UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
Facultad de Minas
Doctorado en Ingeniería – Sistemas e Informática

The Tragedy of the Commons in Artisanal Gold Mining: Evaluation of Mechanisms of Cooperation with Simulation and Economic Experiments

Carlos Adrián Saldarriaga Isaza

This thesis is presented to Universidad Nacional de Colombia – Sede Medellín,
in partial fulfillment of the requirements for the degree of Doctor of Engineering

Supervisors

Santiago Arango Aramburo
Associate Professor
Dept. of Computing and Decision Sciences
Universidad Nacional de Colombia-Sede Medellín

Clara Inés Villegas Palacio
Associate Professor
Dept. of Geosciences and the Environment
Universidad Nacional de Colombia-Sede Medellín

September 2013

UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
Facultad de Minas
Doctorado en Ingeniería – Sistemas e Informática

La Tragedia de los Comunes en la Minería Aurífera Artesanal: Evaluación de Mecanismos de Cooperación con Simulación y Experimentos Económicos

Carlos Adrián Saldarriaga Isaza

Esta tesis se presenta a la Universidad Nacional de Colombia – Sede Medellín como cumplimiento parcial de los requisitos para optar al título de Doctor en Ingeniería

Supervisores

Santiago Arango Aramburo
Profesor Asociado
Dept. Ciencias de la Computación y de la Decisión
Universidad Nacional de Colombia-Sede Medellín

Clara Inés Villegas Palacio
Associate Professor
Dept. Geociencias y Medio Ambiente
Universidad Nacional de Colombia-Sede Medellín

Septiembre 2013

Abstract

This thesis is about how collective action –associative entrepreneurship– can be fostered in artisanal and small-scale gold mining. This kind of association is aimed at, among other things, allowing small-scale gold miners to gather the financial capital that is required to obtain the type of technologies that reduce mercury use in the gold recovery process, and therefore the harmful effects of mercury pollution of ecosystems and human health. Given the public-good dilemma that is faced by these individuals, I study possible institutional arrangements by which associative entrepreneurship may be encouraged. The methods to achieve this include the construction of a behavioral simulation model using System Dynamics. As part of both the model building and its validation process I make use of the results of economic experiments carried out both in the lab and the field.

The results of the economic experiments do not reject the hypothesis which states that sustained collective action does not self-emerge as a solution to the public-good dilemma. In this thesis I analyze two institutional arrangements: co-management and exclusion from private benefits. Of these two, only co-management shows a statistically significant impact on the establishment of a permanent collective action. However, in the field experiment this effect of co-management is undermined when it is combined with exclusion from the private benefits.

From the behavioral simulation model, it is shown that reciprocity, free-riding and profit maximization are the behavioral aspects that mainly drive decision-making when dealing with the public-good dilemma. With an external intervention such as co-management, individuals get more aware of the social dilemma they face and collective action is sustained over time.

From a policy viewpoint these results suggest the importance of interventions programs such as education projects, training in alternative practices and technologies, and campaigns to foster social capital. Moreover, the experimental results cast doubt on the effectiveness of economic incentives to change some practices in the production process of gold. However, simulation results show that the implementation of stricter incentives could make miners to increase their commitment to sustain the entrepreneurial organization.

***Keywords*:** artisanal and small-scale gold mining; mercury pollution; behavioral simulation model; experimental economics; co-management; public-good dilemma; exclusion; collective action; common-pool resource.

Resumen

Esta tesis está relacionada con la manera en que se puede promover la acción colectiva –asociación empresarial– en la minería aurífera artesanal y de pequeña escala. Bajo este esquema de asociación se pretende, entre otros, reunir el capital financiero necesario para obtener el tipo de tecnologías que permiten reducir el uso de mercurio en el proceso de recuperación de oro, así como los efectos nocivos que la contaminación por mercurio produce en ecosistemas y la salud humana. Dado el dilema de tipo bien público que enfrentan estos individuos, se estudian posibles arreglos institucionales bajo los cuales se promueva la asociación empresarial. Los métodos utilizados incluyen la construcción de un modelo de simulación de comportamiento usando Dinámica de Sistemas. Como parte del proceso de construcción del modelo y su validación, se hace uso de los resultados de experimentos económicos realizados en el laboratorio y en el campo.

Los resultados de los experimentos económicos no rechazan la hipótesis según la cual una acción colectiva que se mantenga en el tiempo no surge como una solución al dilema de tipo bien público. En la tesis se estudian dos arreglos institucionales: co-manejo y exclusión de los beneficios privados. De los dos, solamente co-manejo muestra un impacto estadísticamente significativo sobre el establecimiento de una acción colectiva permanente. Sin embargo, en el experimento de campo este efecto se debilita al combinar co-manejo con exclusión de los beneficios privados.

Del modelo de simulación de comportamiento se observa que reciprocidad, oportunismo y la búsqueda de maximización de beneficios son los aspectos conductuales que explican la toma de decisiones al afrontar el dilema de tipo bien público. Con una intervención tal como co-manejo, los individuos adquieren una mayor percepción del dilema social que enfrentan y la acción colectiva se sostiene en el tiempo.

Desde el punto de vista de política, los resultados sugieren la importancia de programas de intervención tales como proyectos educativos, entrenamiento en prácticas y tecnologías alternativas, y campañas para incrementar el capital social. Además, los resultados experimentales ponen en duda la efectividad de incentivos económicos diseñados para cambiar algunas prácticas en el proceso de producción de oro. Sin embargo, los resultados de simulación muestran que la implementación de un incentivo más estricto podría hacer que los mineros incrementen su compromiso con el sostenimiento de la organización empresarial.

***Palabras clave*:** minería aurífera artesanal y de pequeña escala; contaminación por mercurio; modelo de simulación de comportamiento; economía experimental; co-manejo; dilema de tipo bien público; exclusión; acción colectiva; recurso de uso común.

To Laura and Antonio, my light for the long road ahead.

To Luz Adriana, who has always believed in me.

“*Y empezamos de nuevo a entrar, tendidos de punta como lombrices.*
Pero alegres, deshojando cachos. Porque el oro emborracha.
Se sube a la cabeza como el aguardiente.”
Efe Gómez. “La tragedia del minero” (1940).

“*I am thankful to all those who said no.*
It’s because of them, I did it myself.”
Albert Einstein.

Table of Contents

Preface

First and above all, I want to express my deepest gratitude to my supervisors Clara Villegas and Santiago Arango for believing in this project since its beginning. No matter they were at home or overseas, I could permanently count on them to solve my doubts and guide me along this lengthy but wonderful academic route. Working under their kind and outstanding supervision has highly enriched me personally and professionally.

I would like to acknowledge the debt of gratitude I owe to all my supportive family. My parents' unconditional love and the love they have for one another have been always inspiring. Ma' and Pa', *Gracias*!! Thanks also to Alejandro, Claudia, Dora, Gonzalo, Javier, Gonzalo A., don Liby, doña Gloria, Ana and Matilde. Your concern and state of expectancy for my work were always stimulating. I especially thank to Luz Adriana. Her love and company, no matter the distance, motivated me to work harder.

The financial support of the Administrative Department of Science, Technology and Innovation of Colombia (COLCIENCIAS) and its program of scholarships for doctoral programs in Colombia, is acknowledged. This work was also partially carried out with the aid of a grant from Vicerrectoría de Investigación of Universidad Nacional de Colombia.

I am indebted to professors of the evaluation committee of this thesis: Yris Olaya, Marcela Ibañez and Joep Sonnemans. Your questions, comments and time were key in this process.

I am also very thankful to Luis Alfonso Velez, Renzo Ramírez, Oscar Zapata, Diana Ceballos, Alberto Cortés, Alberto Castrillón, Laura Moisá, Elizabeth Santamaría, Edison Henao, Gonzalo Manrique and Liliana Franco for understanding that life is made of ups and downs. And I have to thank to those who did not believe or were against this project. Their thoughts encouraged me to move ahead even more.

Finally, I want to thank many people who introduced me to ideas and concepts of the mining sector and made possible the collection of primary and important secondary data: Alejandro Delgado (UNAL-Medellín); Victor Aguirre (Secretary of Mines, Gobernación de Antioquia); Oseas García, Jesús Rúa and Natalia Gonzalez (GMP-UNIDO); Hernando Henao (ASOMINA, Segovia); Dairon de la Vega (SENA, Segovia); Gustavo Vidales (Secretary of Mines and the Environment, Remedios); and mine administrators Darío Isaza (Mine La Picuda), Carlos Giraldo (Mine Pomo Piñal), Fernando Gómez (Mine Asoplayón), and Dionny Ramirez (Mine El Cogote).

Research assistance of the following people was also very important: Pablo Londoño, Manuela Gonzalez, Eliana Melo, Alejandro Saldarriaga and Jessica Arias.

To them and all other people who in one way or another contributed to this project, *muchas pero muchas gracias*!!!

Medellín, May 2013

Chapter 1
--
Overview

1. Introduction

Mercury-usage in production processes has become a major challenge due to the harmful side effects of this chemical element on ecosystems and human health. Artisanal and small-scale gold mining (ASGM) is one of the main global sources of anthropogenic emissions of mercury (Pirrone et al., 2009), and solutions to phase it out in this sector are part of the scientific and policy agenda. Despite the fact that cleaner and more productive technologies are available to artisanal gold miners (Hilson, 2006; Martínez et al., 2007) these are not frequently employed in the gold recovery process. Switching to alternative technologies is hampered by factors such as lack of funding or financial capital to cover investment costs (Chaparro, 2003), and limited awareness of the toxicity of mercury (Jønsson et al., 2013). This situation can be characterized as a social dilemma. The dilemma involves a trade-off where miners may tend to maximize short-run individual profits by choosing the cheapest and easy-to-handle available technique –mercury amalgamation–. However, in the long-run, the entire community, which includes him, is worse off than with the choice of a cleaner and more productive technology.

A suggested policy to overcome the lack of financial capital has been the creation of associations in which miners themselves collect the necessary funds to obtain the cleaner technology (Hentschel et al., 2002; Spiegel, 2009). Nonetheless, issues such as lack of trust (Chaparro, 2003; Hinton et al., 2003) and low entrepreneurial skills such as teamwork may hinder the establishment or permanence of these associations. Bearing this issues in mind, in this dissertation I test whether artisanal gold miners can solve their social (public-good) dilemma by getting involved in an association with these characteristics. Furthermore, I study possible institutional arrangements by which this kind of collective action may be encouraged. The methods to achieve this include the construction of a behavioral simulation model using System Dynamics. As part of both the model building and its validation process I make use of the results of economic experiments carried out both in the lab and the field.

Decision-making processes in economic, social and managerial systems are characterized by complexity. The complexity that underlies the dynamics of these systems mainly arise because of the feedbacks that govern the relationship among the elements of the system, and because the effects are rarely proportional to the cause(s) (i.e., nonlinearities) and may occur with time delay after the initiation of the cause (Sterman, 2000). One approach that takes account of these complexities in the analysis of systems is the System Dynamics approach (Sterman, 2000). By using a stock-and-flow feedback structure with nonlinear, first-order differential (or integral) equations, System Dynamics involves the use of computer simulation for theory building and policy analysis (Richardson, 2009). By using these methods I aim to build a model that endogenously explains the behavior of ASGM social systems, specifically considering the social dilemma that is studied in this research. The construction of this model rests on the circular causality of the behavioral approach to the rational choice theory of collective action of Ostrom (1998).

