and turn that land into a small chunk of quasi-natural ecosystem that will 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. The challenge with adopting it is that it reduces 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% decrease in yields, which is the opportunity cost of participating.

2.2.1. Treatment 1: No Government Involvement

This treatment gets the participants accustomed to the decision environment in the simplest form possible. If we denote Farming Value (1,000₼ times the card the person is dealt) as FV, the private cost to 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% times the sum of all other farming values in the room. If cards are uniformly distributed from 1-10, then this is $5.5 * 1{,}000 * 5\% * (N-1)$ ₼ $= 275(N-1)$ ₼. Thus, it is socially beneficial for someone to adopt as long as $275(N-1)$₼ $\geq 1,000+0.05FV$ ₼. If cards are uniformly distributed, then, it will be socially beneficial for everyone to adopt if $N-1 \geq {}^{1,000+50}\!/_{275}$ ₼, which requires $N > 4$. In this treatment, participants can focus on the negative externality caused by agricultural activity and can grapple with ideas about public good provision and ecosystem services.

It might be worth pausing after participants make decisions in this treatment to discuss why people made the choices they made. The reflection will 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. The flat payment of 1,500₼ makes it privately optimal for a person to take up the contract if 1,500₼ ≥ $1,000+0.05*FV$ ₼. In other words, adoption is strictly optimal for everyone except for people with a card of 10, and weakly optimal for them. For our pedagogical goals, we like having a payment that encourages full participation in this treatment, knowing that later treatments that add uncertainty will reduce participation from this level. If the instructor wants only partial participation in this treatment, they can change the payment amount to make it privately optimal for only lower card values.

Is the flat payment realistic? De facto, from the local landowner perspective, 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 are no longer flat. Participants submit bids to express what payment they require to be willing to undertake the ecosystem-based adaptation practice, and the policymaker accepts the lowest 50% of the bids into contracts. All contracts are paid the value of the lowest bid *not* accepted. Since this is incentive-compatible, everyone should bid their value. If they are purely self-interested, their values are $1,000 + 0.1 * FV \pitchfork$. (Note that the same amount of ecosystem service is always provided regardless of whether an individual takes up the contract since there is a set number of contracts; therefore, there is no longer an added $0.05 * FV$ private benefit to adoption from increased ecosystem services.).[5] Auctions are common in conservation programs, including the United States Conservation Reserve Program.

Bidding in the auction is engaging and fun, but many find it challenging to understand. It is possible to run all of the remaining treatments with auctions (which requires modifying the spreadsheet), but for simplicity, in the materials we provide they use flat payments.

2.2.4. Treatment 4: Uncertain Direct Effect

This treatment returns to a flat payment for participation and introduces a new ecosystem-based adaptation practice: low-till or no-till farming (Montgomery, 2007).[6] Low-till and no-till farming disturb the soil less than conventional tilling, and as a result, the soil is less subject to erosion and requires less fertilizer as more nutrients stay in the soil. However, the undisturbed nature of the soil makes it prone to weed growth. This treatment can be modified to

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[5] 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.

[6] Its possible to use the same ecosystem-based adaptation practice for all treatments and ask the participants to assume they are independent. We suggest the new treatments to prevent the treatments influencing each other, and to also introduce more examples of real ecosystem-based adaptation practices.

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 is unpredictable and depends on many things, 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 particular kind of uncertainty in this treatment is very straightforward: everyone in the community faces a common weather shock that determines how vigorous weed growth will be that year. That common shock is drawn from a uniform distribution from -30% to +10%. The average effect of low-till farming is the same as the effect of the riparian buffer strip (a yield decrease of -10%). As a result, risk-neutral agents will always participate because the payment equals the expected cost of participating. However, as most people are risk-averse, many people will not participate, especially those with higher cards.

2.2.5. Treatment 5: Uncertain but Correlated Direct Effect

In this treatment and the next treatment, the ecosystem-based adaptation practices are forms of agroforestry (Branca et al., 2011; Jose, 2009; Kiptot et al., 2007).[7] 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, also 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 use some of the land, water, and nutrients that the crops would otherwise use. On the positive side, however, the trees provide a windbreak, which reduces erosion and can also hold

[7] 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.

soil, nutrients, and water in place (rather than letting them run off) so that crops can use them, and trees may also provide local cooling that helps the crops.

However, farmers may be uncertain about how agroforestry will perform in their context. Treatments five and six showcase this uncertainty. There are two features of uncertainty here: systemic and idiosyncratic.

The systemic uncertainty is in the fundamental performance of agroforestry practices. Studies on agroforestry have found mixed evidence of their impacts (Branca et al., 2011; Kiptot et al., 2007). Net effects may depend on the types of trees used, how they are planted, and the local climate. The systemic element of the uncertainty is equally likely to be -30% or +10%.

The idiosyncratic element is somewhere between classic risk and true (Knightian) uncertainty. It arises because land, soil, and microclimate properties can vary quite a bit even within a local area, and thus agroforestry will 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 was a 50%-50% lottery resulting in either -30% or +10%). The idiosyncratic risk has characteristics of risk because participants know the general 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 may generally have a hard time understanding a normal distribution. Because most people are risk averse and ambiguity averse, participants, especially those with higher card values, should become even less inclined to adopt the contract.

The systemic element of risk means that participants can learn from each other's experience with agroforestry, but the idiosyncratic element means that any individual's outcome is imperfectly informative of any other individual's outcome. These concepts are difficult, and requires thorough explanation if participants are to understand. To allow social learning to happen, we recommend playing this treatment twice, drawing attention to the fact that the same fundamental value will be used for both repetitions..

Because agroforestry's effects depend significantly on implementation, the mean and idiosyncratic effects may be entirely different between the two approaches we highlight: border planting and intercropping.

