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Human behavior and the use of experiments to understand the agricultural, resource, and environmental challenges of the XXI century

Juan Camilo Cárdenas*

School of Economics, Universidad de los Andes, Bogotá, Colombia

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Abstract

The use of laboratory[1] experiments in economics, and their later deployment in the field as a tool for exploring how actual decision-makers respond to information, incentives or institutions has brought a revolution to how we model economic systems, and design policies for them. This new century will bring challenges for the study of agriculture, natural resources and the environment, where it will be necessary to have a better understanding of human behavior, in a world where climate on the one hand, and land, labor and food markets are ever more unstable. This article reviews the intellectual history of a rich dialogue between theory and experiments with a particular focus on its relevance for agricultural, resource and environmental issues. Special attention will be given to the case of common-pool resources where this dialogue between models, field work and laboratory experiments continues to provide a rich cross-fertilization for the advance in the understanding of the economic systems that governs these resources. I will close by arguing that agricultural, environmental and resource economists will have to take part of this behavioral revolution by embracing experiments in their teaching, their research and their policy design.

JEL classifications: C90, C92, C93, D01, D03, O13, P32, Q00, Q14, Q15

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1. Introduction

The use of experiments for the study and improvement of agricultural systems has a long history, including examples dating back to when the Pre-Columbian Incas built the terraces at Moray (Perú) creating microclimates with temperatures ranging by 15 °C, to explore adaptations and improvements to their crops. During the late 1800s agricultural experimental stations were established around Europe and the United States, and as Knoblauch et al. (1962) described in their review of the first 100 years of these stations, *"[e]xperimentation, the making of scientific inquiry and the systematic probing of practice, was destined to become the new tool whereby man would enlist the cooperation of nature for the advancement of human welfare."* The contribution of the experimental method to the increase in productivity in the agricultural sector was undoubtedly large due to the curiosity of researchers tinkering with the best combinations of different inputs for producing crops and livestock.

However, the human decision-making dimension was unexplored during that century of experimental research in agriculture. The humans involved in the experiments followed careful instructions from the researchers with respect to daily decisions regarding the application of fertilizer, irrigation or the moment of harvest.

A hundred years later, and despite very clear evidence of the positive benefits of fertilizer to productivity, we barely understand why many farmers in Africa, for instance, do not adopt a practice that is evidently beneficial from a private perspective. That is intriguing, of course, if one assumes that the farmer is a perfectly rational maximizer of the net present value of the benefits and costs of such practice. However, new experiments on fertilizer adoption have shown that poor farmers may fall into cognitive traps that impede making clearly profitable decisions when impatience reshapes the present versus future benefit cost analysis to a (Duflo et al., 2011). With a much richer set of tools and models we now understand better the behavioral mechanisms and biases that explaining why these farmers did not make the technological transition.

*Corresponding author. *E-mail address*: jccarden@uniandes.edu.co (Juan Camilo Cárdenas).

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There are, of course, many other possible explanations for low adoption of fertilizers, beyond the cognitive traps mentioned. Carter (this issue) in this issue reviews a number of issues related to how risky and uncertain environments along with heterogeneous preferences can change the rational choices of decision makers in ways that may seem inefficient and yet reasonable if one considers new developments in behavioral sciences pertaining to hope or aspirations. His approach to the problem may provide explanations for low adoption of technologies and also insights into the implementation of future programs. Others like Suri (2011) provide an alternative explanation, namely, the heterogeneity in the benefits and costs to the adopters of technology. In his explanation, some farmers would have high returns on the adoption except that infrastructure and distance to the suppliers make it not profitable for the adopters. Some others will adopt the technology and receive the gains, while still others will not adopt the technology due to low returns on the adoption of seeds and fertilizer. Bold et al. (2015) suggest also that the low quality of the nutrient content in the fertilizer, most likely due to counterfeiting, may explain some cases of low adoption rates. Their study included sampling different suppliers of fertilizer and testing their nitrogen content, and then using the low- and high-quality fertilizers to study the yield gains in each case. The average low quality of the inputs found in the market would bring down profits and thus explain the low adoption rates. These alternative explanations, however, are not mutually exclusive of the behavioral poverty traps mentioned before.

By better understanding how actual humans, and not a perfectly rational *homo economicus*, make decisions when facing different risks with different seeds, or deciding over spending part of their scarce resources on applying fertilizers or pesticides, or devoting time to a collective enterprise such as building and maintaining a community based irrigation system, we might be able to better understand why some regions get out of poverty while others seem trapped in it.