In this dissertation, the construction of the behavioral simulation model and the analysis done with it is supported and complemented with the conduction of economic experiments. Economic experiments are controlled tests of decision making by human subjects in controlled environments. These tests are used for developing theories of decision making and modeling human behavior (Arango et al., 2012). Because it is hard to collect controlled data in the real word, these experiments with economic agents enable the researcher to gather data to test hypotheses about human behavior. An economic experiment includes three basic elements (Friedman and Cassar, 2004): participant's objective, the system that describes the environment for taking decisions (institutions, behavioral rules), and participant's decisions. In order to gain control of the environment, the factors that may influence the behavior are kept constant, changing just one of them: the treatment (Croson and Gätcher, 2010). In this thesis, in the conduction of economic experiments, both in the lab and the field, I incorporate some of the essential aspects of the social dilemma of small-scale gold mining communities. In particular, I use a class of experiment that allows studying the effect of social preferences on both behavior and organizational processes that entails dilemmas like environmental protection or team work: public-good games (Ledyard, 1995; Camerer and Weber, 2013).

With this work, I contribute to the understanding of social dilemmas faced by users of natural resources, in this case of a non-renewable resource. The results of the economic experiments also provide insights to the scientific discussion about the external validity of laboratory experiments (Guala, 2005). The rest of this introductory chapter is followed by the description of the research problem in Section 2. Then, in Section 3 and Section 4 I present the hypotheses and objectives, respectively. An outline of Chapters 2-5 is done in Section 5, and finally in Section 6 I further discuss the main contributions of this thesis.

2. Research Problem

In Colombia, as well as many other developing countries, there are many communities engaged in gold mining using artisanal techniques. For example, in the Department of Antioquia, Colombia, Giraldo and Muñoz (2012) estimated that approximately 150000 individuals are engaged in ASGM. Despite the high increase in the international price of this mineral in the last decade, no visible economic progress is seen at those sites. Instead, high levels of unsatisfied basic needs (Vergara, 2005) and environmental pollution have been recorded (Cordy et al., 2011). Additionally, these social systems are apparently trapped in vicious circles that keep the communities in a state of economic stagnation, and far from reaching high standards of economic development.

We observe that the salient features that best describe ASGM are low levels of mechanization and technology, labor-intensiveness, considerable environmental degradation, poorly trained miners, low productivity levels, and lack of financial capital. Moreover, these miners operate with little consideration for health or environmental impacts, and have a slight knowledge of existing mineral reserves. The way these elements would interact with each other can be represented in a causal diagram like the one shown in Figure 1.1. This feedback loop diagram shows the causal structure that would explain the vicious circles that cause the poverty-trap in ASGM. In general, this poverty-trap is caused by the interaction of self-reinforcing mechanisms (Azariadis and Stachurski, 2005) such as a technology trap (Fofack, 2008) and a savings trap (Asilis and Ghosh, 2002).

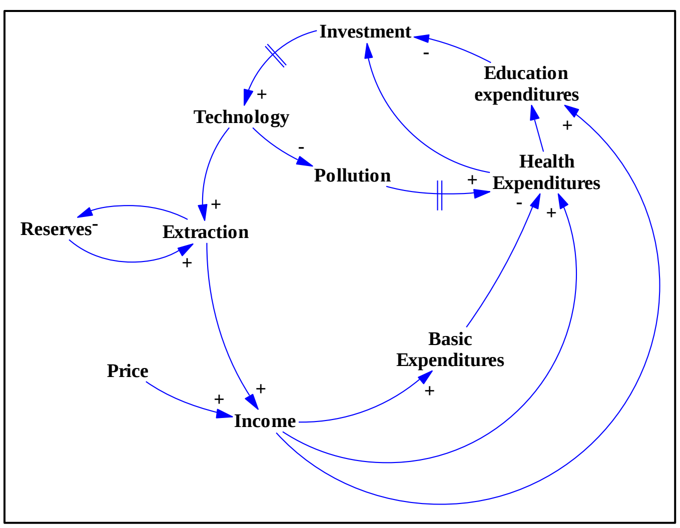


Figure 1.1. Dynamic hypothesis for poverty-trap in ASGM.[1]

[1] This feedback loop represents the cause-effect relationships through arrows. When the arrow is positive (+), it means that a change in the variable in which the link starts, generates a change in the same direction in the other variable (ceteris paribus). The arrow is negative (–) when both variables change in opposite directions, provided the variable in which the link starts, changes first. Small parallel lines denote delays. See Sterman (2000) for a further explanation.

Several scholars have found out that these elements are among the most relevant to understand the dynamics of social systems in ASGM (Hilson and Ack-Baidoo, 2011). Nonetheless, it has reiteratively pointed out the importance of a proper understanding of the dynamics of gold mining communities, before designing and implementing any policy or support measure (Hentschel et al., 2002; Hilson, 2005, 2006; Hilson et al., 2007; Dondeyne et al., 2009). Poor performance of many projects aimed at regularizing and providing assistance to ASGM has been attributed to an insufficient understanding of: the dynamics of target communities, the organization of processing activities, operators' needs and the geological conditions (Hilson, 2007).

Therefore, it is still pending to have a deeper and formal knowledge of how the elements that best describe ASGM social systems interact with each other, and how these self-reinforcing mechanisms work. In an effort to better understand the dynamics underlying ASGM communities, I propose the construction of a behavioral simulation model. This model attempts to account for the complexity that characterizes this type of social systems. This complexity is reflected in a system structure with social, economic, environmental, and institutional aspects that entails feedback relationships, nonlinearities, and delays. In particular, in this thesis I focus my attention to the social (public-good) dilemma as it relates to the technology trap that causes pollution to persist. This simulation approach goes beyond the analysis done so far by other authors (Heemskerk, 2001, 2005; Hilson and Pardie, 2006; Spiegel, 2009), in the sense that it analyzes the attributes that would prevent the use of cleaner technologies, in a way that allows for the making of strategies for overcoming resistance to technological change.

The aim of this model is twofold. The model is expected to explain the endogenous dynamics of this technology trap in ASGM. But even more important it is to propose and assess possible leverage policies to counteract the current adverse effects of this activity, and promote it as a source of economic prosperity and sustainable development. Specifically, this work is intended to be an analysis of ASGM in the Department of Antioquia, Colombia. Nonetheless, provided the commonalities of this type of socio-ecological system worldwide, some extrapolations may be done.

Collective action and cooperation have been seen as a possibility to overcome the social dilemma for users of some common-pool resources that involve renewable resources; thus, one question that deserves to be answered is to what extent cooperation among artisanal gold miners may also work to solve their social dilemma. Specifically, from the behavioral simulation model and economic experiments, the questions I want to answer in this research is whether and how it is possible for artisanal gold miners to find in cooperation –associative entrepreneurship– a way of overcoming the social dilemma they face nowadays.

The access to better technology might be thought as a *sine qua* non condition, which aims to improve the levels of productivity and reducing mercury in ASGM operations. However, the lack of accessibility to credit markets and low saving rates make it difficult to achieve. Miners associations are thus seen as a possibility of increasing their financial capacity, which would allow adopting of the technology required to implement better practices (Hinton et al., 2003; CDS, 2004; Ghose and Roy, 2007; Hentschel et al., 2002). Nonetheless, to what extent this concept of associative entrepreneurship can be applied to ASGM is still unknown and is one question I seek to answer in this research.

In this thesis I also study two possible institutional arrangements to foster collective action for the improvement of one of the processes associated with the exploitation of this non-renewable resource: the gold recovery process. One of these mechanisms is co-management. This mechanism is understood as the interaction between internal communication and an external non-coercive party (Moreno-Sánchez and Maldonado, 2010). In the case of ASGM, the task of the external party is to provide technical assistance, training and any other kind guidance in the process of switching to alternative technologies. In general, according to mining leaders of Antioquia, Colombia, there seems to be a good judgment of small gold miners toward the role of profit, non-profit and multilateral organizations in the process of switching to cleaner technologies.[2]

Another mechanism to be tested is the option that once the technology is acquired and the public good is provided (lower mercury emissions), non-contributors may be excluded from the private benefits (more productivity) that the technology providing the public good generates. The empirical tests of these mechanisms are done via a framed threshold public good game with artisanal and small-scale miners.

3. Hypotheses

One hypothesis of this research is that sustained collective action (associative entrepreneurship) would not self-emerge as a solution to the social dilemma faced by households engaged in ASGM. This dilemma is supposed to be solved by creating an association of miners to collect financial capital in order to acquire alternative technologies and implement better mining and recovery practices.

Instead, the intervention of a third non-coercive party (co-management) may be needed to promote a larger and well established association of miners that allow them to access to cleaner and more productive technologies.

[2] Personal communications that were held in 2011 with the following artisanal miners from Antioquia, Colombia: Luis Cardeño, Fernando Gómez, Arturo Rodriguez, and Hernando Henao.

Another mechanism that might trigger collective action in ASGM would be the exclusion of those miners who do not contribute to the provision of a cleaner and more productive technology, from the private benefits (more productivity) derived from the technology that reduces a public bad (mercury pollution).

4. Objectives

4.1 General Objective

To explore the effect of different institutional arrangements on collective action of mining households involved in artisanal and small-scale gold mining, via simulation and experimental economics

4.2 Specific Objectives

a) To identify the most relevant aspects that characterize ASGM, and to select the variables to be considered in the simulation model and the design of the economic experiment.
b) To describe and explain the dynamics underlying ASGM systems through a system dynamics model.
c) To identify the mechanisms by which it might possible to induce a change in production behavior of subjects engaged in ASGM.
d) To test the influence on cooperation, of both co-management and the possibility of exclusion of non-contributors from the private benefits derived from the technology providing a public good.
e) To propose and assess policy scenarios targeted to ASGM communities using simulation.

5. Chapters Outline

The development of this thesis is divided into four self-contained but related chapters which are described in the following four subsections.

5.1 Chapter 2

Based on a survey of the existing literature, in Chapter 2 I offer a description of the common features that define ASGM in the developing world. In this chapter I show that the scheme of exploitation underlying ASGM may be corresponded with the scheme of common pool resource. However, the main social dilemma that resource users in ASGM face is different to the one analyzed in previous literature about common pool resources. Rather than in the extraction or availability of this non-renewable resource, their social dilemma concerns the pollution resulting from the gold recovery process; i.e. a public-good dilemma. In this process, the application of mercury amalgamation makes ASGM an activity with a high negative environmental impact, mainly due to mercury pollution (Hilson and Pardie, 2006; Tomicic et al., 2011). As a result, nowadays artisanal gold miners are exposed to increasingly lower levels of environmental quality due to mercury pollution. This environmental impact poses a health risks to these communities with several type of diseases such as neurological disorders or kidney damages (Tomicic et al., 2011).

Besides the characteristics of common-pool resource and a public-good dilemma, in Chapter 2 I identify some commonalities of ASGM in different countries of the developing world as follows: low levels of mechanization and technology, labor intensiveness, low awareness of environmental degradation, poor training, high transience among some miners, and lack of financial savings. I also identify and discuss some approaches that may help to improve the understanding of the societal dynamics underlying ASGM communities. These approaches are the multi-tier framework proposed by Ostrom (2007), and the ones that are employed in this thesis: behavioral simulation models such as System Dynamic models (Sterman, 2000), and experimental economics (Friedman and Cassar, 2004). Moreover, taking into account that this sector has been nearly overlooked by resource economists, I present some topics and challenges for a research agenda for social scientists and engineers, particularly in the fields of environmental, ecological, and development economics. For instance, the analytical aforementioned approaches may applied to the analysis of the different components of the poverty-trap in ASGM such as technology and savings traps, and the role of leaders and economic incentives in the diffusion and use of alternative technologies.