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

This treatment, which uses intercropped agroforestry (described above), builds on treatment 5 by introducing a pilot bonus. This is an additional government payment for people to adopt the practice in the first of the two paired periods. Risk aversion and ambiguity aversion should drive participants to shy away from agroforestry. However, the discovery of the practices' fundamental value provides information that is valuable to everyone; information acts as a public good because yields are publicly visible. Because of this public good element, this kind of experimentation is underprovided relative to what is optimal, and thus a subsidy for early adopters may improve outcomes.

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 independently-drawn fundamental value 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 policy issues and solutions addressed in the game, with the target audience being instructors. Participants can be directed to the handout we provide with this paper and any of the readings we refer to in Appendix IV.

3.1 Climate Change

Climate change is a dramatic public goods problem. Greenhouse gases emitted anywhere in the world generate physical impacts that we're already feeling today and that are predicted to intensify over time (IPCC, 2014a). According to the Intergovernmental Panel on Climate Change (IPCC), "Impacts from recent climate-related extremes, such as heatwaves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability" (IPCC, 2014b). The human cost of climate change's impacts will be greatest in tropical and low-lying areas (IPCC, 2014a), and low-income populations in such places 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 unavoidable at this point, and thus communities and individuals need to take action to lessen the pain that those impacts will cause. These actions are broadly referred to as adaptation.

3.2 Adaptation and Ecosystem-Based Adaptation

Adaptation comprises large-scale projects that are undertaken or funded by governments as well as individual-scale actions taken by households or firms. Adaptation modes are sometimes 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 and policy initiatives as well as ecosystem-based adaptation (also known as green adaptation). In this game, we focus on ecosystem-based adaptation.

Ecosystem-based adaptation 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 in place of development, can reduce vulnerability to the erosion and flooding that are rendered more likely by increased variability in precipitation, thus improving water quality.

Individual ecosystem-based adaptation 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." Ecosystem-based adaptation projects, including watershed management, forest restoration, and mangrove protection, are underway in almost 60 countries (Rizvi et al., 2015). Many ecosystem-based adaptation projects also provide mitigation of local and global environmental damages; for example, agroforestry may reduce erosion from extreme weather while also absorbing carbon dioxide. Table 3 describes examples of ecosystem-based adaptation from the United Nations Development Programme's Ecosystem-Based Adaptation Programme.

Table 3: Examples of Ecosystem-Based Adaptation Projects

Nepal	Peru	Uganda
• maintaining and restoring ecosystems along roads to reduce landslides • restoreing wetlands, springs and ponds to ensure year-long drinking water supply • soil nutrient management to increase soil moisture during dry periods	• restoring water channels and reservoirs to support micro-watersheds & wetlands to secure provision of water for the reserve communities and downstream users • grassland management to enhance pastoral livelihoods and increase resilience to drought and frost • vicuña management to produce animal fiber for livelihoods and communal livestock management in natural grasslands	• improved water retention through roadside drainage bunds and run-off retention drains • a gravity flow engineered irrigation scheme, combined with reforestation, soil and water conservation • riverbank restoration to create a hybrid grey-green solution to catchment-scale water management • tree planting using agroforestry to stabilize soil to reduce landslides

Source: (UNDP, 2015)

Adaptation benefits are typically avoided damage costs, though ecosystem-based adaptation may provide additional benefits in the form of ecosystem services. Adaptation, including ecosystem-based adaptation, generally has costs as well; if it did not, the agent would have theoretically already taken the adaptation action.[8] 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 the 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 ecosystem-based adaptation decisions chosen by individuals likely to be efficient? It is efficient to take a discrete adaptation action if the total costs of the action are less than the total benefits it provides; a continuous adaptation action is efficient if a level of adaptation is chosen such that 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 costs and benefits.

[8] Of course, some agents, particularly in markets with limited access to credit, may not have the capital to make up-front investments that would be beneficial to themselves. Other policies can help ease such constraints.

Some ecosystem-based adaptation is undertaken on public lands, and in those cases, policymakers can directly evaluate total costs and total benefits and presumably make the efficient decision.

However, some adaptation actions require individuals or firms to change their behaviors and their use of natural resources. Some of the people most exposed to climate risks and thus most in need of adaptation are farmers, so those are the adaptation decisions this game focuses on. Farmers are already changing their 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' ecosystem-based adaptation actions provide positive externalities: benefits that accrue to others inside and outside their communities. These benefits come in the form of ecosystem services (Millennium Ecosystem Assessment, 2005), such as habitat provision, water filtration, limiting erosion, and local climate regulation, that support human life and livelihoods directly or indirectly. These are public goods because they are non-rival (e.g., a person can benefit from increased biodiversity without detracting from others' benefits) and non-excludable (e.g., no-one can be stopped from enjoying reduced flooding). Because ecosystem services are positive externalities (modeled in our game by other farmers' improved crop yields), people's tendency to focus on their own costs and benefits will cause them to do less ecosystem-based adaptation than would be efficient without policy intervention.

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 (PES) programs (Forest Trends et al., 2008). Payments for ecosystem services monetize externalities by giving payments to providers of ecosystem services. These payments may be orchestrated through global organizations like the United Nations or the Food and Agricultural Organization, 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 can be offered to the provider of the ecosystem services. This is a Pigouvian solution and should be both efficient and cost-effective. As noted above, efficiency requires provision of the social welfare maximizing total amount of ecosystem service (here, ecosystem-based adaptation adoption). Cost-effectiveness requires that the costs of providing this level 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 parcels for which adoption costs are low enough for adoption to be socially beneficial will adopt the practice. However, sometimes the level of social benefits is uncertain or difficult to estimate. In these cases, policymakers can designate a target amount of ecosystem service provision and choose a payment level that would achieve that amount. Alternatively, a flat payment is determined based on the budget available. Either of these may not be efficient but is still cost-effective.

Opt-in payments for ecosystem services programs of these types allow the policymaker to be ignorant of the direct and opportunity costs of participation for any individual since individuals decide whether to participate based on their private knowledge of their costs. This is the advantage of such schemes over mandates that specify which parcels should adopt practices; if the policymaker knew the distribution of costs but couldn't attribute costs to individual parcels, such mandates could achieve efficiency but not cost-effectiveness.