This article offers a brief recap of ways the behavioral revolution of the last few decades has transformed the study of economics and impacting how we understand the functioning of agricultural, natural resource and environmental systems. Two valuable attempts to survey the implications of behavioral and experimental economics for the environmental and resource economics literature are Shogren and Taylor (2008) and Croson and Treich (2014). These two reviews of the literature stress how the behavioral regularities that have been well documented and modeled over these decades have direct implications for the study of resource and environmental issues, although their focus is mostly on environmental economics issues, with no mention to agricultural settings where there are major implications for understanding and policy design.

It should also be noted that most of the work reviewed in these two articles refers to laboratory experiments conducted with college students with little attention paid to the more recent work bringing the lab to the field and using subjects that are more familiar with the problems being studied. Croson and Treich (2014), I should note, do report on random controlled trial interventions that use behavioral insights to explore how individuals respond to different monetary and nonpecuniary incentives. These two surveys, nevertheless, provide a valuable inventory of key issues in terms of the limits that the conventional rationality assumption of a perfectly calculative, self-controlled and selfish economic agent has, and how these limits or biases will have direct implications to environmental issues in terms of the emergence of externalities and the potential effectiveness of policies when these biases affect how individuals may respond to changes in the incentives.

One of the main reasons the behavioral revolution has influenced the mainstream of economics dis the compelling evidence brought by the experimental approach on regularities that violated earlier assumptions about human behavior. The use of controlled experiments, changed forever the discipline once seen only as an observational science. The wealth of experimental evidence on certain regularities in human behavior has reshaped many domains in economic analysis including choices under uncertainty, care for others or for justice, or the asymmetric valuation of losses and gains. Exploring the exact transmission mechanisms through experimentation has allowed models of economic rationality to be improved in recent decades.

As changes in the biophysical and institutional environments become more frequent and unpredictable, greater threats and opportunities emerge. After identifying the new context and challenges for rural societies, I will focus on the particular case of common-pool resources and gather new insights from the behavioral sciences that may help us explain how tragedies of the commons emerge or are avoided. Such new learning is possible use of experimental methods in the lab and the field allow us to better understand the social dilemmas associated with natural resources jointly shared by a group. At the end I will close with a few reflections on how this behavioral revolution should change the ways we use economic reasoning in the classroom, the policy-making board and our research.

2. The behavioral revolution and why it matters

A special section of the Journal of Economic Perspectives under the title of "Anomalies" used to start with the following sentence: *"Economics can be distinguished from other social sciences by the belief that most (all?) behavior can be explained by assuming that rational agents with stable, well-defined preferences interact in markets that (eventually) clear. An empirical result qualifies as an anomaly if it is difficult to 'rationalize' or if implausible assumptions are necessary to explain it within the paradigm."* The purpose of that section, coordinated by Richard Thaler, was to document research that found violations of these assumptions. The section disappeared from this widely read journal, not because there was no material of value. On the contrary, the discovery of systematic violations of many assumptions about economic behavior based on the *homo economicus* model of an individual maximizer of net present value of his own material consumption, with perfect calculative capabilities and perfect information about outcomes, led this section to disappear, but not its contents. What were considered "anomalies" became foundations for rethinking entirely these assumptions about economic behavior. Today all major general economics and applied or subfield journals in the discipline acknowledge and publish on a regular basis research that documents these violations, or explorations of alternative theoretical models that explain behavior of more "real" humans, and not "econs" as Thaler labels these unrealistic robots. As Shogren and Taylor (2008) argue for the case of environmental problems, relying on the conventional model of *homo economicus* for policy-making would work only if people behaved that way. Unfortunately, humans show these behavioral biases which justify a rethinking the design of policy instruments and thus the models supporting them.

Among the key aspects of these new descriptions of economic rationality are how humans value gains and losses, how they discount near future values against values far away in time; how they manage self-control; how they care about others or about how fair a result is; or the limited capacity of the brain to evaluate multiple scenarios with the consequent use of heuristics to reduce the cognitive load of such complex enterprise.

We now have at our disposal a number of experiments, results and models that provide better tools to help us study why some times markets work well and in other cases fail to do so; why sometimes the state may be effective in some cases and fail in others; or why communities may be a way to fill the gaps not solved by markets and states, and fail in others. These experiments—some of which are described in Table 1, fall within the category of "mechanism experiments" as discussed in Ludwig et al. (2011), as they are aimed at understanding the channel of transmission through which a particular policy mechanism may impact an outcome variable.

Frequently, the decision-making situation for a firm or a household involves trade-offs that require understanding the behavioral foundations of the decision. Take our fertilizer problem at the introduction. Devoting valuable cash, or borrowing to purchase fertilizer involve solving several behavioral challenges. One is the intertemporal decision. The alternative uses of that cash in the present may pose a difficulty if one has a present-biased intertemporal preferences which may alter the future value of the increased yield. See Kaur et al. (2015) for an example of a field experiment designed to evaluate these intertemporal biases and measure the problems of self-control and their economic inefficiencies. Although the experiment was conducted in an urban labor market for data entry, it could easily be applied to agricultural settings, such as in the experiments by Bandeira et al. (2011).