5.2 Chapter 3

Previous literature has identified different type of mechanisms, policy instruments and institutional arrangements for the sustainable management of common-pool resources and public goods. Some of them are as follows: pollution charges (Stavins, 2001) or other types of external regulation (see, e.g., Cardenas et al., 2000; Dickinson, 2001), face-to-face communication (see, e.g., Ledyard, 1995; Ostrom, 2010), and information disclosure (see, e.g., Ledyard, 1995; Smith, 2010). By running a framed field experiment with artisanal gold miners from Antioquia (Colombia), in Chapter 3 I test the effect of two mechanisms or institutional arrangements on associative entrepreneurship in ASGM: (i) the interaction between internal communication among community members and an external non-coercive party, namely co-management, and; (ii) exclusion from the private benefits that the alternative technology used in the gold recovery process may offer to the miner –i.e., more productivity–.

In the context of the research problem, a more productive and cleaner technology for gold recovery could be accessed to under an association scheme that involves entrepreneurial activities. Under the terms of this association miners should contribute to a common fund to raise the financial capital required to buy the technology. Besides these conditions, the field experiment considers the conditions of non-exclusion and non-rivalry in the positive externalities derived from the cleaner technology. With these conditions in mind, a threshold public good game was used in a 2x2 experimental design. The control treatment of this field experiment is a standard threshold public good game that was framed according to the aforementioned conditions. Treatments 2 and 3 were additionally framed taking into account our two institutions of interest, exclusion from private benefits and co-management, respectively. Lastly, in Treatment 4 co-management interacts with exclusion from private benefits which allows testing whether the effects of co-management are crowded in or crowded out by an economic incentive such as exclusion from the private benefits stemming from the cleaner technology.

Non-parametric and parametric methods of data analysis were employed. The latter includes an analysis of individual contributions in the game with five set of explanatory variables: socioeconomic characteristics, perception variables, attitudinal variables, and dynamic and treatment variables. Additionally, given the oscillating pattern of contributions in the TPGG, an analysis of the standard deviation of contributions across the game was done. In general, I find that miners by themselves cannot permanently sustain collective action, but that it is feasible under co-management.

5.3 Chapter 4

One of the assumptions on which the methods of experimental economics rest is the parallelism precept (Smith, 1976, 1982). This precept states that the patterns of behavior observed in laboratory experiments are very likely of being observed in the field, as long as certain conditions hold. This precept, however, has been subject of debate since the early stages of experimental economics. On the one hand, experimental economics has proven to be useful in the analysis of markets (Guala, 2005; Fehr and Gächter, 2008). On the other hand, in the analysis of social preferences, the correspondence between the behavior of students and non-students (Carlsson et al., 2012), as well as of the behavior of non-students in a field experiment and in a natural situation (Voors et al., 2012), does not appear to hold.

With the aim of contributing to this debate, Chapter 4 of this dissertation discusses and analyzes the issue of external validity of economic experiments. By using the same experimental design of Chapter 3, with just slight differences in the experimental procedures, I analyze whether the decisions university students make in the context-enriched situation of the experimental game converge to what miners do in the same framed experiment. The differences in the experimental procedures concern aspects such as the recruiting system and the facilities where the experiments were run. This work contrasts with previous literature in which the comparison between lab and field has considered context-free situations (see, e.g., Carpenter et al., 2005; Laury and Holt, 2008; Carlsson et al., 2012).

In general, the behavior of both subject pools is similar to that reported in other multi-period context-free threshold public good games made in the lab (Croson and Marks, 2000; Cadsby and Maynes, 1999; Cadsby et al. 2008). Non-parametric and parametric analyses of the experimental data show behavioral convergences and divergences between students and miners. Although students perform better than miners in the game, some degree of convergence is observed not only the control treatment or base case, but also in the co-management and exclusion treatments. However, when these two institutional arrangements are combined the effects differ between these subject pools. Similarly to previous literature (see, e.g., Laury and Holt, 2008; Carlsson et al., 2012), a conclusion from these results is that in experimental economics the extrapolation of lab results should be taken cautiously.

5.4 Chapter 5

Chapter 5 presents the building process of the behavioral simulation model that is aimed to investigate the feasibility of collective action in the context of the public-good dilemma I study in this dissertation. Heemskerk (2001, 2005), Hilson and Pardie (2006) and Spiegel (2009) have represented the core interrelationships that drive poverty-traps in ASGM. From their visual models, however, it is not clear what prevents the use of cleaner technologies in ASGM, or how its use can be encouraged.

The construction of the model takes into account the theory of collective action in social dilemmas proposed by Ostrom (1998), is based on the methods of System Dynamics (Sterman, 2000), and is supported with results obtained in the economic experiments of Chapters 3 and 4. The dynamic hypothesis consists of three reinforcing feedback loops (reciprocity, profit maximization and awareness of the dilemma) and one balancing group (free-riding). Some of the nonlinearities of the system dynamics model are represented in four graph functions as follows: willingness to cooperate, temptation to free-ride, profit maximization and social dilemma awareness. Moreover, the model contains time delays that are referred to players' knowledge formation in variables such as group's reputation and relative payoff. The validation of the model is based on the standard procedures of System Dynamics which implies the application of tests of model structure and behavior (Barlas, 1996).

With this model is possible to discern what personality traits prevent the successful establishment of associations that lead to solving the social dilemma of ASGM communities. Simulations thus reveal that features such as reciprocity and temptation to free ride partially explain why the self-establishment of this kind of association is troublesome. These simulations also show that a sustained collective action is feasible when miners completely understand the social dilemma they face. A policy implication of this result is the importance of external interventions in the form of programs that make artisanal gold mining communities recognize and understand this social dilemma. An intervention of this kind, like co-management in the context of the economic experiment, leads to better outcomes in terms of the collective action subjects can achieve. The simulation model also shows a positive effect on the provision of the technology of an economic incentive that tends to completely exclude free-riders from certain benefits of the alternative technology.

The paper thus illustrates the usefulness of simulation methods in the design and support of policies targeted at natural resource-based communities such as ASGM. Further applications of these methods could be directed toward the study of other social and economic components of the ASGM's poverty-trap and mechanisms to overcome it.

6. Main Contributions and Conclusions

A premise used in this thesis is that in order to design policies focused on ASGM communities a better understanding of their societal dynamics is required. One first step on this regard is the identification of the main characteristics of ASGM, which are also the aspects that explain poverty-traps in this sector. After a comprehensive review and analysis, I found that the main aspects are the use of rudimentary techniques, and low levels of both education and awareness of environmental degradation. Thus, such problems are identified as the main drivers of the public-dilemma that these communities face: mercury pollution.

Some analytical approaches are identified to understand the dynamics underlying ASGM communities: behavioral simulation models, the multi-tier framework proposed by Ostrom (2007), and experimental economics. These methods can, for instance, be applied to study some cultural patterns such as conspicuous consumption and its relationship with poverty traps in ASGM, and to the analysis and assessment of mechanisms to break out these cycles of poverty. In this thesis, by using two of these approaches, experimental economics and a behavioral simulation model, from chapters 3 to 5 we assess the feasibility of associative entrepreneurship to address mercury pollution in ASGM, including mechanisms by which this type of collective action can be encouraged.

The application of modeling by simulation and experimental economics to the study of ASGM issues is innovative for two reasons. Firstly, the understanding of the societal dynamics of ASGM communities so far has been based on mental models of scientist, researchers and practitioners who after being in the field have written down and published their perceptions. Some of these perceptions have been translated into visual models which illustrate the poverty-trap in ASGM. By using simulations methods, I go further and formalize the technology trap which is a part of the feedback processes that explain how artisanal miners turn out to be trapped in vicious cycles of poverty.

Secondly, besides top-down approaches such as simulations models, it is also important to have first-hand or primary information that provide insights concerning the decisions miners make and the “why” behind these decisions. Conducting field economic experiments and the measurement of micro-situational variables are approaches that go in this direction (Anderies et al., 2011). For example, Heemskerk (2001, 2002, 2003), one of the few examples in the literature, collected and used microdata to analyze social issues of ASGM in Suriname.

Field economic experiments have proven to be a useful tool to test hypotheses about human behavior and management of natural resources (Anderies et al., 2011). Despite the extensive evidence of this usefulness, experimental economics had not been employed before to investigate many of the problems that characterize ASGM worldwide. In this thesis, by testing behavioral hypothesis in controlled environments, I show how experimental methods can help to enhance our understanding of the dynamics of ASGM communities, as well as to support the design of policies aimed at increasing the well-being of these communities.

The results of the economic experiments that were run in the field with artisanal gold miners do not reject the hypothesis which states that sustained collective action would not self-emerge as a solution to the social dilemma faced by households engaged in ASGM. Two mechanisms or institutional arrangements were analyzed in this dissertation: co-management and exclusion from private benefits. Of these two, only co-management shows a statistically significant impact on the establishment of a permanent collective action. However, this effect of co-management is undermined when it is combined with exclusion from the private benefits.

I also constructed a behavioral simulation model based on the methods of system dynamics, with the aim to understand the experimental results. This model considers a causal structure with four loops as follows: reciprocity, free-riding, profit maximization and awareness of the social dilemma. After calibrating the model with the results of the field economic experiments, I can show that reciprocity, free-riding and profit maximization are the behavioral aspects that mainly drive decision-making when dealing with the public-good dilemma. However, after an external intervention such as co-management, individuals get more aware of the social dilemma they face and thus contributions are such that the provision of the public good is sustained over time

I run experiments with miners and students, with the same treatments. Comparison of performance of miners and university students in the framed economic experiment shows that the extrapolation of experiments run in the lab with university students to a different pool of subjects, should be taken cautiously. On the one hand, in this comparison I find that three treatments had the same kind of effect. In the co-management treatment players from both subject pools tried to coordinate their actions in order to achieve efficient and equitable outcomes. Moreover, there were no clear effect of exclusion, and in the base case contributions have a tendency to be decreasing and oscillating around the efficient outcome. On the other hand, in the treatment where co-management and exclusion are combined the effects differed between the subject pools: meanwhile students could agree on contributing a number tokens that generate Pareto-efficient and equitable outcomes, miners could not. In regards to the achievement of efficient outcomes, university students performed better than miners and got more efficient outcomes.

From a policy viewpoint these results suggest the importance of interventions programs such as education projects, training in alternative practices and technologies, and campaigns to foster social capital. Moreover, these experimental results cast doubt on the effectiveness of economic incentives to change some practices in the production process of gold in ASGM. However, simulation results show that the implementation of stricter incentives could make miners to increase their commitment to sustain the association.

In general, it can be argued that more education and training would make individuals to better the understanding of the system and estimate the consequences of their actions considering also others' actions. This understanding does not only generate better outcomes to the individual but also to his social group. However, to what extent the degree of education is an important driver of these differences in performance is an unanswered question for future research.

References

[1] Anderies, J., Janssen, M., Bousquet, F., Cardenas, J., Castillo, D., Lopez, M.C., Tobias, R., Vollan, B., Wutich, A., 2011. The challenge of understanding decisions in experimental studies of common pool resource governance. Ecological Economics 70, 1571-1579.

[2] Andriamasinoro, F., Angel, J.-M., 2012. Artisanal and small-scale gold mining in Burkina Faso: suggestion of multi-agent methodology as a complementary support in elaborating a policy. Resources Policy 37, 385-396.

[3] Arango, S., Castañeda, J., Olaya, Y., 2012. Laboratory experiments in the system dynamics field. System Dynamics Review 28(1), 94-106.

[4] Asilis, C.M., Ghosh, A.R., 2002. The savings trap and economic take-off. Oxford Economic Papers 54(1), 20-43.

[5] Azariadis, C., Stachurski, J., 2005. Poverty traps, in: Aghion, P., Durlauf, S. (Eds.), Handbook of Economic Growth, Vol. 1, part 1. Elsevier, Amsterdam, pp. 295-384.

[6] Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics. System Dynamics Review 12 (3), 183- 210.

[7] Cadsby, C., Maynes, E., 1999. Voluntary provision of threshold public goods with continuous contributions: experimental evidence. Journal of Public Economics 71(1), 53-73.