In some cases, policymakers have a fixed budget, or participation costs are so uncertain that they could not effectively target a flat payment. In these cases, conservation auctions achieve ecosystem service provision at the lowest possible cost while getting participants to provide information about their costs. Landholders submit bids that state what they would be willing to do and at what price. If all land would provide the same ecosystem benefits, the policy body can then simply accept the lowest bids up until they meet their desired number of contracts or their budget (if benefits vary, a weighting scheme can be used). If the auction is incentive compatible as in the game, bidders should submit bids equal to their true costs of participation, assuring cost-effectiveness. Conservation auctions are in widespread use worldwide, including in the United States Conservation Reserve Program and projects under the United Nations REDD+ program.

In the context of ecosystem-based adaptation, Wertz-Kanounnikoff et al. (2011) demonstrate that a well-designed payments 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 ecosystem-based adaptation practices are new. The effects these practices may have on yields may be uncertain (Doswald et al., 2014), and to the extent to which they have been tested, it may be 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 might work 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, everyone could learn from their experience about the technology's performance, so the information generated from this experimentation is a public good as the benefits accrue broadly and are non-rival. People, therefore, do not have the incentive to adopt the new technology as much as would be optimal, and this has been borne out in lab experiments (Raeburn et al., 2016).

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

We have described the context of the game at a level of technical detail appropriate for the instructor running the game, who we assume has a background in economics. Next, we discuss how the instructor can lead discussions and design assignments around these topics.

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 be engaged in conversations in 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 exercises 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 below.

Another broad prompt is, "What is missing from this game?" Ask for real-life complicating features, and discuss whether these features have implications for how policy should be designed. This is particularly fruitful if participants are policymakers or stakeholders, as it might help them better envision how payment for ecosystem services or ecosystem-based adaptation might work in their own 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 given climate change. Participants can brainstorm locally-relevant examples of ecosystem services that are important for 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 IPCC's latest Assessment Report (IPCC, 2014b) 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 to 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 what cost-effectiveness would require in this setting and whether it was achieved in their play of the game. Participants can identify the types of implementation costs and discuss whether universal adoption is efficient in the game. Participants can be asked what an alternative command and control policy might look like, and how incentive-based payments for ecosystem services may have pros and cons relative to that. A discussion of how non-self-interested preferences may affect cost-effectiveness can also be fruitful.

It may be worth pointing 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, as well as the potential redistributional (i.e., equity) effect of these transfers. Taxation may also be a leaky bucket: it may have a social cost through distorted incentives or administrative costs.

The game also provides room to discuss the payment mechanism for the contracts. We like to ask, "What are the benefits of a flat payment versus an auction?" It's important to ensure that the potential informational advantage of the auction is aired. In advanced academic settings, students can be asked to prove that nth-price procurement auctions are incentive compatible; in less technical settings, participants can discuss the intuition behind this theory by noting that your bid influences whether you will win the auction but not how much you pay. The instructors guide provides detailed discussion notes on these aspects.

This game does not cover all issues regarding payment for ecosystem services programs. Dissanayake and Jacobson (2020) describe another game that focuses on additionality, verifiability, and community governance in the context of REDD+ (Reducing Emissions from Deforestation and forest Degradation), a global program to incentivize protecting forests, mainly aimed at tropical countries. Alternatively, the game in Dissanayake and Jacobson (2016) uses a setting modeled on the U.S. Conservation Reserve Program to explore how ecosystem service benefits vary spatially and may depend on the spatial configuration of conserved land.

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, prospect theory, and subjective expected utility and how they would guide behavior here. Risk aversion, loss aversion, and ambiguity aversion are important and distinct concepts that naturally appear here. Which of these theories are most descriptive of how people actually behave, if any? Are there other biases that are not accounted for here? Which, on the other hand, should drive society's decision-making? It can be useful to discuss the importance of judging decisions ex ante rather than ex post.

It can also be productive to consider separately upside and downside risk, 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 the potential for substantial downside risks, then some would prescribe a precautionary policy approach. Distribution of risk within society is also relevant: in the agroforestry treatments, each farmer naturally focuses on their own outcome, while society essentially has 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 several kinds of discussion about the role of information . As noted above, distributed information about costs is an argument for incentive-based systems rather than mandates, and for auctions rather than flat payments. Participants can also discuss how people learn new information; in higher-level economics classes, Bayesian learning and how agents may have priors and may update those priors as they accumulate information can be discussed. Most centrally, participants can discuss information revelation and diffusion for a new technology, and how that feeds into efficiency and adoption and the incentive to innovate. 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 an undergraduate environmental and resource economics class at a liberal arts school in the United States, once with graduate students in agricultural economics at a large university in China, once in an economics seminar setting, and once with policymakers and stakeholders from various countries at capacity building training sessions held in Zambia and Uganda. Only the first setting was conducive to a post-game survey; out of the 32 participants, 12 completed an optional online survey. In this section, we discuss our experiences in general, and we discuss responses from the survey.

Each time we have played the game, we found that participants engaged deeply with decision-making and the context of the game. Since the treatments build in complexity, discussions between the treatments proved useful in explicating important concepts. Visual depictions of uncertainty, in the form of plots drawn on the board, combined with playing the game, seemed effective in helping participants understand these concepts. Participants were struck by the importance of accounting for risk aversion when trying to field a program of this type. Participants yielded some of the fodder for the discussion ideas we provide in the preceding section, including questions about the distribution of costs and benefits.

In survey responses, most respondents reported that the game helped them learn somewhat or very much about each of the main learning objectives (listed previously in Table 1): ecosystem-based adaptation (100%), payments for ecosystem services programs (100%), adaptation (92%), climate change (67%), risk and uncertainty (83%), auctions (67%), agriculture in developing countries (67%), and how agents learn about new technologies (58%). Further, all students said they enjoyed the game somewhat or very much, said that the game was a good use of time. and recommended its future use.