Second, there is the uncertainty aspect of using the fertilizer, which combined with an uncertain climate, most probably imposes a situation of ambiguity (not knowing the probability distribution) rather that of uncertainty (knowing the odds of each possible outcome). Engle-Warnick et al. (2007) and Sanou et al. (2015) are good examples analyzing how risk preferences affect the probabilities of adoption of new technologies. Carter (this issue) also reviews this literature and provides a unifying framework for such analysis.

Third, the (lack of) use of fertilizers in that particular village may be subject to social norms that impose extra costs on deviants, or to the effects of peer-effects that alter adoption of a particular practice. Kremer and Miguel (2007), for instance, show that adoption of deworming practices, clearly beneficial from the private standpoint, is subject to social network effects that reduced take-up rate as more people in the community were exposed to the program. Their conclusion is that these sort-term programs are not sustainable in the sense that the adoption will not continue without heavy subsidies from donors or governments. These issues are not settled, however. Carter et al. (2013) show on the other hand that a voucher program for fertilizer and improved seeds does have lasting effects in income and productivity in Mozambique.

Also, social norms or conventions may emerge in agricultural contracts that generate equilibria that cannot be explained through conventional economic reasoning. An example described in Young and Burke (2001) provides an alternative theoretical model that explains the way norms for sharecropping contracts may emerge within a location and be sharply different from those in a neighboring location, even when these differences cannot be explained through differences in wages or soil productivity.

Finally, there might be environmental concerns about the impacts from the use of agrochemicals on runoff and contributions to eutrophication which may decrease the use by farmers as more environmental organizations raise awareness of these ecological problems.

All these aspects may produce effects on the behavior of farmers that deviate from the standard model of the maximization of the net present value of present and future costs and benefits accrued to the farmer himself. Most of these behavioral aspects of decision-making have multiple applications in our area of interest, namely, in economic systems associated with agriculture, natural resources and the environment.

These behavioral explanations do not preclude analysis using other potential explanations. Take, for instance, de Janvry et al. (1991) seeking to explain the paradox where governments argue that poor farmers do not respond rapidly to price incentives and better technologies while farmers complain about variabilities in prices and labor supply. These authors provide a structuralist explanation in which market failures induce farmers to shift inefficiently toward their own labor and output self-consumed in the household. To build their argument, they use a conventional model of utility maximization by the household, subject to the usual constraints on cash income, production technology, and market prices for outputs. Their optimality conditions are then used to simulate reactions by farmers to different shocks in market prices, taxes or changes in production technologies, showing the inefficiencies derived from the "rational" response by the farmers.

Table 1
Adapted from Cardenas (2009)

Household and firms . . .	Behavioral dimension	Preferences involved	Trade-offs involved in the decision-making	Experimental designs
. . . are not certain about the returns from adopting a technology	Risk exposure, risk aversion and poverty	Risk aversion, ambiguity aversion, loss aversion	Riskier & higher vs. safer & lower returns	Lotteries, varying variance, and expected returns
				Lotteries with (un)defined probability distributions
. . . need formal and informal insurance mechanisms	Risk preferences	Other-regarding preferences	Private vs. state vs. communal insurance over risks	(Lotteries) risk and risk-pooling games
	Self-government and social networks	Risk preferences		Existing and controlled Social networks experiments in combination with social preferences experiments
. . . have impatience and present-biased needs	Time discounting, saving rates, pensions	Time preferences	Consumption today vs. consumption tomorrow	Payments spaced in time
. . . live in communities and may care about other nonkin	Pro-sociality toward others today (fairness, inequality)	Other-regarding preferences (altruism, fairness, inequality aversion)	My consumption today vs. sharing with kin today	Social preferences: altruism (DG,UG, TPP), reciprocity (UG, TG, GiftEx), cooperation (PD, CPR, VCM)
	Pro-sociality toward kin in the future	Time preferences	My consumption today vs. sharing with others today	
	Pro-sociality toward nonkin in the future		My consumption today vs. saving for kin tomorrow	
. . . live in a physical environment they may intrinsically value for its cultural, or ecological services	Protection of the environment	Ecological preferences	Consumption today vs. resource exhaustion tomorrow	WTA/WTP (Choice experiments, conjoint experiments)
		Time preferences	Consumption today vs. extinction tomorrow	Donation/charity experiments
		Other-regarding preferences	Protecting today vs. consumption of others (next generations) tomorrow	CPR, VCM
. . . interact with markets of credit, production factors and outputs	Market-based growth through competition, specialization and access to credit and microfinance.	Risk aversion, risk-pooling	Market vs. state vs. community based management of the local and global commons	Market-based institutions (ITQs, fees, quotas, command, & control)
		Entrepreneurship		CPR games, VCM games
		Other-regarding preferences		Market behavior (double auction, posted offers)
		Competitiveness		
. . . benefit from public goods that require provision	Provision of public goods (education, health, security, recreation, etc.)	Other-regarding preferences	Market vs. state vs. community based provision of local public goods	CPR, VCM with endogenous vs. external regulations

DG = dictator game, UG = ultimatum game, TPP = third party punishment, TG = trust game or investment game, GiftEx = gift exchange, CPR = common-pool resource game, VCM = voluntary contributions game.