[8] Cadsby, C., Croson, R., Marks, M., Maynes, E., 2008. Step return versus net reward in the voluntary provision of a threshold public good: an adversarial collaboration. Public Choice 135(3-4) 277-289.
[9] Camerer, C., Weber, R., 2013. Experimental organizational economics, in: Gibbons, R., Roberts, J. (Eds.), Handbook of Organizational Economics. Princeton University Press, Princeton, pp. 213-262.
[10] Cardenas, J.C., Stranlund, J., and Willis, C., 2000. Local environmental control and institutional Crowding-Out. World Development 28, 1719-1733.
[11] Carlsson, F., He, H., Martinsson, P., 2012. Easy come, easy go: the role of windfall money in lab and field experiments. Experimental Economics, DOI: 10.1007/s10683-012-9326-8.
[12] Carpenter, J.P, Harrison, G.W., List, J.A., 2005. Field experiments in economics: an introduction, in: Carpenter, J.P., Harrison, G.W., and List, J. (Eds.), Field Experiments in Economics. Elsevier, pp. 1-15.
[13] CDS -Centre for Development Studies-, 2004. Livelihoods and Policy in the Artisanal and Small-Scale Mining Sector -An Overview. University of Wales Swansea, UK.
[14] Chaparro, E., 2003. Small-scale mining, a new entrepreneurial approach. Serie Recursos Naturales e Infraestructura No. 9. CEPAL, Santiago, Chile.
[15] Cordy, P., Veiga, M., Salih, I., Al-Saadi, S., Console, S., Garcia, O., Mesa., L.A., Velásquez-López, P., Roeser, M., 2011. Mercury contamination from artisanal gold mining in Antioquia, Colombia: the world's highest per capita mercury pollution. Science of the Total Environment 410-411, 154-160.
[16] Croson, R., Marks, M., 2000. Step returns in threshold public goods: a meta- and experimental analysis. Experimental Economics 2(3), 239-259.
[17] Croson, R., Gächter, S., 2010. The science of experimental economics. Journal of Economic Behavior & Organization, 73(1), 122-131.
[18] Dickinson, D.L., 2001. The carrot vs. the stick in work group motivation. Experimental Economics 4, 107-124.
[19] Dondeyne, S., Ndunguru, E., Rafael, P., Bannerman, J., 2009. Artisanal mining in central Mozambique: policy and environmental issues of concern. Resources Policy 34, 45-50.
[20] Fehr, E., Gächter, S., 2008. Wage differentials in experimental efficiency wage markets, in: Plott, C., Smith, V. (Eds.), Handbook of Experimental Economics Results. Elsevier, pp. 120-126.
[21] Fofack, H., 2008. Technology trap and poverty trap in Sub-Saharan Africa. World Bank Institute, Policy Research Working Paper 4582.
[22] Friedman, D. and Cassar, A. (2004). Economics lab: an intensive course in experimental economics. London, UK: Routledge.
[23] Ghose, M., Roy, S., 2007. Contribution of small-scale mining to employment, development and sustainability – an Indian scenario. Environment, Development and Sustainability 9, 283-303.
[24] Giraldo, J., Muñoz, J.C., 2012. Informalidad e ilegalidad en la explotación del oro y la madera en Antioquia. EAFIT-Proantioquia, Medellín, Colombia.
[25] Guala, F. (2005). The methodology of experimental economics. Cambridge University Press, NY.

[26] Heemskerk, M., 2001. Do international commodity prices drive natural resource booms? An empirical analysis of small-scale gold mining in Suriname. Ecological Economics 39 (2), 295-308.
[27] Heemskerk, M., 2002. Livelihood decision making and environmental degradation, small-scale gold mining in the Suriname amazon. Society & Natural Resources 15 (4), 327-344.
[28] Heemskerk, M., 2003. Risk attitudes and mitigation among gold miners and others in the Suriname rainforest. Natural Resources Forum 27, 267-278.
[29] Heemskerk, M., 2005. Collecting data in artisanal and small-scale mining communities: measuring progress towards more sustainable livelihoods. Natural Resources Forum 29(1), 82-87.
[30] Hentschel, T., Hruschka, F., Priester, M., 2002. Global Report on Artisanal and Small-Scale Mining. International Institute for Environment and Development, London, UK.
[31] Hilson, G., 2005. Strengthening artisanal mining research and policy through baseline census activities. Natural Resources Forum 29, 144-153.
[32] Hilson, G., 2006. Abatement of mercury pollution in the small-scale gold mining industry: restructuring the policy and research agendas. Science of the Total Environment 362, 1-14.
[33] Hilson, G., 2007. What is wrong with the Global Support Facility for small-scale mining? Progress in Development Studies 7, 235-249.
[34] Hilson, G., Ack-Baidoo, A., 2011. Can microcredit services alleviate hardship in African small-scale mining communities?. World Development 39, 1191-1203.
[35] Hilson , G., Pardie, S., 2006. Mercury: An agent of poverty in Ghana's small-scale gold-mining sector? Resources Policy 31, 106-116.
[36] Hilson, G., Hilson, C., Pardie, S., 2007. Improving awareness of mercury pollution in small-scale gold mining communities: Challenges and ways forward in rural Ghana. Environmental Research 103, 275-287.
[37] Hinton, J., Veiga, M., Veiga, A., 2003. Clean artisanal gold mining, a utopian approach?. Journal of Cleaner Production 11, 99–115.
[38] Jønsson, J.B., Charles, E., Kalvig, P., 2013. Toxic mercury versus appropriate technology: Artisanal gold miners' retort aversion. Resources Policy 38, 60-67.
[39] Laury, S., Holt, L., 2008. Altruism spillovers: are behaviors in context-free experiments predictive of altruism toward a naturally occurring public good? Journal of Economic Behavior & Organization 65, 9-29.
[40] Ledyard, J., 1995. Public Goods: A survey of experimental research, in: Handbook of Experimental Economics, Roth, A., Kagel, J. (Eds.), Princeton University Press, Princeton, pp. 111-194.
[41] Martínez, E., Wolf, E., Pinzón, J., Pineda, J., 2007. Resultados y experiencias exitosas de proyectos relacionados con el manejo del mercurio en la minería de oro en Colombia con fines preventivos. Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Bogotá.
[42] Moreno-Sánchez, R., Maldonado, J., 2010. Evaluating the role of co-management in improving governance of marine protected areas: An experimental approach in the Colombian Caribbean. Ecological Economics 69, 2557-2567.

[43] Ostrom, E., 1998. A behavioral approach to the rational choice theory of collective action. The American Political Science Review 92, 1-22.
[44] Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences 104, 15181-15187.
[45] Ostrom, E., 2010. Revising theory in light of experimental findings. Journal of Economic Behavior & Organization 73, 68-72.
[46] Pirrone, N., Cinnirella, S., Feng, X., Finkelman, R.B., Friedli, H.R., Leaner, J., Mason, R., Mukherjee, A.B., Stracher, G., Streets, D.G., Telmer, K. 2009. Global mercury emissions to the atmosphere from natural and anthropogenic sources, in: Mercury Fate and Transport in the Global Atmosphere, Pirrone, N., Mason, R. (Eds.). Springer, pp. 3-48.
[47] Richardson, G.P., 2009. The core of system dynamics, in: Encyclopedia of Complexity and Systems Science, Meyers, R.A. (Ed.). Springer.
[48] Smith, V.L., 1976. Experimental economics: induced value theory. American Economic Review 66(2), 274-279.
[49] Smith, V.L., 1982. Microeconomic systems as an experimental science. American Economic Review 72, 923-955.
[50] Smith, V.L., 2010. Theory and experiment: what are the questions? Journal of Economic Behavior & Organization 73(1), 3-15.
[51] Spiegel, S., 2009. Socioeconomic dimensions of mercury pollution abatement: engaging artisanal mining communities in Sub-Saharan Africa. Ecological Economics 68, 3072-3083.
[52] Stavins, R.N., 2001. Experience with market-based environmental policy instruments. Discussion Paper 01–58, Resources for the Future.
[53] Sterman, J. D., 2000. Business Dynamics: System Thinking and Modeling for a Complex World. Irwin McGraw-Hill, Homewood, USA.
[54] Tomicic, C., Vernez, D., Belem, T., Berode, M., 2011. Human mercury exposure associated with small-scale gold mining in Burkina Faso. International Archives of Occupational and Environmental Health 84, 539-546.
[55] Vergara, O., 2005. Minería y Dinámicas Regionales en Colombia. Universidad Externado de Colombia, Bogotá.
[56] Voors, M., Turley, T., Kontoleon, K., Bulte, E., List, J., 2012. Exploring whether behavior in context-free experiments is predictive of behavior in the field: Evidence from lab and field experiments in rural Sierra Leone. Economics Letters 114, 308-311.

Chapter 2

--

The public good dilemma of a non-renewable common resource: a look at the facts of artisanal gold mining[1]

Abstract
Millions of people worldwide are involved in artisanal and small-scale gold mining. Many of them live in conditions of poverty and insalubrities due to the mercury amalgamation of gold and the application of other rudimentary techniques. In spite of this, the sector has been nearly overlooked by resource economists. In this paper we analyze the sector based on a survey of the existing literature. We find some commonalities of artisanal and small-scale gold mining in different countries of the developing world as follows: low levels of mechanization and technology, labor intensiveness, low awareness of environmental degradation, poor training, high transience among some miners, and lack of financial savings. Moreover, with these commonalities in mind, we present some topics and challenges for a research agenda in the field of environmental, ecological, and development economics.

1. Introduction

The extraction of minerals has been the material basis of many economies (Tilton, 1992). The extraction of hydrocarbons or non-fossil minerals and their industrial uses have expanded the wealth of many nations in recent centuries. However, non-renewable resources continue to represent the most elemental mean of livelihood for some of the poorest populations in the world (Swain et al., 2007). The extraction of minerals all over the world has been studied by both natural and social scientists. Economists are not the exception and over the years have developed theoretical and empirical models studying the optimal rate of extraction of non-renewables (see for instance Hotelling, 1931; Pindyck, 1981; and Managi et al., 2004).

Yet, there are other dimensions of the non-renewable extraction that deserve some attention: the externalities generated from it, and also the dependence of such extractions of millions of people

[1] This chapter is published in *Resources Policy*.

in the world using artisanal techniques. A clear example of it is the artisanal and small-scale gold mining (ASGM) in which miners who want to maximize private profits employ the cheapest technological alternative for the recovery process: mercury amalgamation. This technique leads to environmental and health problems in the long run due to the mercury pollution it generates.

With the end of solving the pollution problem generated by the recovery process better production technologies, which are generally more expensive for acquiring and harder to operate, must be employed. Therefore, miners face the dilemma related to the pollution resulting from the gold recovery process; i.e., a public-good dilemma in which private benefits are apparently higher when using mercury amalgamation and social welfare is improved by using a cleaner technology.

In addition to environmental pollution, ASGM faces several social, political and economic difficulties that deserve some attention. With these facts in mind, many scholars have stressed the importance of a good understanding of the dynamics of ASGM communities before designing and implementing any policy (Hentschel et al., 2002; Hilson, 2005, 2006; Hilson et al., 2007; Spiegel, 2009; Dondeyne et al., 2009). Nonetheless, in spite of the known conditions of ASGM, this subject has been overlooked in the environmental, ecological, and development economics literatures.

This paper does not present the results of any empirical research conducted by the authors. Instead, we survey the literature related to ASGM with the objective of gaining a broad picture of ASGM that would foster the understanding of the main conditions characterizing this activity in the developing world. Such an understanding is the first necessary step for the design of policies to overcome the social dilemma; i.e., to regulate both extraction and pollution from the resource exploitation. With this description in mind, we aim to discuss a research agenda for this fairly unexplored topic in the resource, environmental, ecological and development economics literatures. Specifically, we discuss feasible theoretical approaches and methods to analyze behavioral patterns and for policy assessment in ASGM. Within this discussion, our main focus is the social dilemma associated with the use of mercury amalgamation in the recovery process and the social factors that impede the resolution of such dilemma.