When asked what their takeaways were, many students reflected on how incentives drove participants' choices; one 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?*[9] *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. The informal feedback and the discussions from the other instances of playing the game, including with the policymakers, reflected similar positive outcomes. Overall, the participants felt the game was a good use of

[9] In this play of the game, the realized common effect was large and negative.

time and that it allowed an in-depth exploration of the issues surrounding ecosystem-based adaptation adoption. For the policymakers, for instance, one primary reflection was the ability of the game to increase the improve their understanding of the constraints that farmers face when they make environmental decisions. Only a handful of them had thought about the tradeoffs that farmers and communities face, especially regarding yield uncertainty.

6. Possible Extensions and Modifications

We provide the spreadsheet and all materials in editable and customizable formats so that the instructor can modify the game to their purposes. As noted previously, the instructor can cut some treatments or add repetitions of others, or change the later treatments to use auctions instead of flat payments. Parameters can also be changed to reflect situations of interest; for example, opportunity costs or externalities can be increased or decreased. It is also easy to modify the spreadsheet to give an increasing marginal cost of damages from the agricultural externality, though that requires more explaining to the participants.

Also, as noted earlier, the instruction text can be edited to highlight a different context; after all, ecosystem-based adaptation and the diffusion of new production techniques are as relevant in Indiana as in India. Indeed, the incentive structure of the game applies equally well to any setting in which technology could be adopted that yields uncertain private costs to the adopter but provides positive externalities to others, including many other cases of ecosystem service provision that have nothing to do with adaptation. In particular, the structure presented here translates well for water quality preservation in the context of developed countries and programs like Environmental Quality Incentives Program (EQIP)[10] in the United States.

The game could be modified to receive participant decisions through cell phones or clickers. This would speed up the game and would force participants to commit to their choices before they hear what others are doing. (There is, of course, a fixed cost associated with doing this, and we have found that verbal decisions work well enough for us.)

The instructor running the game can also invent their own treatments. There are infinite variations, but we list a few ideas here.

Negative Externalities with a Directional Flow

To emphasize a spatial or directional diffusion pattern for the flow of negative externalities, the instructor can make each row only affect some number of cells above and/or below that row in the spreadsheet. This is intuitive, because if the externality occurs through surface water quality, then there should be a downstream flow direction of the eroded sediment.

Additional Forms of Uncertainty

Additional uncertainty can be applied to different elements of the game and in different ways. Yield, in the case of no adoption, could be subject to risk, as it increasingly is in the era of climate change. That would bring up questions of risk-risk tradeoffs. Alternatively, the uncertainty could be a matter of risk-ambiguity tradeoffs. Depending on the degree of risk, the ecosystem-based adaptation practice could reduce the risk that the adopter faces while reducing average yield. Uncertainty could also be applied to the ecosystem benefits to highlight questions about whether government and individuals should respond differently to uncertainty. Uncertainty

[10] https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

can also be added to the public benefits or costs of ecosystem-based adaptation. One way to do this would be say that each participant gets a randomly drawn amount of the total public benefits.

Technological Innovation

The instructor could bring innovation into the game rather than having the ecosystem-based adaptation technology be exogenously supplied. A group of participants can be designated to make decisions as the innovator instead of as farmers. The innovator chooses how much to invest, and this investment amount determines the fundamental yield effect endogenously. Parameters should probably be set such that for some decisions, the average yield effect is positive so that participants would be willing to pay some positive price to adopt the technology; in this case, government payments would be replaced by a price paid to the innovator. There can be a first treatment in which this decision translates into productivity impacts without noise, and then a second with noise, to build complexity piece by piece. This version of the game might be best played using an auction in all rounds so that the price is endogenous.

Strategic Adoption

The game, as presented, is not strategic in a game theoretic sense because each participant has a dominant strategy: each participant's decision affects others' payoffs, but does not affect their best response (except through channels such as reciprocity and inequality aversion). The game can be modified to change that. For example, if early adopters can get property rights of the technologies they have adopted and then sell those technologies to others in later periods, this can set up a gold rush-type incentive. As another example, there could be multiple possible adaptation practices available at once, with complementarities such that more benefits are generated if more people coordinate on one practice.

7. 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 ecosystem-based adaptation 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.

This game is context-rich and detailed. As such, it is not well suited to being squeezed into a short time frame, and it benefits from extra time spent on discussion. However, those same features let participants learn about a wide variety of topics and render the game more realistic and engaging.

The game is useful for capacity building workshops and trainings for policymakers and stakeholders in addition to academic classes. Our experiences conducting the game show that participants are drawn to the rich context of the game and that the game helps participants understand key topics surrounding the adoption of ecosystem-based practices as well as broader issues.

Our iterations of game testing and play have given us confidence that the game can be useful to many of our colleagues, so we are pleased to share it with you. Enjoy the game, and let us know what you think!

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Appendix I: Instructors' Guide

Ecosystem Based Adaptation Game – Instructors' Guide

- Materials you need:
  - Copies of the instructions (1 per player or group)
  - Playing cards, numbers 1-10 (i.e. remove face cards and jokers), enough for 1 per player. You can instead use index cards with numbers written on them.
    - If you want to keep face cards in, you can, and just enter them into the spreadsheet as value 10. Bear in mind that this will shift the distribution of values in the room so that the flat payment we have programmed in will no longer bring adoption by half of participants (assuming risk neutral payoff maximizers).
    - If your group is small and you randomly hand out cards from a full deck, you may randomly end up with a draw of numbers that has an expected value far from the expected value of 5.5 for the deck; this doesn't matter a huge amount but if it bothers you, you can minimize the problem by only using part of the deck
  - Money if you plan to pay in cash
- Figure out roughly how many participants you will have; if the number is very large you might want to put people in pairs or trios. This group work can have additional pedagogical value.
- Prepare the spreadsheet:
  - The spreadsheet columns into which you enter information are highlighted in yellow (except for some cases in which you'll copy and paste from another part of the spreadsheet, as explained shortly).
  - In the spreadsheet, ensure that the yellow columns are blank – delete farming values and conserve / bid decisions. (Not essential but might reduce confusion).
  - Drag down the spreadsheet rows to include enough positions for your group (one per player), or delete extra rows if your group is smaller.
  - You might want to adjust the yield multiplier in the "Parameters" tab of the spreadsheet for your group size. We set it to 5%, but for a larger group (e.g., 40 or more players) it might be better to have a smaller value, like 2%. If you do this, make sure you also change it in the instructions.
    - EBA adoption should be privately costly but provide public good benefits; at the same time, the externality benefit from EBA adoption shouldn't be so large as to totally swamp other values.
    - Farming Values range from 1,000-10,000.
    - The costs of adoption (in Baseline) are 1,000 + 10% * Farming Value.