Table 1 summarizes a number of instances where households or firms face a choice affected by behavioral biases and the preferences involved in such decisions. The table also describes the type of trade-offs involved in the decision and associated to the behavioral bias. The last column enumerates the types of experiments that are used for measuring these behavioral biases and confirm or reject these hypotheses. The purpose of this table is to guide the reader in various domains where agricultural, environmental and resource issues are relevant.

For each row of Table 1, the experiments in the last column have provided regularities that have questioned the assumptions or models used in economics. For instance, as people regularly value differently a gain or a loss of the same monetary amount, new models of rationality with loss aversion have emerged to understand behavior in the stock market. The strong evidence that humans are willing to reject an unfair offer in the ultimatum game (UG) and forego a net positive income gain, or their willingness to avoid the incentives for free-riding and voluntarily contribute to public goods has made it possible to rethink models of public goods provision, the role of costly punishment, and how social norms may emerge to sustain cooperation among humans.

The progress over these decades—greatly enriched by close collaboration between experimental and game-theoretical tools—has given birth to what has been labeled Behavioral Game Theory (See Camerer, 2003). A synthesis of four major dimensions of rationality, suggested by Camerer (2003), where the behavioral revolution has departed from the original principle of rationality, is presented in Table 2. Each of these domains is defined by the principle used in the conventional or mainstream model, then the behavioral principle developed to enrich the conventional approach and its respective psychological foundation or mechanism that has been documented in the literature. The last column connects these to the examples of relevance for the study of agricultural, resource, and environmental issues.

Overall, the behavioral economics revolution has supported its claims to becoming part of the mainstream by using controlled lab and field experiments providing the empirical support for redefining economic models, and the assumptions underlying in those models.

The context in which decisions are made for agricultural, environmental or natural resource systems call for improvement of those assumptions and the models used to study behavior and outcomes. These production systems, due to their direct interactions with the natural base, are highly stochastic (e.g., climate, water use, soil productivity) and involve strong interdependence among agents (e.g., watersheds, pollution, runoff) which make it necessary to deal with the way behavioral factors influence the decision-making processes. This is becoming increasingly important because: (i) markets for outputs and inputs will most likely continue to show greater variability with global warming; (ii) AAs these markets become more integrated,, the impacts of policies or events in one region will have greater impacts on prices in others. As an FAO briefing report put it, *"Increased vulnerability is being triggered by an apparent increase in extreme weather events and a dependence on new exporting zones, where harvest outcomes are prone to weather vagaries; a greater reliance on international trade to meet food needs at the expense of stock holding; a growing demand for food commodities from other sectors, especially energy; and a faster transmission of macroeconomic factors onto commodity markets, including exchange rate volatility and monetary policy shifts, such as changing interest rate regimes."* (FAO, 2010)

The second source of volatility will come from local to global climate-related events. Not only the greater variance in the signals that the agricultural sector will increasingly see, but also the more frequent high costs/low probability extreme events that will create a new environment for decision-makers. The need for more realistic behavioral analysis will be critical. Kahneman and Tversky (1979) had already warned us, through their Prospect Theory, that humans overweight low probabilities, creating behavior not consistent with the conventional expected utility models. Continuing with the implications from Prospect Theory, we know that humans tend to be more risk averse (concave utility function) when facing gains but more risk tolerant (convex utility function) when facing losses. This behavioral phenomena has helped explained the systematic difference between Willingness to Pay and Willingness to Accept when valuing changes in environmental variables. The implications of these findings are enormous, as cost-benefit analysis, which relies on a symmetric effect of increases or decreases in the demand function for the case of changes in welfare, namely consumers' surplus, will fail in generating an equivalent value for an environmental change, if comparing a gain or a loss of such environmental benefit.

The increasing rate of natural extreme events such as floods, droughts, or hurricanes implies that the valuation of these low-probability events with considerable costs will have to be evaluated through a behavioral lens to understand the welfare implications and design policy interventions. As Croson and Treich (2014) argue, the fact that the behavioral biases produce unconventional valuations of environmental changes (e.g., losses valued differently from negative gains, future values in the present valued differently than those same valuations when the individual reaches that moment) creates an additional problem: Which values should the policy-maker use for her prescriptions when making an economic assessment?