In the next section, we provide a general overview of the common features characterizing ASGM worldwide. Furthermore, we identify the major challenges for the sector, and for scholars and policy makers working with these communities. Then, in section 3 we present a brief discussion of the reviewed works and a possible future research agenda for social scientists, particularly for natural resource, environmental, ecological and development economists. In section 4 we conclude.

2. Commonalities of Artisanal Gold Mining Worldwide

Since the pre-colonial period, ASGM has contributed to the economic development of many countries (CDS, 2004). Currently, approximately 25% of the world's gold production is generated by ASGM (Chouinard and Veiga, 2008). For several millions of people involved in this economic sector, gold extraction is the most attractive activity in terms of income generation. However, the application of conventional practices, mercury amalgamation being the most representative, makes ASGM an activity with a high negative environmental impact, primarily due to mercury pollution (Hilson and Pardie, 2006; Swain et al., 2007; Tomicic et al., 2011). This environmental impact returns to the community itself, neglecting the possibility of developing other economic activities, as well as posing a health risk.

Previous studies have identified what has been named a "poverty trap" for some communities involved in labor-intensive extractive jobs such as artisanal gold-miners (Spiegel, 2009; Hilson and Ack-Baidoo, 2011). According to Azariadis and Stachurski (2005, p. 326), a poverty trap is "any self-reinforcing mechanism which causes poverty to persist." These mechanisms may be determined by cultural, institutional or structural conditions that put these communities into vicious cycles from which it is difficult to escape and that may influence the rate of depletion of the resource (Hilson and Pardie, 2006). In the following, we describe the conditions that may drive these mechanisms in ASGM.

2.1 Legal and Institutional Aspects

Gold mining using either artisanal methods or methods with a low degree of mechanization and low productivity is practiced by over 10 million people in the developing world (Spiegel and Veiga, 2005). In countries such as Tanzania, Zimbabwe and other territories of sub-Saharan Africa as well as some Latin American countries, such as Colombia and Peru, ASGM is essential for many communities that find in the extraction of gold a complementary source of income (Kitula, 2006; Maponga and Ngorima, 2003; Spiegel, 2009; GEMMA, 2007). In other cases, in countries such as Colombia or Ghana, geographical or climate (drought) conditions or the low productivity of soil make ASGM almost the only possible source of livelihood for many villagers (Hilson and Potter, 2005; Hilson and Pardie, 2006; PEA, 2010).

These circumstances, however, are not the only factors encouraging the practice of ASGM. In addition, some specific economic reforms promoted by the World Bank or the IMF in developing countries may have created another set of conditions for the emergence and rise of poverty. The implementation of these reforms may cause public sector employees to lose their jobs due to the privatization of selected stated-owned enterprises and then to move to other economic sectors with job opportunities such as ASGM (Hilson and Potter, 2005; Banchirigah, 2006). Likewise, reforms to the mining sector in some African and Latin American countries, intended to promote foreign investment in large-scale projects, have caused the displacement of rural communities that have no option other than moving on to ASGM (Banchirigah, 2008; Molano, 2011).

Legalization, formalization and enforcement are regarded as another challenge to ASGM in some countries analyzed in the literature. There is consensus that governments should legalize small-scale mining and implement sector-specific legislation before considering any effort to address any problems related to ASGM (Veiga, 1997; Hilson, 2002a; Chaparro, 2004; Ali, 2009; Giraldo and Muñoz, 2012). With regard to legislation, it is clear that an illegal mining activity is referred to that undertaken without a mining license (Fisher, 2008; Hilson and Maponga, 2004; Enriquez, nd). In many countries, however, legalization of the mining sector has left out ASGM. Sector-specific reforms designed to stimulate foreign investments in large-scale projects (Banchirigah, 2008; Molano, 2011), bureaucratic licensing schemes (Hilson and Potter, 2005; Fisher, 2007; Elejalde, 2012), and lack of enforcement (Teschner, 2012) have excluded small-miners from access to and rights over mineral resources.

Nevertheless, in their struggle for survival, many miners continue to extract the mineral either from areas without any assigned entitlement or from properties of large-scale mines (Ali, 2009). In the latter case, unauthorized miners may operate for several days inside mines owned by large-scale companies, under serious hazardous conditions. The regulation of these miners, who are referred to as ninjas in Mongolia (Ali, 2009), and machuqueros in Colombia (Navia, 2005), may be a tough problem to solve. On one side, large-scale companies are interested in wiping out transgressors, and on the other side, regulators should consider fostering conditions for alternative livelihood programs targeting these groups of miners. Finally, another ingredient of illegality in ASGM is the participation of illegal armed groups that have turned to gold mining to finance their activities or for money laundering (Vergara, 2005; Grätz, 2009; Maconachie, 2009; Romero, 2011).

Some other features can also help to understand that in addition to being poverty-driven, ASGM involves self-reinforcing mechanisms that trap artisanal miners in a cycle of poverty. It is observed that these mechanisms embrace not only the legal and economic context surrounding the activity but also socio-economic and cultural aspects that shape miners' behavior in issues such as the management of natural resources as well as the miners' own economic decisions. These mechanisms are explained below.

2.2 Mining Techniques and Ecosystem Degradation

One particular feature found in ASGM is the application of conventional practices. These techniques make ASGM an activity with a high negative environmental impact, namely mercury pollution and land degradation (Lin et al., 1997; Hilson, 2002b, 2002c; Mol and Ouboter, 2004; Betancourt et al., 2005; Hilson and Pardie, 2006; Swain et al., 2007; Tomicic et al., 2011).

Specifically, because of its relatively low cost, mercury is employed to amalgamate free gold during the process of grinding the whole gold ore in, for instance, ball mills. Additionally, the mercury of the amalgam is burned off into the atmosphere to recover gold (Cordy et al., 2011).

In addition to the low recovery of gold, the outcome of the entire process is the high loss of mercury, which is deposited in the rivers and the air, which in turn are bioaccumulated in soils, water, plants and animals (Prieto and Gonzalez, 1998; Prieto, 2010). More than a few effects on human well-being attributable to mercury pollution have been documented: neurological disorders ranging from loss of eyesight to tremors and paralysis, kidney and lung damages, and effects on the reproductive system (Tirado et al., 2000; Hilson and Pardie, 2006; Tomicic et al., 2011).

In addition to its low cost, two main factors may explain the massive consumption of mercury in ASGM. First, a widespread characteristic of artisanal gold miners is their low degree of education (Hentschel et al., 2002; Heemskerk, 2005). In some cases, low education levels may actually be explained or exacerbated by the participation of children in mining activities. Many of these children, instead of attending school, start their participation in ASGM at a very young age (Keita, 2001; Jaques et al., 2006). Widely accepted consequences of miners' low education are twofold: the disregard miners have for environmental and health-related issues (Spiegel and Veiga, 2005; Hilson, 2006; Imparato, 2010), and the lack of the skills necessary to operate better technologies (Kazilimani et al., 2003; Shoko, 2003).

Furthermore, the lack of credit facilities, combined with the slight savings of mining households and distrustful attitudes toward alternative technologies, become a barrier to having enough working capital and adopting cleaner, more productive technologies (Amankwah and Anim-Sackey, 2003; Enriquez, nd; PEA, 2010; Hentschel et al., 2002; Seeling, 2003; Heemskerk, 2005).

At the aggregate level, China is considered the largest source of environmental mercury derived from ASGM. On the other side of the world, Colombia is the world's third-largest source of mercury from ASGM (Cordy et al., 2011). Moreover, in Antioquia, Colombia, Cordy et al. (2011) estimated mercury emissions to the environment that makes this region the world's highest per capita emitter of mercury from gold mining. Low-productive techniques such as sluice boxes and gold panning (Escalante, 1971; West, 1972) as well as mercury amalgamation were introduced in the colonial period by Spaniards to this and other regions of America (Martínez et al., 2007). These continue to be massively popular techniques despite the fact that cleaner, more productive, and financially viable technologies are available to miners (Veiga, 1997; Pinzón et al., 2003; Pantoja et al., 2005; Hilson, 2006; Martínez et al., 2007). The situation described above parallels the artisanal gold mining sector in Ghana (Hilson, 2002a).

2.3 Cultural Patterns

In the cases described above, we observe that most of the people who currently engage in ASGM may do so because of a tradition that has been passed down the generations. However, the desire to preserve ancestral practices has not always led to unhealthy results in this sector. For example, in Chocó, Colombia, a Fair Trade gold initiative (Childs, 2008) has offered to Afro-Colombian communities the possibility of gold panning in rivers or streams without the need to use mercury or cyanide in the alluvial mining process. The so-called Oro Verde program, which operates within common property areas governed by these communities, has allowed these communities not only to rescue and employ ancestral practices of gold recovery but also to set a minimum price and receive a premium price for their gold (Vera, 2010).

Another part of the cultural portrayal is the conspicuous consumption usually seen in many villages or towns with ASGM (Hinton et al., 2003; CDS, 2004; GEMMA, 2007; Grätz, 2009; Bryceson and Jønsson, 2010). The peculiar manner in which artisanal gold miners spend their income has contributed to the formation of the stereotype of the artisanal gold miner. Among these spending habits, excessive drinking, prostitution, and gambling are among the services an artisanal miner often pays for every time he receives earnings from mining gold (GEMMA, 2007; Grätz, 2009; Bryceson and Jønsson, 2010). We interpret this typical type of behavior as something that undoubtedly prevents any sort of productive investments in either economic activity or the local economy. Various cultural features with historical roots could help us to explain the behavior that artisanal miners exhibit in different locations of the world.

For example, since the 18th century, mining communities from some regions in Colombia (Nordeste and Bajo-Cauca regions in the Department of Antioquia), have been recognized for certain behavioral patterns that Lenis (2007) has classified as "unrestrained." With regard to culture and customs, miners' local folklore states that "gold and money are spent on aguardiente, rum, and women" and that when getting back to the mine there will always be gold available (del Valle, 2007). Such unrestrained behavior, still seen in the 21st century, leads to wasteful expenditures, excessive alcohol consumption, the unwillingness to save money, and damage to the ecosystem due to inappropriate waste disposal. Consequently, these behavioral patterns, following the perception of gold as a non-scarce resource, result in obstacles to economic development. This lack of economic progress is evident, for instance, in the high index of unsatisfied basic needs of gold mining zones in Colombia (Vergara, 2005), and of other countries like Bolivia, Tanzania, or China (Enriquez, nd; Bryceson and Jønsson, 2010; Shen and Gunson, 2006).

2.4 Gold as a Common Resource in Artisanal Mining

The analysis of some of the characteristics underlying ASGM enables us to classify this extraction process as a common pool resource (CPR). Generally speaking, a CPR is defined as a system where the extraction of resource units by one user subtracts from the quantity of the resource potentially available to others (Janssen et al., 2010). Regarding rivalry in ASGM, it is obvious that any gram of gold extracted by one miner or group of miners is not available to others. Nonetheless, the issue of exclusion is not definite. In this survey, we provide some insights into why this mineral resource is not subject to a complete system of exclusion and thus why ASGM could also be studied as a CPR.

As mentioned above, the extraction of gold may or may not be subject to a legal license issued by a government. When the extraction is illegal, the resource is under "open access," and almost anybody can dig up gold. When the activity is legal, the mere fact that a miner holds a license to exploit the resource does not necessarily imply a complete exclusion of other potential miners. With regard to large-scale mining, companies established in developing countries have been in a permanent state of conflict with villagers, who are in principle excluded from gold exploitation (CDS, 2004; Aubynn, 2009). In some cases, miners often encroach upon mines of large-scale companies (Amankwah and Anim-Sackey, 2003; PEA, 2010). In others, small-scale miners do extract gold close to or in zones licensed to but not exploited by those companies (Beltrán, 2004).