        - If you use 5% the private benefits are 5% * Farming Value and the external benefits are roughly 5% * number of other participants * 5,500 (if cards are uniformly distributed from 1-10).
    - Decide what treatments (contract periods) you want to play. You can delete the tabs of any you don't want to play, and if you want to play any treatments more times than is already built in to the spreadsheet, you can create copies of the relevant worksheets. Adjust the "Total Earnings" tab to delete columns for treatments you are not using or add columns so all rounds are reflected.
    - Save the spreadsheet with a new name so you can store your results.
    - If you want to make changes to the recording table on the last page of the instructions, go to the Excel worksheet's last tab and make changes there; copy the image of the table (e.g., using the "snipping tool" or your computer's screen shot function) and paste it into the instructions. Make it as large as possible.
- If desired, modify our slides. (While the spreadsheet is pretty indispensable for this game, the slides are not, though we do provide some images and context that might be useful.)
- If you want to make any modifications to the game that require the recording sheet in the instructions to be changed, change that in the "rec.sheet.for.instructions" sheet of the Excel workbook, and use a screen shot (we prefer to do that of a zoomed in print preview of this worksheet).
- See the paper that accompanies this game for suggestions about leading discussions; the slides we provide also contain a few discussion questions on the final slide.
- Session setup
    - Bring up the spreadsheet on the projector
    - Bring up the slides on the projector if you plan to use the slidesHand out instructions, one per player
        - We suggest distributing the instructions before the session and asking the participants to read them before the session
    - Shuffle cards and give each player a card; <u>don't let them choose their own</u>
    - If you don't feel you can interact with players and enter their data into the spreadsheet at the same time, recruit one player to be a helper. Some people don't find this necessary, but some people feel more comfortable this way.
        - If you want to have players pass their decisions up in written form, you'll definitely want a helper
- Go around the room asking players to call out card values, and fill in the "Card" column from sheet "1-nogov-entervalues" (the yellow column).
    - As you go, ask each player to write down his or her player number.
    - Go in a predictable order through the classroom that you will repeat for all decisions (e.g. go along each row of seats in turn) and do this quickly; set a fast pace and show an expectation that everyone will be ready to respond. This norm will make all rounds go faster.
    - Emphasize to those later in the sequence of logging decisions that they cannot change their written decisions as other are sharing the decisions.

    - Advise them NOT to make their decisions for all the rounds yet, but to make a decision for each round in its allotted time.
- For each period:
    - Explain the specific EBA practice and policy environment for this contract period
    - Go to the tab on the spreadsheet for this treatment
    - Ask players to make their decisions and to write them down in their recording tables to commit to them.
    - Go around the room and ask players to call out decisions (adopt or no for most periods; bid value for auction). Record them in the spreadsheet.
        - If you want to ensure that players will commit to decisions before hearing others' decisions, you can give them slips of paper to write decisions on and have them hand the decisions up to you to be recorded.
    - At the end of the round, announce the outcomes. Show the earnings column, and show the summary block. Tell the players to record their outcomes. You will need to zoom in and scroll around the spreadsheet to ensure everyone can see their outcomes.
    - We find that a short discussion after each round, followed by a substantial discussion at the end, is most fruitful.
- Specific period instructions:
    - 1: No government
    - 2: Flat adoption subsidy
    - 3: Auction
        - It's helpful to write on the board a set of ordered sample bids (e.g. $1, $2, $3, $4, $5) and circle the winners and point to the payment that would result, while explaining the process out loud. Write from lowest to highest so the winners are on top and you can circle them and point to median bid.
        - The spreadsheet should automatically determine which bids win and what the winning bid amount is.
        - More than half of the bids will win if there are ties at the median bid.
            - If you want exactly half of the bids to win, you can select the tied bids and assign random numbers to them to break the tie. We find this takes time and adds enough complication that it is probably not worthwhile unless you particularly want to focus on features of the auction.
        - Make sure that you tell them (or that they can see) whether they won and what the payment was.
        - Go to the tab "bid supply curve," select columns A and B, and sort by A (Farm Val). The bids will show up as a supply curve, and you can discuss this as a supply curve (where marginal costs are opportunity costs)
        - If anyone asks, you can note that while in all of the other periods, you should count the 5% of farming value ecosystem boost rate you would get from your own EBA adoption as part of your net incentive to adopt, in this

treatment that's no longer true because the number of parcels and thus the amount of ecosystem boost is fixed since half the bids will be accepted.

  - After the treatment, you can explain why it should be incentive compatible to bid one's true value. We intuitively explain this by pointing out that in this mechanism, your bid influences whether you will win the auction but not how much you pay. You will never bid below your value because you might get a contract with a payment below your opportunity cost; you will never bid above it because you might miss out on a contract that you would have been willing to take. If winners were paid their bids, they would have an incentive to shade bids upward.

- 4: Uncertain direct effect (also with notes relevant for periods 5A & B & 6A & B)
  - For this and later periods, the columns that depend on the uncertain yield have a "#VALUE" in them. This is to prevent the numbers from changing as respondent decisions are being entered (since the random number generator will regenerate when anything is typed); the uncertain yield value column is filled in with black so the values in it can't be seen.
  - Once everyone's decision is entered, copy the adoption effects (the blacked out values: column M ("Random direct adptn effect") in 4, O ("Random my effect") in 5A and 6A) and paste <u>values</u> (using paste-v or the menus as shown below) to column H (which is blacked out in 5A and 6A).