A third source of change in a new environment for these agricultural systems is the more connected world through communications and networks. The potential for information sharing platforms is much greater with mobile phone technology and increasing internet penetration, although the net welfare impacts are mixed (Nakasone et al., 2014). Greater access to communications technologies will lower costs to agricultural households and firms in exchanging information will have regarding prices and access to markets for outputs or factors. Therefore, social norms and social ties will probably play greater roles as these networks are now geographically more interconnected than the very localized—and often isolated—network of a village of the past. The spread of information across interconnected local networks will imply a much more complex environment in terms of price signals and opportunities. These effects will be seen not only in the market but also in the political arena. The interconnectedness will also play an important role in the globalization of local social movements and their possibilities for gathering global support to the local causes of indigenous and marginalized communities, as we have seen already in some urban and rural movements.

Using the new tools of behavioral and experimental economics will help us understand how individuals respond to incentives, information, or institutions. With a world that can be more variable, uncertain and interconnected, the use of a behavioral approach will provide a more accurate picture of how

Table 2
Adapted from Camerer (1999)

Conventional rational principle	Behavioral principle	Psychological foundation	Relevance for agricultural, natural resource, and environmental economics
Expected utility	Prospect theory	Psychophysics, adaptation: loss-aversion, reflection, mental accounting, nonlinear	Valuation of gains and losses regarding farming, natural resource use or environmental events
			Technology adoption
			Natural disasters
Equilibrium (mutual best response)	Learning, evolution	Generalized reinforcement, replication by fitness	Agricultural markets volatility in prices for outputs and inputs
			Multiple equilibria, poverty traps
			Emergence of social norms and conventions
Discounted utility	Hyperbolic discounting	Preference for immediacy (temptation)	Valuation of future environmental benefits from soil conservation, or using new pest control, or fertilization techniques
			Self-control problems with possible long-term gains vs. short-term payoffs from traditional practices
Own-payoff maximixation	Social utility	"Spend" money on other people (reciprocate, dislike inequality)	Altruistic or reciprocal exchange with neighbors
			Aversion to inequity within communities.

individuals and firms make decisions, and thus provide better foundations for sound policies.

3. The path taken in the study of common-pool resources

The case of common-pool resources is one where behavioral economics has contributed enormously to better bridging gaps between reality, policy and theory. Survey papers such as Croson and Treich (2014) and Shogren and Taylor (2008) have done an excellent job in covering an important part of the literature on environmental issues. However, their treatment of common-pool resource and resource management issues is rather short. The relevance of common-pool resources in the management of forests today could not be greater. Communities managed about 27% of the forests in the developing world by 2007, up from 22% just five years before (Larson et al., 2010). The historical evidence that groups have failed in many cases, and succeeded in many others, in managing shared or joint-access resources calls for an explanation in terms of the micro-foundations of behavior and their interactions with the institutional context. Experiments, as has been argued in this article, can be useful to disentangle the interactions between choices and institutions.

Over the past two centuries, we have used a canonical model of economic behavior based on a selfish individual, pursuing private gain, who would not be interested in contributing to the common-pool if his marginal private benefit from doing so is smaller than his marginal private cost (Clark and Munro, 1975; Gordon, 1954). The Tragedy of the Commons became the landmark metaphor to illustrate that no individual, unilaterally, would be interested in contributing to the common good unless clear private property rights were defined or government intervened to internalize the externality. Yet empirical evidence from around the world showed some situations where groups were able to overcome the tragedy through self-governed mechanisms, and others where such attempts failed.

In her seminal 1990 book "Governing the Commons," Elinor Ostrom documented a number of cases where communities were dealing with natural resources for which there was joint access. Her analysis generated a set of eight principles to explain the conditions under which successful cases endured without collapsing or exhausting the resource. Some of these principles were associated with the way groups defined the rules of the game to solve the collection action dilemma, by establishing boundaries, rights and responsibilities for the group, and a system of monitoring and sanctioning for those not complying with them. This approach expanded the rather narrow set of policy possibilities available at the time for solving the problem, and summarized essentially in either redefining the property rights by dividing up the common-pool into individually owned units; or a state-based solution in which a government agency controlled the access and level of extraction of the resource as if the entire common-pool were owned by a single manager. In either way, a fractioned set of individual private properties or an aggregated private-like property, the manager would select the level of extraction that maximized the net benefits by equalizing the marginal benefits of the extraction with the marginal costs of the operation. Transferable quotas or permits and Pigouvian taxes were also used suggested for internalizing the coordination failure among common-pool users via market mechanisms. By estimating the value of the externality exerted by each resource user, one could either charge them with such fee to stop over extraction, or by assigning rights of extraction to the users and allow them to exchange their rights through monetary transactions, driving innovative technological changes to a point where permit owners would be interested in selling them as long as the total number of permits will not exceed the socially optimum number of permits or quotas.