Common to ASGM are also the low barriers to entry in terms of capital needs and required skills (Heemskerk, 2002; Amankwah and Anim-Sackey, 2003; Siegel and Veiga, 2010). In addition, in this open-entry occupation, people with high mobility between different mining sites are usually engaged (Bryceson and Jønsson, 2010). Provided that many of these transient miners do not hold an entitlement to extract gold, they can access the mineral resource either as employees in a small-scale mine or by obtaining a lease agreement. Under the terms of such an informal arrangement, the miner or a group of them must share the benefits of the extraction with the title holder. Payment to the title holder can take various forms; some examples include, in Ghana, the distribution of one third of all profits to the concessionaire (Hilson and Potter, 2003), in Suriname, a fee consisting of 5-10% of gold production (Heemskerk and Oliviera, 2004), and in Colombia, 30-40% of the ore that is mined (personal communication with Jesús Rua in 2011).

In many cases, the transience of some artisanal gold miners is linked to the availability of the resource, and information of it (Chaparro, 2003). A notorious example is the case of Serra Pelada in the Brazilian Amazon. After a solitary gold panner found gold in 1980, the government encouraged people to move there by creating the first artisanal mining reserve. Over eighty thousand people from different parts of the world had arrived there by 1983 (Veiga, 1997). A similar case occurred in 2004 in Tanzania, where a villager, having discovered a gold deposit, did not manage to develop a claim. News of the discovery spread rapidly, and soon people were flocking to the area seeking to mine gold (Fisher, 2008). The same perception appears to prevail among small-scale miners in Antioquia, Colombia. In this region, informal miners appear to live in a constant state of expectancy of who is doing well, with the purpose of tracking winners' movements and competing for resources.

2.5 The Tragedy of this Non-renewable Common

With these facts in mind, we then argue that the socio-ecological systems involved in ASGM can fit the definition of CPR. However, what exactly is the tragedy of this non-renewable common? In 1968, Garret Hardin presented "The Tragedy of the Commons," portraying a common pasture opened to a set of herdsmen. Assuming rational self-interested pastoralists, Hardin concluded that each pastoralist would add as many animals as possible to his herd, with the inevitable result of the overharvesting and destruction of the common, unless an external authority imposed corrective rules. In such a setting, each resource user must cope with a social dilemma in which the attainable short-run private benefits from harvesting are at odds with long-term collective interests (Ostrom, 1998).

With regard to exhaustible resources, there is an obvious and inevitable result: their depletion. In spite of this, economic theory suggests that non-renewable resource producers may exploit the resource at a socially optimal rate (Hotelling, 1931). However, with price trends for non-renewable resources that do not support the so-called Hotelling rule, in recent decades several scholars have used formal and experimental methods in an attempt to explain the failure of this rule. Rather than the exhaustibility issue, other decision factors could come into play when producers determine how much mineral to extract, such as uncertainty, myopic behavior, or strategic behavior (Pindyck, 1981; Veldhuizen and Sonnemans, 2011). Indeed, in some regions with ASGM gold has been exploited for centuries, and there is as yet no concern about its depletion (del Valle, 2007).

Survey evidence shows that in ASMG, the question that miners face is not whether to extract the resource or what the optimal rate is but how to extract and recover the resource. ASMG is a unique livelihood activity, in which the earnings miners receive from gold are relatively significant (Siegel and Veiga, 2010), and the ignorance of existing mineral reserves is salient (Lahiri-Dutt; 2004). Unlike users of replenishable CPR, one social dilemma additionally faced by resource users in ASGM can be found in the way in which gold is recovered. In the gold recovery (ore beneficiation) process, every miner tends to employ the cheapest available technique – mercury amalgamation– apparently to gain the maximum short-run benefit for himself. However, the entire community, which includes him, is worse off than if a cleaner and more productive technology were used. Therefore, unlike the social dilemma analyzed in the previous literature on renewable CPR, the dilemma that ASGM faces is not only found in the extraction and availability of this non-renewable resource or in its depletion. An additional dilemma concerns the reduction of pollution resulting from the gold recovery process; i.e., a public-good dilemma (Ostrom, 1998).

In addition to the social dilemma, every miner faces an individual dilemma. This situation can be viewed as involving a within-person externality, or "internality." In the field of behavioral economics, internality refers to situations in which a person ignores a consequence of his own behavior for himself. According to Herrnstein et al. (1993) this phenomenon can occur for reasons such as lack of awareness of the consequence, or a motivational downgrading of otherwise obscure consequences of action. In the context of ASGM, we argue that the internality occurs when the decision made by a miner in the present on how to recover gold imposes health costs in the long-run to the miner himself (internal costs) in addition to the community to which he belongs (external costs). These costs, both internal and external, are simply not considered at the moment of making the decision of how to recover gold.

In many field settings, with evidence gathered for renewable resources, such as forests or fisheries, it has been shown the possibility of stimulating collective action or self-organization as an alternative to solve the social dilemma associated with the use of CPRs (Ostrom, 2010). A wide range of scholars around the world have noted that a set of conditions would enable users of CPRs to overcome the tragedy of the commons. Mechanisms such as communication, reciprocity, learning, and the development of a set of norms and rules may trigger this possibility (Basurto and Ostrom, 2009; Ostrom, 2010). The existence of these mechanisms would avoid the intervention of an external authority.

In ASGM, there are small associations of miners created with the aim of reducing costs and increasing productivity, but these associations are mostly formed for the process of mining gold from vein or placer deposits (Echeverry and Jaime, 1988; Chaparro, 2003; Bryceson and Jønsson, 2010; GEMMA, 2007; PEA, 2010). We note that these associations would be of special importance for underground gold mining, where initial and exploration costs are greater. Additionally, there are occasions where miners may get together to address legal issues such as the procurement of explosives or obtaining mining entitlements.

However, it seems like, contrary to experimental and field evidence for renewable resources (Ostrom, 2010), these associations have seldom been effective in resolving the social dilemma these communities deal with. The existence of different objectives or interests, disputes concerning the administration, a lack of a long-term vision, or a lack of trust may be some of the barriers hindering either the establishment or longevity of these cooperatives (Chaparro, 2003; Hinton et al., 2003; miner's personal communication).

In sum, ASGM is a labor intensive activity that employs low technology, and has a high negative impact on environmental quality, which represents a public-good dilemma. Furthermore, we observe that, contrary to some CPR systems in which self-organization may emerge as an opportunity to overcome the social dilemma, in ASGM the intervention of an external authority or third party may be needed to promote better practices and technologies (CDS, 2004; Chaparro, 2003; Amankwah and Anim-Sackey, 2003; Shen and Gunson, 2006).

2.6 Intervention Programs

Launched by the United Nations in 2002, the Global Mercury Project is an important capacity-building initiative, created with the aim of "removing barriers to the adoption of cleaner practices of small-scale gold mining" (Spiegel and Veiga, 2005, p. 362). Experiences with this sort of intervention show varying results. For instance, a number of assistance projects aimed to create enterprises in Mali failed due to several reasons such as considering only technical aspects, and ignoring important socioeconomic issues (Keita, 2001). On the other hand, some interventions in Bolivia and Colombia, as well as Mali, have reported positive results (Bocangel, 2001; García and Molina, 2011; Keita, 2001). In these countries, persistent training campaigns encouraged some miners to use retorts during the mercury burn-off stage.

However, as Jennings (2003) notes, interventions must go beyond the presentation of technical solutions to the problems of mining and processing; attention to economic and social issues should also be paid. For instance, an interesting form of intervention is the promotion or strengthening of cooperatives of miners. Given the lack of communication and collective action among miners (Hinton et al., 2003), the role of a third party could go in the direction of fostering organization within the sector (Kazilimani et al., 2003).

The promotion of associative entrepreneurship has been on the policy agenda of some governments and independent bodies. In addition to improving the relationship with the state, this type of association would enable miners to accumulate the financial capital required to obtain cleaner and more productive technologies that are beyond the budget of most miner families (Hinton et al., 2003; Hilson and Potter, 2003; Heemskerk and Oliviera, 2004; CDS, 2004; Ghose and Roy, 2007; Spiegel, 2009; Hentschel et al., 2002). This capital is difficult to obtain from the financial system, which perceives small-scale mining as a risky financial activity (Chaparro, 2003). This fact, added to the low tendency of miners to save money for investing (see section 2.3), make us think of associative entrepreneurship an option for small-scale miners to increase their financial capital.

However, given the low predisposition of miners to engage in long-lasting cooperative efforts, is it truly possible for artisanal gold miners to find in cooperation a mean for overcoming their social dilemma? Among the few examples is "La Llanada," in the Department of Nariño, Colombia, where there exists an association in which each community member must contribute a determined amount of money. This association has enabled its members to create an enterprise for both exploitation and recovery, eradicating the consumption of mercury (Franco, 1998; León, 2011). Similarly, in Mali and Mozambique small-scale miners united their efforts and capital to improve mine efficiency, whereas technical assistance enabled them to have some control over mercury pollution (Keita, 2001; Dondeyne et al., 2009). However, in the case of Mozambique, technical support from the government has only succeeded when miners extract gold encased in rocks. When gold is found in alluvial deposits, the mining activity may not be long-lasting, which may discourage the formation of an association (Dondeyne et al., 2009).

To what extent this concept of associative entrepreneurship can be applied to other sites with ASGM is still unknown from this literature review, particularly in sites with severe negative environmental impacts due to mercury pollution, such as the region of Antioquia in Colombia (Cordy et al., 2011). In recent years, the government of Antioquia, jointly with UNIDO's Global Mercury Project, has encouraged the use of technologies to reduce mercury discharges. A feature of the campaign has been the encouragement of miners to associate among themselves for entrepreneurial purposes. In our opinion, although reductions in mercury utilization and pollution have been reported (García and Molina, 2011), artisanal miners and external organizations have much difficult work to do to accomplish the goal of phasing out the utilization of mercury. A question worth asking is whether each artisanal gold miner has the capabilities required to organize with other miners to create an enterprise in an attempt to improve their production processes. If these miners do not, another question to answer is how collective action may be encouraged. This point is further discussed in the next section.

3. Discussion

ASGM is the main source of subsistence for millions of people living in developing countries and perhaps is the only livelihood alternative for those communities. Therefore, we can say that for these communities, the question to ask is not whether to extract gold but how to do it. In addition to offering technical alternatives, as a first step in the design of policies to solve the sort of problems previously discussed, several authors have called attention to the importance of first understanding the societal dynamics of communities involved in ASGM (Hentschel et al., 2002; Hilson, 2005, 2006; Hilson et al., 2007; Spiegel, 2009; Dondeyne et al., 2009). The poor performance of many projects aimed at regularizing and providing assistance to ASGM has been said to be due to an insufficient understanding of the dynamics of target communities, the organization of processing activities, operators' needs and geological conditions (Hilson, 2007).

In this attempt, with a survey of the literature we have described the commonalities of ASGM systems located in developing countries: low levels of mechanization and technology, labor-intensiveness, considerable environmental degradation, low productivity levels, and lack of capital. Additionally, in view of the findings of this survey, it may be said that poverty is both a cause and an effect of ASGM. In all, we can observe that several social, economic and cultural factors are traversal to the commonalities already described in section 2, and which are important elements of the dynamics that underlies ASGM. This set of factors includes: low education levels and poor training of miners; conspicuous consumption; lack of trust in others and towards alternative technologies; insufficient communication, and; unusual collective action to cope with the social dilemma they face.