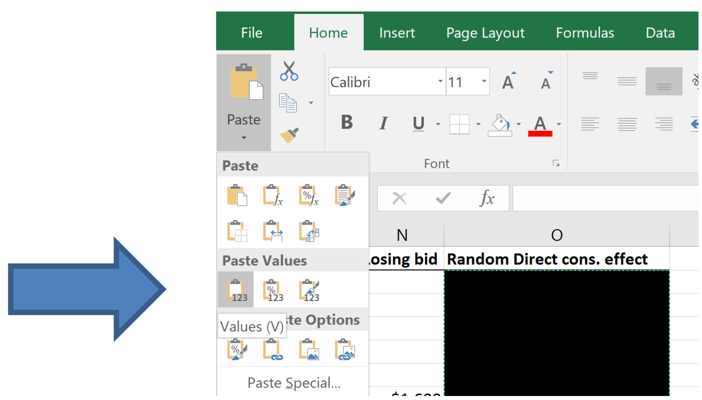


Figure 1: How to "Paste Values" from the Menu on Excel

  - This will now update the columns that had said "#VALUES" with actual numbers based on the realized Direct adoption effects.
  - Tell adopters their Direct adoption effects. Ask the class whether this was a good year or a bad year – it will be obvious which it was.
  - If you want participants to see the yield effect value (for transparency, to help explain why people had the yield effect amounts they got) you can copy the value from cell P10 and paste-special-values to a new blank cell or you can specify "no fill" (under Home in the Font tab) for cell P10.

- 5A & 5B: Uncertain but correlated
  - This treatment consists of two paired periods, the first period in which the mean value of the yield distribution and the idiosyncratic effects are realized and the pilot year of decisions are made, and the second period which uses the same values from the first period.
  - Emphasize that people need not take the same action in both periods, but that the values will be the same across both periods
  - The randomness in this and the next period are hard for people to understand. Before the round, you might want to show them a couple of normal distributions to explain the shared and idiosyncratic random effects (using the one in the slideshow we provide or sketching them on the board). Lay out two bell curves, pointing out that the mean of the distribution is randomly chosen to be high or low, and then to sequentially show some individual people's idiosyncratic values as dots in different places on one of the distributions.
  - See guidance from period 4 above regarding copying and pasting the random values that represent the realized yields (in the blacked out cells)
  - If you want to see the mean personal direct effect, you can copy the value from cell R10 and paste-special-values to a new blank cell or specify "no fill" for the cell).
    - You are not getting new values in the second period, so you will not have to do this in the second period worksheets.
- 6A & 6B: Pilot bonus
  - Conduct of this pair of periods is exactly like 5A & 5B; these just add a bonus automatically for adoption in the first of the paired periods.

- At the end of all rounds, go to the summary ("Total Earnings") tab. This shows each person's earnings in each period and adds those up, and uses the conversion factor to convert into potential dollar earnings.
  - Type somewhere in the spreadsheet to recalculate the random number column (make this moment dramatic!).
  - Copy and paste-special-values to fix which player numbers are chosen.
- If desired (and we encourage this!), pay some participants, based on information in the "Total Earnings" tab (in which participants are identified by their "position" and card number)
  - We suggest payment in cash or through a payment app right on the spot.
  - To randomly choose those to pay (which may be considered fairest): The spreadsheet has a "Random number" column that will recalculate whenever anything is typed in the spreadsheet. The formatting will automatically highlight the top 10% of random values. You can use this to pick 10% of the group randomly to pay actual money. If instead you want to pay some other number of participants: copy the random numbers and paste their values; select columns A-M of this sheet and sort by column M (Random number); and take as many as you want from the top of the list.

  - Alternatively, you could pay those who earned the most, to incentivize careful decision-making even more.
  - You could instead give students extra credit that is somehow proportional to their earnings.
  - Note that in any of these cases, earnings will be heavily dependent on the card that each student randomly received; if this bothers you or your students, you can normalize their earnings by their Farming Value or the maximum potential earnings they could have made.
  - Yet another option is to pay some value related to group earnings to a charity supported by the group or relevant to the environment or development.
- Save the spreadsheet and share it with the class!

Appendix II: 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 wellbeing. 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 adopters, 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 below. 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; cannot afford basic necessities; health suffers; children removed from school at a young age
2,000₼ to 5,000₼	Basic necessities are met; some schooling for children; but a life shock (e.g. major illness) can push them 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 round. 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 rounds divided by 10,000₼/$ to convert it into dollars).

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%)

<u>Contract Period 3: Conservation Auction</u>

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₼.

<u>Contract Period 4: Uncertain Direct Effect</u>

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:

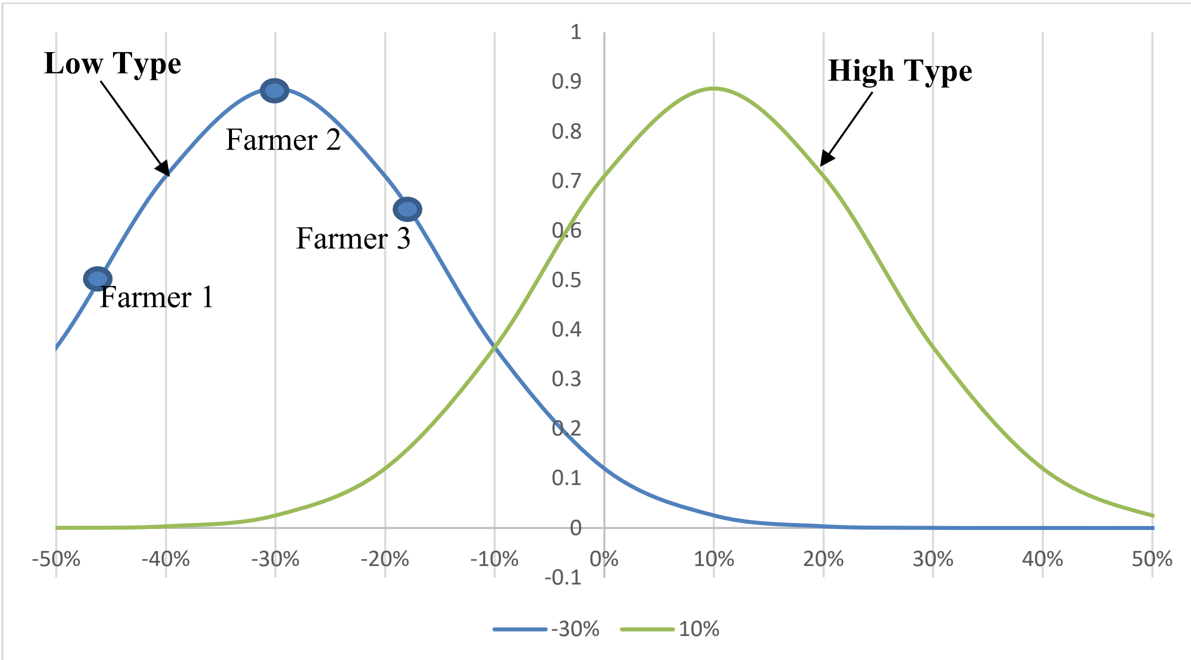
Earnings = Farming Value * (1 + # adopters * 5%)

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. At the same time, 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. 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 mean value of the distribution of possible effects, but can learn about it from seeing others' yield effects.

The figure below 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. 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 has distribution 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 not make the same decision in both rounds. 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%)

Contract Periods 6A & 6B: Uncertain but Correlated Direct Effect, with Pilot Bonus

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

The EBA practice again uses trees, but in this case through intercropping: 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, the same kind of uncertainty surrounds intercropping's effects on your yields as did for border agroforestry. There is some unknown mean effect, and that mean value 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 not make the same decision in both rounds. 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
Round	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 correlatec	₼			%	₼	%	₼	₼	₼	₼	₼
5B	Uncertain but correlatec	₼			%	₼	%	₼	₼	₼	₼	₼
6A	Pilot bonus 1	₼			%	₼	%	₼	₼	₼	₼	₼
6B	Pilot bonus 2	₼			%	₼	%	₼	₼	₼	₼	₼

Appendix III: Handout for Participants

Ecosystem-Based Adaptation to Climate Change

Climate change is already having significant impacts on both human and ecological systems, and those impacts will only increase (IPCC, 2014). Through ecosystem-based adaptation, human communities can use biodiversity and ecosystems to adapt to ecological and climatic shifts and thus reduce the damages they face (Doswald et al., 2014; Wertz-Kanounnikoff et al., 2011)

Climate change adaptation initiatives are classified as hard engineering (also known as grey) adaptation, or soft adaptation, which comprises ecosystem-based solutions (green adaptation) and policies and social initiatives (Chambwera et al., 2014; Depietri and McPhearson, 2017). While hard adaptation modes like revetments and sea walls may be needed to protect some communities, ecosystem-based adaptation can also be successful, and in some cases may be better than pure engineering solutions (Rao et al., 2013). However, many ecosystem-based adaptation techniques are relatively new and there are uncertainties about their costs and benefits (Doswald et al., 2014).

> **Adaptation:** Actions taken to help communities and ecosystems cope with changing climate conditions (UNFCCC, 2013; VCCCAR).
> **Ecosystem:** A community made up of living organisms and nonliving components that interact as a functional unit.
> **Ecosystem Services:** The benefits that people derive from ecosystems (Millennium Ecosystem Assessment, 2005).

Ecosystem-based adaptation measures reduce climatic risk by keeping climate hazards outside communities, increasing adaptive capacities, or helping communities be prepared for or recover from climate hazard impacts (Wamsler et al., 2016). Ecosystem-based adaptation relies on sustainable management, conservation, and restoration of ecosystems. The relationship between ecosystems and adaptation is, however, complex and multidirectional: ecosystem-based adaptation can help humans adapt to climate change, while non-ecosystem-based adaptation efforts can either protect or endanger biodiversity and ecosystem services (Secretariat of the Convention on Biological Diversity, 2009). Similarly, many initiatives to preserve ecosystems can yield both climate adaptation services and non-climate-related ecosystem services, like serving as habitat for important species. For example, mangrove forests provide an array of ecosystem services and protect coastal areas (Faunce and Serafy, 2006).

The table below describes examples from the United Nations Development Programme's Ecosystem-Based Adaptation Program (UNDP, 2015).

Nepal	Peru	Uganda
• maintaining and restoring ecosystems along roads to reduce landslides • restoring wetlands, springs and ponds to ensure year-long drinking water supply • soil nutrient management to increase soil moisture during dry periods	• restoring water channels and reservoirs to support micro-watersheds & wetlands to secure provision of water for the reserve communities and downstream users • grassland management to enhance pastoral livelihoods and increase resilience to drought and frost • vicuña management to produce animal fiber for livelihoods and communal livestock management in natural grasslands	• improved water retention through roadside drainage bunds and run-off retention drains • a gravity flow engineered irrigation scheme, combined with reforestation, soil and water conservation • riverbank restoration to create a hybrid grey-green solution to catchment-scale water management • tree planting using agroforestry to stabilize soil to reduce landslides

Source: (UNDP, 2015)

Adaptation is often most crucial in issues relating to water. Shifts in population and changes in human behavior in response to climate change will increase water stress, rendering adaptation even more necessary. For example, in Uganda, farmers are moving into wetlands because of increasing rainfall variability and land degradation on historically traditional agricultural lands (UNDP Green Climate Fund, 2017), while in other countries like Guinea, farmers are moving out of rich coastal areas due to salinity and sea level rise (UNDP Green Climate Fund, 2019). Thus, adaptation measures must respond to changes in both weather conditions and human populations.