However, for ecological, cultural, or political reasons, sometimes common-pool resources cannot be managed using the privatization or state-based management solutions. Assigning private property to fisheries that travel along coastlines or assigning ownership of pieces of the atmosphere to countries are not feasible. Breaking down into private ownership or transferring the management of a territory with a long cultural history to the state could also be undesirable if society values the practices that indigenous or ancestral communities have over the territory (imagine privatization of the territory for nomadic groups or hunter-gatherers that depend on accessing large tracts of the Amazon for their survival). Whether for technological, ecological, or cultural and political reasons, self-governed common-pool resources should exist, but also have existed over millennia, and in cases preceding the arrival of private property and state-based management. This does not imply, though, that self-governance will always work.

The value of Ostrom's work was precisely to take the analysis away from the simple private versus state ownership and management dichotomy to a richer, but more complex rationale of why and when self-governance might work. She conjectured that the more of these eight principles were present in the situation, the more likely the group would manage its common-pool in a sustainable manner. As reminder for some readers not familiar, the principles can be summarized as follows (Ostrom, 1990):

(i) There are clearly defined boundaries for those considered users and those outsiders.

(ii) There are clear rules that are adapted to local conditions on the appropriation and provision of the common resource.

(iii) There are collective-choice arrangements allowing users to participate in the decision-making process.

(iv) There is an effective monitoring system, with monitors who are part of the group or at least accountable to them.

(v) Sanctions are gradual and proportional to violations of the rules created by the group.

(vi) There are mechanisms for access to the group members and for conflict resolution at low cost.

(vii) Authorities at higher levels recognize the self-governance of the group.

(viii) For larger common-pool resources, there is a nested set of organizations of various levels.

Three aspects come to mind when reviewing these principles. First, each of these principles could be subject to an empirical test using experiments either in the field or the lab; and in fact, a great deal of experimental literature has sought to test them. Both as context controls or as treatment variables, each of these principles offers a possible mechanism through which collective action may emerge. There is a large literature on self-regulation, sanctions, monitoring and control associated with principles (iv) and (v) in various forms, testing for example the level of monitoring, the severity of the sanctions, or the proportionality of the fines against the violations. Second, these principles focus mostly on the "rules of the game" as formal rules and informal norms or prescriptions about expected behavior by the commons resource users; and third, they do not mention, at least explicitly, the behavioral foundations required to solve these social dilemmas. However, and as I will argue, it was precisely the behavioral aspect that made possible the emergence and implementations of these principles. Ostrom in fact was fully aware of this, as she later developed in her 1998 Presidential Address to the American Political Science Association, her later work using experiments, and her Nobel lecture (Ostrom, 1990, 1998, 2006, 2010; Ostrom et al., 1994).

But let us start with the institutional aspect—that of the rules, and then move on to the behavioral component afterwards. Notice that for all of these eight principles there is an implicit second-order collective action problem, on top of the joint access problem with respect to the resource use. For them to work through participation, rules, norms, and sanctions, the group must create and maintain a set of norms about individual actions; this requires a private effort that is greater than the private benefit from enforcing them. Attending meetings, monitoring peers, ostracizing when needed, helping others to maintain these rules, all require a set of behavioral characteristics that are not quite compatible with the model of *homo economicus* where participating in these nonproduction activities would be costly and provide no smaller private returns as the group size increases. But humans are not *homo economicus*. Reciprocality of preferences, trust and trustworthiness, sensitivity to social emotions such as shame and guilt, use of simple rules of thumb–heuristics–or feelings of aversion to inequality and preferences for fairness are some of the behavioral traits used by resource users in their decision making. Thse are used not only when solving both the first-order collective action problem of self-restraint in the extraction of the resource, but also for the costly second-order dilemma of maintaining the norms and rules that these eight principles require to be effective.

Research through observation in the field of these cases, by various natural and social scientists (e.g., Acheson, 1998; Baland and Platteau, 1996; Berkes, 1989; Ostrom, 1990; Wade, 1988), drove also theorists to rethink the models that were available at the time. New approaches that emerged from the advances from earlier work by Maynard Smith (1982) and Axelrod (1998) helped pushing the frontier with better economic models for common-pool resources. One of the best examples is Sethi and Somanathan (1996) who developed an evolutionary model capable of explaining how social norms and endogenous punishment can emerge in a group, and sustain a stable level of extraction from the common-pool, thus avoiding the tragedy of the commons.