In an effort to improve the understanding of the dynamics underlying ASGM communities, there are approaches that might go beyond the analysis conducted thus far. Examples of those analytical approaches are behavioral simulation models (Sterman, 2000) and the multi-tier framework proposed by Ostrom (2007), which are briefly discussed in this section.

3.1 Some Analytical Approaches

Simulation has become an important methodology for theory development in the literature on organizations (Davis et al., 2007) and the understanding of the dynamics governing a social system (Bowles, 2004). For instance, Andriamasinoro and Angel (2012) discuss the advantages that simulation methods could provide to the design of policies focused on ASGM. Also in other contexts, simulation has proved to be a useful tool in the analysis of global markets for exhaustible resources such as helium (Cai et al., 2010) or metals (van Vuuren et al., 1999).

Hence, we think that simulation methods can help to explain the endogenous dynamics underlying social systems involved in ASGM and leverage policies can be proposed and assessed. These policies should be aimed at counteracting the current harmful effects observed in ASGM. With these methods we can model the complexity of socio-economic systems involved in the management of natural resources (see for instance Castillo and Saysel, 2005). This complexity is reflected in a structure with social, economic, environmental, and institutional aspects that incorporates feedback relationships, nonlinearities, and delays. In the case of ASGM, it would be possible to consider issues such as investment decisions or the perception of the unhealthy effects of pollution. In both cases the temporal difference between cause and effect can be substantial (Hilson, 2006).

An approach to complement simulation methods is the multi-tier framework proposed by Ostrom (2007). Ostrom (2007) and Ostrom et al. (2007) pointed out the necessity of moving beyond the panaceas proposed to solve complex problems and instead to create an accurate diagnosis of every socio-ecological system. In other words, the authors suggest that there cannot be a single solution for all CPR systems and that it is better to consider every socio-ecological system in its general context. For instance, Basurto and Ostrom (2009) explained why some fisheries may self-organize and solve the underlying CPR dilemma using such approach.

To begin moving toward a diagnostic theory of ASGM, one should identify the tiers and linkages among the variables, including their subcategories, that constitute the structure of a socio-ecological system. Under the multi-tier framework of Ostrom (2007), a set of highest-tier and second-tier variables are identified and analyzed. At the broadest conceptual level, the interactions among a set of attributes are analyzed: the resource system, the resource units generated by the system, the users of the system, and the governance system (Basurto and Ostrom, 2009). In the case of ASGM, we may say that these attributes are gold mines, gold, small-scale gold miners, local and regional governments, researchers, nongovernmental organizations, local and nonlocal miners, and companies interested in the mineral resource. An additional stage of this multi-tier approach is to create a theoretical integration that helps to understand how these variables interact to produce the observed outcomes of the complex socio-ecological system.

3.2 Approach for Understanding Economic Behavior

Both the social dilemma involved in the exploitation of a CPR and the study of different mechanisms to overcome it have received increasing attention from scholars in the lasts two decades (Ostrom, 2010). This growing literature has studied different types of resources mainly renewable resources such as fisheries and forest exploitation. Most of these studies have focused on analyzing the social dilemma related to the extraction and availability of the resource and on identifying mechanisms that could prevent users from behaving as rational economic agents. However, these studies have not taken into consideration another social dilemma that may arise in the process of exploiting a CPR and that could potentially interact with the CPR dilemma and be overcome with the same mechanisms. A clear example of a CPR in which there are additional social dilemmas that follow the extraction process is the case of ASGM. Although ASGM has the characteristics of non-excludability and rivalry proper of a CPR, users in this sector face the dilemma related to the reduction of the pollution resulting from the gold recovery process; i.e., a public-good dilemma.

In this sense, we think that there is room for resource economists and political scientists to engage in future research that includes the sort of analysis conducted for other types of socio-ecological systems. The conducting of field economic experiments (Harrison and List, 2004) could be considered in this future research, together with the measurement of micro-situational variables. Research of this sort would provide some insight concerning the decisions miners take and the "why" behind these decisions (Anderies et al., 2011).

For the particular case of ASGM, there is a class of economic experiments that may be suitable to analyze organizational structures and economic performance. One class of such experiments comprises experiments using simple interaction among agents to study the effect of social preferences on behavior (Camerer and Weber, 2013). For example, public good games are a useful tool for the analysis of organizational processes that entails dilemmas such as environmental protection or teamwork (Ledyard, 1995). In an extension of this game, a public bad game, Moxnes and van der Heijden (2003) showed that the actions of a leader may induce other members of the group to desist from making investments in a public bad. This type of result may represent an interesting issue to analyze in field experiments with artisanal gold miners. For instance, García and Molina (2011) reported that in Antioquia, Colombia, motivation by a local leader for the application of an improved retort encouraged some other miners to take advantage of this improvement.

With very few exceptions, we observe that self-organization does not appear to be a solution to the social dilemma faced by ASGM communities. Instead, authors such as CDS (2004) and Chaparro (2003) point out that the intervention of external parties might be needed for miners to organize. A key role of the third party would be to foster associative entrepreneurship. Conceptually, we think that this type of cooperation may allow artisanal miners to raise the financial capital necessary to acquire better technologies and overcome the lack of access to credit markets. This is another hypothesis that could be tested in field economic experiments with artisanal gold miners. For another kind of CPR, for instance, Moreno-Sánchez and Maldonado (2010) experimentally showed a good performance of a mechanism in which the interaction between internal communication of community members and an external non-coercive party takes place. In all, field experiments could serve to test this and other mechanisms triggering this type of collective action in ASGM.

In addition, with field work, economic field experiments included, issues from behavioral economics such as internalities (Herrnstein et al., 1993), self-control (Thaler and Shefrin, 1981), or Veblen's ideas on conspicuous consumption might be studied. For instance, Kocher et al. (2012) have theoretically and experimentally shown that self-control is positively correlated to contributions in linear public good games, and Moav and Neeman (2012) have theoretically shown a relationship between conspicuous consumption, income, human capital, and poverty traps. To what extent economic inequality affect decisions in public-good dilemmas (Cardenas et al., 2002) situations is an issue that might also be studied with the kind of economic experiments already mentioned.

Sometimes members of organizations can only achieve mutual gains if they make mutually consistent decisions. However, the uncertainty on other members' decisions is likely to discourage a member from making the best decision. These situations can be studied with the application of coordination games. For example, in the minimum effort coordination game proposed by van Huyck et al. (1990), the payment received by each member of a specific group depends on the minimum effort made by any of the members. In addition to this setting, for any level of effort, there is a cost. In the context of ASGM, if miners simply continue operating with the technology that generates the lowest cost in the short run and evade their social responsibility to use cleaner technologies (with higher costs), the higher private and social benefits of alternative technologies will be unattainable.

Pollution charges are environmental policy instruments whereby the producer of the pollution is charged a fee on the amount of the pollution he generates (Stavins, 2001). The application of this instrument has been suggested to manage mercury pollution in Colombia (von Humboldt Institute, 1999). Although the application of these instruments has been effective in dealing with certain pollutants in the developing world (Sterner, 2003), it is not clear how their implementation in the case of ASGM will be effective. Among other issues, widespread illegality, the low technological level involved, social conflict, or simply the lack of operational resources to enforce such a policy could make this implementation unfeasible. However, the implementation of environmental policy instruments in ASGM is another interesting topic for future research.

Lastly, to propose mechanisms or approaches by which scholars can convince policy makers of the feasibility of implementing the solutions resulting from future researches remains a challenge. Andriamasinoro and Angel (2012) offer some guidance on this regard.

4. Conclusion

ASGM is the main source of subsistence for millions of people living in developing countries and perhaps is the only livelihood alternative for those communities. In an effort to better understand the dynamics underlying ASGM communities, we presented a survey analysis to describe the commonalities of ASGM systems located in developing countries. These commonalities are as follows: low levels of mechanization and technology, labor-intensiveness, considerable environmental degradation, low educated and poorly trained miners, low productivity levels, lack of capital, and high transience among miners. Additionally, addressing the call made by Spiegel (2009), we have provided potential directions of ecological/environmental and development economics research efforts. This research agenda and its intended efforts are just first steps to move forward and find solutions to the problems we see in ASGM; solutions that can then be implemented successfully.

We identified possible analytical approaches in order to get better insights to address the problems found in ASGM. Such approaches consider the development of behavioral simulation models (Sterman, 2000) and analysis via the multi-tier framework proposed by Ostrom (2007). Moreover, experimental economics could enhance the knowledge that about the behavioral patterns of these communities we have and complement the analysis. Some of these issues are, for instance, self-control, conspicuous consumption, and the role of leaders and external parties, or any other mechanisms, in solving the social dilemmas of these communities.

There are certainly other avenues of research, such as the role that microfinance could have in improving the economic conditions of people in ASGM (Hilson and Ack-Baidoo, 2011) or the effects that common property versus open access may have on the management of resources. In summary, the primary goal is the reversion of the negative environmental and social impacts of ASGM and to convert this activity into a source of not only livelihood but also of well-being for a growing number of people in Africa, America and Asia.

References

[1] Ali, S., 2009. Mining dilemma. Alternatives Journal 35, 8-11.

[2] Amankwah, R.K., Anim-Sackey, C., 2003. Strategies for sustainable development of the small-scale gold and diamond mining industry of Ghana. Resources Policy 29, 131-138.

[3] Anderies, J., Janssen, M., Bousquet, F., Cardenas, J., Castillo, D., Lopez, M.C., Tobias, R., Vollan, B., Wutich, A., 2011. The challenge of understanding decisions in experimental studies of common pool resource governance. Ecological Economics 70, 1571-1579.

[4] Andriamasinoro, F., Angel, J.-M., 2012. Artisanal and small-scale gold mining in Burkina Faso: Suggestion of multi-agent methodology as a complementary support in elaborating a policy. Resources Policy 37, 385-396.

[5] Aubynn, A., 2009. Sustainable solution or a marriage of inconvenience? The coexistence of large-scale mining and artisanal and small-scale mining on the Abosso Gold fields concession in Western Ghana. Resources Policy 34, 64-70.

[6] Azariadis, C., Stachurski, J., 2005. Poverty traps, in: Aghion, P., Durlauf, S. (Eds.), Handbook of Economic Growth, Vol. 1, part 1. Elsevier, Amsterdam, pp. 295-384.

[7] Banchirigah, S.M., 2006. How have reforms fuelled the expansion of artisanal mining? Evidence from sub-Saharan Africa. Resources Policy 31, 167-161.

[8] Banchirigah, S.M., 2008. Challenges with eradicating illegal mining in Ghana: A perspective from the grassroots. Resources Policy 33, 29-38.

[9] Basurto, X., Ostrom, E., 2009. Beyond the tragedy of the commons. Economia delle fonti di energia e dell'ambiente 1, 35-60.

[10] Beltrán, H., 2004. Govt., Frontino Gold Mines resolve informal mining invasion -Colombia. Business News Americas Nov./15/2004. [Accessed 1/31/2012, www.bnamericas.com/news/mining/Govt_Frontino_Gold_Mines_resolve_informal_mining_invasion].

[11] Betancourt, O., Narváez, A., Roulet, M., 2005. Small-scale gold mining in the Puyango River Basin, Southern Ecuador: A Study of Environmental Impacts and Human Exposures. EcoHealth 2, 323-332.

[12] Bocangel, D., 2001. Bolivia Estudio Regional/Nacional sobre Pequeña Mineria y Artesanal Proyecto MMSD. MMSD/IIED and WBCS No. 71, UK.

[13] Bowles, S., 2004. Microeconomics, Behavior, Institutions, and Evolution. Princeton University Press, New Jersey.

[14] Bryceson, D.F., Jønsson, J.B., 2010. Gold digging careers in rural East Africa, small-scale miners' livelihood choices. World Development 38, 379-392.