While some ecosystem-based adaptation can occur at the community level, some adaptation must happen on land parcels owned by individuals (Scarano, 2017). Adopting these practices can be costly for landowners; for example, the community may be best served by an unfarmed buffer strip near a waterway, but that may be a farmer's most productive land. Laws exist to require such practices in some cases (Uganda, 2000), but they can be hard to enforce. Alternatively, payments for ecosystem services programs may be effective in promoting ecosystem-based adaptation, but such programs are not a panacea and will only be effective in certain conditions (Wertz-Kanounnikoff et al., 2011).

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Wamsler, C., Niven, L., Beery, T.H., Bramryd, T., Ekelund, N., Jönsson, K.I., Osmani, A., Palo, T., Stålhammar, S., 2016. Operationalizing ecosystem-based adaptation: harnessing ecosystem services to buffer communities against climate change. Ecology and Society, 21(1).

Wertz-Kanounnikoff, S., Locatelli, B., Wunder, S., Brockhaus, M., 2011. Ecosystem-based adaptation to climate change: What scope for payments for environmental services? Climate and Development, 3(2), 143-158.

Appendix IV: Readings to Accompany the Game

Instructors may wish to have their participants read some relevant articles and reports before or after the class session, and may also wish to make some optional readings available to those who want to learn more. We gather here some useful readings for these purposes or the instructors's engagement with the subject, organized by topic.

Climate change in general:

- IPCC "AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability" (IPCC, 2014a) https://www.ipcc.ch/report/ar5/wg2/ - all components available in several languages); dense but accessible to a lay audience; particularly helpful components:
    - "Summary for Policymakers" (IPCC, 2014b) comprehensive
    - Chapter 17, "The Economics of Adaptation" (Chambwera et al., 2014) and other chapters on adaptation
    - Regional chapters, which also include discussions of impacts and adaptation
- The Secretariat of the Convention on Biological Diversity (2009) also discusses a variety of relevant issues with a particular focus on biodiversity; section 2.3 (which is quite brief) of this report specifically addresses ecosystem-based adaptation.

Ecosystem services and payment for ecosystem services programs:

- Any environmental economics textbook, such as Hanley et al. (2013) or Tietenberg and Lewis (2016), will provide a comprehensive treatment accessible to people who have had at least basic introductory microeconomics.

- There are many policy briefs on ecosystem services that are non-technical and practical (rather than theoretical), such as the very short Wunder (2005) and the slightly-longer Khanal et al. (2013), on Nepal.
- A more general discussion of the state of global ecosystems can be found in the Millennium Ecosystem Assessment (2005); the synthesis report is quite long, but the summary for decision-makers is only 24 pages and contains useful visuals.
- The Economics of Ecosystem Services and Biodiversity (Kumar, 2010) efforts bring together the economics aspects of ecosystem services; the full set of publications they provide is large, but the synthesis report is only 38 pages and provides a comprehensive overview of the how economics links to ecosystem services and biodiversity.
- Participants will also likely find the Handbook on TEEB (Nunes et al., 2014) to be a useful collection of case studies and research papers highlighting the use of economics methods to better understand and provide ecosystem services.

Adaptation and ecosystem-based adaptation:

- Daigneault et al. (2016) performs cost-benefit analysis for hard and ecosystem-based adaptation measures as protection against flooding and is quite relevant.
- A report by Rizvi et al. (2015) summarizing the cost-benefit analysis of ecosystem-based adaptation programs is a bit longer than for students to be required to read. However, specific sections of the report can be shared based on some of the six different country experiences presented. The level of technical detail should be broadly accessible.

- Wertz-Kanounnikoff et al. (2011) is an accessible interdisciplinary journal article that assesses how well payments for ecosystem services may work in promoting ecosystem-based adaptation.
- Also suggest that participants browse websites that discuss ecosystem-based adaptation initatives, such as:
    - http://adaptation-undp.org/projects/mountain-eba
    - https://www.unenvironment.org/explore-topics/climate-change/what-we-do/adaptation-and-resilience/ecosystem-based-adaptation
    - https://www.iucn.org/theme/ecosystem-management/our-work/ecosystem-based-approaches-climate-change-adaptation

Sustainable Development:

- UN Sustainable Development Goals (https://sustainabledevelopment.un.org/)
- United Nations Development Programme (http://www.undp.org/content/undp/en/home.html)
- United Nations Environment Programme (http://drustage.unep.org/)
- International Union for Conservation of Nature (https://www.iucn.org/) (as these organizations have supported governments with the implementation of several ecosystem-based adaptation projects.

Technology adoption and diffusion in agriculture:

- Jack and Tobias (2017) is a short, non-technical report that discusses issues of information and technology adoption in agriculture in developing countries, with evidence-based policy suggestions.
- Scholarly articles that empirically study elements of technology diffusion, uncertainty, and learning as applied to agricultural technology in developing countries include Raeburn et al. (2016), Crane-Droesch (2017), Beaman and Dillon (2017), Caeiro (2019), Pates and Hendricks (2020), and Gupta et al. (2020). These are economic journal articles and, as such, are technical enough that they are best suited to graduate or advanced undergraduate classes.

Risk and uncertainty:

- You can find a general treatment in just about any microeconomic textbook at your desired level.
- Behavioral economics texts will cover additional related topics such as prospect theory and loss aversion, subjective expected utility and ambiguity aversion, and risk perception.
- The aforementioned article by Raeburn et al. (2016) explores ambiguity (and how its resolution can be a public good) using a lab-in-field experiment; again, this is better suited to participants with more advanced economics backgrounds.
- There are many journal articles on topics related to risk.
- It is also easy to find journalistic articles that emphasize risk in relevant situations; for example, Cornish (2018) discusses the uncertainties and factors that drive the adoption of genetically modified organisms in agriculture in developing countries.

Reviewers Appendix: Slides

We provide an editable Powerpoint that the instructor can use during game play as desired. For ease of reviewing, we also include the printout of the slides to the paper in this appendix, but as the slides will be available for download with the article, the printout will not be necessary in the published version of the article.