With new theoretical models at hand, controlled experiments in the laboratory began to play a role. The seminal book by Ostrom et al. (1994) became the starting point of a number of experiments that adapted pure public goods games but incorporated the nonlinearities of the biophysical properties of natural resources. Later, Falk et al. (2002) used the experimental model that Ostrom and her colleagues had developed for their experiments, and transformed the payoffs function by incorporating the notion of inequity aversion (Fehr and Schmidt, 1999). From that transformed model they were able to explain better the data gathered in the laboratory for these common-pool resource experiments. The basic argument of an inequity-aversion based model of common-pool resources was that a combined mechanism of guilt from those who would over extract when the others were cooperating, and envy by those that were obtaining lower payoffs from restraining themselves while the others were over exploiting the common-pool, could sustain a level of extraction that was lower than the one predicted by a model based on the *homo economicus* model.

Meanwhile, during those same periods, the first experiments with a common-pool resource situation were run in the field, outside of the laboratory and with participants that were more familiar with the situation in place (Cardenas, 2000, 2003). The results replicated in the basic patterns those of the laboratory, although outcomes shifted toward more cooperation than observed between college students.

However, the understanding of common-pool resources is far from settled (Anderies et al., 2011). Many dimensions are yet to be explored. Both at the ecological, behavioral and institutional levels there are variables that can play roles we do not yet comprehend fully. Take stock dynamics, for example. Only small steps have been taken to incorporate dynamic effects in these experiments (Janssen et al., 2013). We are just beginning to understand how humans deal with the problem of a dynamic stock, as pioneering work by Moxnes (1998) has already shown, for instance, that on top of the difficulty of solving the social dilemma within a group, humans tend to underestimate the dynamic (regrowth vs. depletion) factor when introduced in these experiments, not anticipating the severe impacts of reducing the resource stock and thus its capacity to renew itself.

Another problem that needs to be addressed is the explanation for why we observe so much variation within subjects and across them in the laboratory. Although we have been able to explain much of the variation across groups in average levels of extraction and aggregate outcomes, there remains considerable heterogeneity, not only across individuals but also within individuals over time. Even more recent models of common-pool resources do not necessarily explain these stylized facts. For instance, models that are based on repeated games may predict the emergence of cooperation over time through reciprocal altruism or tit-for-tat strategies but they do not predict that players would maintain a diverse strategies even after large numbers of rounds.

The same can be said about models that incorporate other-regarding preferences in utility functions. These models predict levels of resource extraction that are socially more efficient than the *homo economicus* prediction but they also predict convergence toward an internal solution with no intrasubject variability. In an attempt to address this challenge, Cardenas et al. (2015) develop a simple parameter-free model, based on the concept of Sampling Equilibrium (Osborne and Rubinstein, 1998) that offers an alternative explanation for these phenomena and predicts observed behavior in the laboratory from past experiments. However, this model does not perform as efficiently when predicting the behavior observed in experiments in the field lab.

Nevertheless, the use of experiments has contributed immensely to the understanding of the behavioral foundations behind the successes or failures of groups in overcoming the tragedy of the commons (Ostrom, 2006). With respect to self-governance, the study of how face-to-face communication is capable of coordinating the beliefs, intentions, and actions of the resource users has augmented the understanding of how groups can engage in nonbinding agreements and through repetition create a set of norms based on a virtuous cycle of trust, reciprocity and reputation (Ostrom, 1998). It is quite remarkable that, in study after study, when group members are allowed to have a nonbinding conversation, the efficiency of the common-pool increases, questioning the conjecture that preplay communication and nonbinding commitments are innocuous. These findings provide support for alternative theoretical frameworks such as Charness (2000) and Charness and Dufwenberg (2006) which show that a model with guilt aversion or clear signaling strategies can drive players to socially efficient outcomes even where there are incentives against these goals.

A second set of results on which there is some consensus comes from laboratory experiments where group members can, at a personal cost, punish others in the group. In these cases a significant number of players choose an endogenous sanctioning strategy and it seems to increase social efficiency.

With respect to external regulatory incentives, however, the evidence is mixed. A number of experiments have involved different types of imperfect monitoring where fines are implemented. Some of these studies show positive effects, or complementarities between regulations and self-governed mechanisms, while others have shown crowding-out effects where the intrinsic motivations to cooperate are eroded (Cardenas et al., 2000; Lopez et al., 2012; Velez et al., 2012).

A further area of research with promising applications for the commons problem which deserves attention is looking inside the black box of organizations that manage these resources.[2] From cooperatives to resource users' associations there are hierarchical structures making decisions regarding a shared resource. Understanding the behavioral mechanisms that drive decisions within these organizations deserves attention as they

[2] I thank an anonymous reviewer for raising this point of upmost importance.

involve principal–agent problems on top of the social dilemmas they encounter when facing the problem of shared resources. An interesting experimental study involving experiments in the field, for a nonresource problem, is reported in Banerjee et al. (2012). It looked at different mechanisms that were supposed to improve the performance of organizations providing public goods (police stations and police officers) by altering the incentives—both pecuniary and nonfinancial—within the police micro structure. Another study within private production organizations, the soccer ball industry quite famous in Pakistan, is reported in Atkin et al. (forthcoming) where the authors designed an experiment to test for changes in labor productivity due to a technological improvement and the unexpected workers' response due to other incentives that may reduce productivity. The fact that there is so much variation within industries with apparently similar price sets and technologies (Gibbons and Henderson, 2012) opens the question for what is the relative role of managerial decisions within organizations. The case of natural resource use and agricultural firms is no exception to these issues and therefore continuing this behavioral and experimental research trend for these sectors should prove fruitful.

Overall, our understanding of the possibilities of cooperation in commons problems, through a mixture of behavioral and institutional factors, has been immensely enriched by the use of experiments both in the lab and the field. We are heading toward a better understanding the connections between the cognitive mechanisms and the emergence of the norms and rules that are described in Ostrom's eight principles of institutional design. As said before, the mere existence and robustness of such rules and norms requires in itself solving a collective action problem. Here again the field and laboratory evidence shows a heterogeneous set of actions and participation levels by the group members, with some community members taking on a more active role in terms of leadership than others; heavier participation in the social sanctioning and shaming than others, or in the design of the rules themselves. Participating in the design, monitoring and sanctioning of rules requires also elements of behavior mentioned before (e.g., altruism, trust, reciprocity, inequity aversion, preferences for fairness) for contributing to the self-governance system, in the same manner that these attributes are critical to creating the self-restraint required for stopping the over exploitation of the resource.

With this particular case of common-pool resources, I wanted to illustrate the progress made over the last decades thanks to the use of experimental and behavioral tools to address old and new questions in these agricultural settings. Other areas in natural resource management and agriculture could benefit through the same dialogue between the lab, the field, and the theorists. Like Carter (in this issue), I believe that behavioral sciences have contributed to our understanding of why previous models do not seem to predict observed human behavior and why some prescriptions do not seem to work. This brings me to the final point on why the tool of experimentation that triggered these behavioral insights should be welcomed.

4. Embracing experiments in the lab, the classroom and the village

There is an intricate relationship between the *research* we do, the material we use in our *teaching* and how we *practice* economics as consultants, advisors or policy-makers. Behind all three there has been a model of human behavior that is based on a rational agent that cares only about himself, is perfectly calculative, and is capable of self-control when it comes to balancing the future and the present. Take the case of behavior oriented toward self as opposed to caring about group goals. Not surprisingly, when students of economics, business, and finance participate in experiments where there are tensions between the individual goals and the group well-being, they come closer to the free-riding prediction than students with different training. The so called "Prisoners' Dilemma," as a metaphor, has been widely used for teaching the problem of free-riding when it comes to solving social dilemmas. Economics has been using this metaphor to argue that no rational person should cooperate. In fact, cooperating in the prisoners' dilemma could be viewed as two outlaws covering each other's back and against the goal of justice.

In the same fashion, when economists use this game to explore social interactions they often apply it to the case of duopolies. Once again, cooperation in such a domain is detrimental to society as a whole as two duopolists colluding implies a reduction in the consumer surplus and generation of social net losses. Notice that we have placed a much greater value at teaching the virtues of the "gains from trade" model, and deservedly so, while putting the "gains from cooperation" as an unfeasible practice, at best, and as a socially undesirable outcome when two duopolists collude. From such teaching, the possibility of cooperation is rarely included as a solution to coordination failures emerging from these social dilemmas, and therefore, the likelihood that self-governance could emerge as a one more possibility in the menu of policy options in your typical textbook. Translate that into the practice of the profession. How often do you hear graduates from economics including the possibility of self-governed solutions in their toolbox, as opposed to the usual "internalization of prices" through taxes, subsidies or tradeable permits?

Which brings another implication for the way we teach. The positive pedagogical impact of experiments has already been documented (see Ball et al., 2006; Frank, 1997). By having our students get involved in the kind of decision-making challenges we present in the board and the text, we can engage students in exploring the difficulties that economic players face in their daily lives. These experiments can be used to illustrate the human biases and difficulties for making choices when it comes to trade-offs between the present and the future, others and self, or the difference between valuing gains and losses.

With the arrival of the behavioral revolution in economics, the teaching, research, and practice of economics has to come to grips with another model of human behavior and with it comes a much noisier and more complicated landscape.

But a more realistic one. In the same way that experimentation in agricultural experiment stations brought valuable knowledge and increases in productivity a hundred years ago when different combinations of fertilizers were tested, experimentation on how farmers adopt or fail to use fertilizers in Africa has provided a better understanding of the poverty traps maintaining the huge rural gaps persisting today in the rural world.

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