[15] Cai, Z., Clarke, R.H., Glowacki, B.A., Nuttall, W.J., Wa, N., 2010. Ongoing ascent to the helium production plateau–Insights from system dynamics. Resources Policy 35, 77-89.

[16] Camerer, C., Weber, R., 2013. Experimental organizational economics, in: Gibbons, R., Roberts, J. (Eds.), Handbook of Organizational Economics. Princeton University Press, Princeton, pp. 213-262.
[17] Cardenas, J.C., Stranlund, J., Willis, C., 2002. Economic inequality and burden-sharing in the provision of local environmental quality. Ecological Economics 40, 379-395.
[18] Castillo, D., Saysel, A.K., 2005. Simulation of common pool resource field experiments: a behavioral model of collective action. Ecological Economics 55, 420-436.
[19] CDS -Centre for Development Studies-, 2004. Livelihoods and Policy in the Artisanal and Small-Scale Mining Sector -An Overview. University of Wales Swansea, UK.
[20] Chaparro, E., 2003. Small-scale mining, a new entrepreneurial approach. Serie Recursos Naturales e Infraestructura No. 9. CEPAL, Santiago, Chile.
[21] Chaparro, E., 2004. La pequeña minería y los nuevos desafíos de la gestión pública. Serie Recursos Naturales e Infraestructura No. 70. CEPAL, Santiago, Chile.
[22] Childs, J., 2008. Reforming small-scale mining in sub-Saharan Africa: Political and ideological challenges to a Fair Trade gold initiative. Resources Policy 33, 203-209.
[23] Chouinard, R., Veiga, M., 2008. Results of the Awareness Campaign and Technology Demonstration for Artisanal Gold Miners, Summary Report. UNIDO, Vienna.
[24] Cordy, P., Veiga, M., Salih, I., Al-Saadi, S., Console, S., Garcia, O., Mesa., L.A., Velásquez-López, P., Roeser, M., 2011. Mercury contamination from artisanal gold mining in Antioquia, Colombia: The world's highest per capita mercury pollution. Science of the Total Environment 410-411, 154-160.
[25] Davis, J., Eisenhardt, K., Bingham, C., 2007. Developing theory through simulation methods. Academy of Management Review 32, 480-499.
[26] del Valle, F., 2007. Estrategias Culturales para el Desarrollo del Nordeste y Bajo Cauca Antioqueño. Secretaría de Productividad y Competitividad Gobernación de Antioquia - Corporación Cirros, Medellín, Colombia.
[27] Dondeyne, S., Ndunguru, E., Rafael, P., Bannerman, J., 2009. Artisanal mining in central Mozambique: Policy and environmental issues of concern. Resources Policy 34, 45-50.
[28] Echeverry, J., Jaime, L., 1988. La minería del oro en Antioquia y su impacto macroeconómico. Ensayos sobre Política Económica 14, 5-38.
[29] Elejalde, R., 2012. Otra mina, en Minas. El Mundo Jan./15/2012 [Accessed 1/31/2012, http://www.elmundo.com/portal/opinion/columnistas/otra_mina_en_minas.php].
[30] Enriquez, J.C., nd. Minería, Minerales y Desarrollo Sustentable en Bolivia. Servicios Ambientales S.A. [Accessed 31/1/2012, http://pubs.iied.org/pdfs/G00581.pdf].
[31] Escalante, A., 1971. La Minería del Hambre, Condoto y la Chocó Pacífico. Ediciones Universidades Medellín, Córdoba y Simón Bolívar, Colombia.
[32] Fisher, E., 2007. Occupying the margins, labour integration and social exclusion in artisanal mining in Tanzania. Development and Change 38, 735-760.
[33] Fisher, E., 2008. Artisanal gold mining at the margins of mineral resource governance, a case from Tanzania. Development Southern Africa 25, 199-213.
[34] Franco, G., 1998. Modelo Técnico Económico de Desarrollo de un Distrito Minero. Undergraduate thesis, Universidad Nacional de Colombia – Sede Medellín.

[35] Fukuyama, F., 1996. Trust: The Social Virtues and the Creation of Prosperity. Free Press Paperbacks, New York.
[36] García, O., Molina, J., 2011. Avances en la solución de impactos ambientales causados por la minería aurífera artesanal en el Nordeste de Antioquia, in: Barrezuela, E., Domínguez-Cuesta, M. (Eds.), Técnicas aplicadas a la caracterización y aprovechamiento de recursos geológico-mineros. Red Minera XXI, CYTED, Instituto Geológico y Minero de España, pp. 40-50.
[37] GEMMA, 2007. Diseño de una Estructura Productiva Autónoma, Sostenible y Socialmente Viable para la Minería del Nordeste Antioqueño. Grupo de Estudios en Georrecursos, Minería y Medio Ambiente, Universidad Nacional de Colombia – Sede Medellín.
[38] Ghose, M., Roy, S., 2007. Contribution of small-scale mining to employment, development and sustainability – an Indian scenario. Environment, Development and Sustainability 9, 283-303.
[39] Giraldo, J., Muñoz, J.C., 2012. Informalidad e ilegalidad en la explotación del oro y la madera en Antioquia. EAFIT-Proantioquia, Medellín, Colombia.
[40] Grätz, T., 2009. Moralities, risk and rules in West African artisanal gold mining communities: a case study of Northern Benin. Resources Policy 34, 12-17.
[41] Hardin, G., 1968. The tragedy of the commons. Science 142, 1243-1248.
[42] Harrison, G. List, J., 2004. Field experiments. Journal of Economic Literature 42, 1009-1055.
[43] Heemskerk, M., 2002. Livelihood decision making and environmental degradation, small-scale gold mining in the Suriname Amazon. Society & Natural Resources 15, 327-344.
[44] Heemskerk, M., 2005. Collecting data in artisanal and small-scale mining communities: Measuring progress towards more sustainable livelihoods. Natural Resources Forum 29, 82-87.
[45] Heemskerk, M., Oliviera, M., 2004. Perceptions of Small-scale Gold Miners on Self-organization and Formalization in Suriname, South America. GMD Project, Suriname.
[46] Hentschel, T., Hruschka, F., Priester, M., 2002. Global Report on Artisanal and Small-Scale Mining. International Institute for Environment and Development, London, UK.
[47] Herrnstein, R.H., Loewenstein, G.F., Prelec, D., Vaughan, W., 1993. Utility maximization and melioration, internalities in individual choice. Journal of Behavioral Decision Making 6, 149-185.
[48] Hilson, G., 2002a. Promoting sustainable development in Ghanaian small-scale gold mining operations. The Environmentalist 22, 51-57.
[49] Hilson, G., 2002b. Small-scale mining and its socio-economic impact in developing countries. Natural Resources Forum 26, 3-13.
[50] Hilson, G., 2002c. The environmental impact of small-scale gold mining in Ghana: Identifying problems and possible solutions. The Geographical Journal 168, 57-72.
[51] Hilson, G., 2005. Strengthening artisanal mining research and policy through baseline census activities. Natural Resources Forum 29, 144-153.
[52] Hilson, G., 2006. Abatement of mercury pollution in the small-scale gold mining industry: Restructuring the policy and research agendas. Science of the Total Environment 362, 1-14.
[53] Hilson, G., 2007. What is wrong with the Global Support Facility for small-scale mining? Progress in Development Studies 7, 235-249.
[54] Hilson, G., Ack-Baidoo, A., 2011. Can microcredit services alleviate hardship in African small-scale mining communities?. World Development 39, 1191-1203.

[55] Hilson, G., Hilson, C., Pardie, S., 2007. Improving awareness of mercury pollution in small-scale gold mining communities: Challenges and ways forward in rural Ghana. Environmental Research 103, 275-287.

[56] Hilson, G., Maponga, O., 2004. How has a shortage of census and geological information impeded the regularization of artisanal and small-scale mining? Natural Resources Forum 28, 22-33.

[57] Hilson , G., Pardie, S., 2006. Mercury: An agent of poverty in Ghana's small-scale gold-mining sector? Resources Policy 31, 106-116.

[58] Hilson, G., Potter, C., 2003. Why is illegal gold mining activity so ubiquitous in rural Ghana? African Development Review 15, 237-270.

[59] Hilson, G., Potter, C., 2005. Structural adjustment and subsistence industry, artisanal gold mining in Ghana. Development and Change 36, 103-131.

[60] Hinton, J., Veiga, M., Veiga, A., 2003. Clean artisanal gold mining, a utopian approach?. Journal of Cleaner Production 11, 99–115.

[61] Hotelling, H., 1931. The economics of exhaustible resources. Journal of Political Economy 39, 137-175.

[62] Imparato, N., 2010. Artisanal gold and transformational exchange: toward a public-private partnership in Tanzania. Journal of Cleaner Production 18, 462-470.

[63] Jaques, E., Zida, B., Billa, M., Greffié, C., Thomassin, J.-F. 2006. Artisanal and small-scale Gold mines in Burkina Faso: today and tomorrow, in: Hilson, G. (Ed.), Small-scale Mining, Rural Subsidence and Poverty in West Africa. Practical Action Publishing, Rugby, UK, 114-134.

[64] Janssen, M., Holahan, R., Lee, A., Ostrom, E., 2010. Lab experiments for the study of social-ecological systems. Science 328, 613-617.

[65] Jennings, N., 2003. Addressing labour and social issues in small-scale mining, in: Hilson, G. (Ed.), The socio-economic impacts of artisanal and small-scale mining in developing countries. A.A. Balkema Publishers, Lisse, The Netherlands, pp. 140-148.

[66] Kazilimani, E., Bukali da Graça, F., McMahon, G., 2003. Artisanal mining baseline survey of Mozambique, in: Hilson, G. (Ed.), The socio-economic impacts of artisanal and small-scale mining in developing countries. A.A. Balkema Publishers, Lisse, The Netherlands, pp. 218-243.

[67] Keita, S., 2001. Study on Artisanal and Small-Scale Mining in Mali. MMSD/IIED and WBCS No. 80, UK.

[68] Kitula, A.G.N., 2006. The environmental and socio-economic impacts of mining on local livelihoods in Tanzania: A case study of Geita District. Journal of Cleaner Production 14 , 405-414.

[69] Kocher, M., Martinsson, P., Myrserth, K., Wollbrant, C., 2012. Strong, bold, and kind, self-control and cooperation in social dilemmas. Working Papers in Economics No. 523, University of Gothenburg, Sweden.

[70] Lahiri-Dutt, K., 2004. Informality in mineral resource management in Asia: Raising questions relating to community economies and sustainable development. Natural Resources Forum 28, 123-132.

[71] Ledyard, J., 1995. Public goods: a survey of experimental research, in: Roth, A., Kagel, J. (Eds.), Handbook of Experimental Economics. Princeton University Press, Princeton, pp. 111-194.

[72] Lenis, C.A., 2007. Una Tierra de Oro: Minería y Sociedad en el Nordeste de Antioquia siglos XVI-XIX. Instituto para el Desarrollo de Antioquia (IDEA), Medellín, Colombia.
[73] León, J., 2011. La Llanada, la 'tercera vía' en minería. La Silla Vacía [Accessed 1/31/2011, http://www.lasillavacia.com/historia/la-llanada-la-tercera-en-mineria-22654].
[74] Lin, Y., Guo, M., Gan, W., 1997. Mercury pollution from small mines in China. Water, Soil and Air Pollution 97, 233-239.
[75] Maconachie, R., 2009. Diamonds, governance and 'local' development in post-conflict Sierra Leone: Lessons for artisanal and small-scale mining in sub-Saharan Africa? Resources Policy 34, 71-79.
[76] Managi, S., Opaluch, J., Jin, D., Grigalunas, T.A., 2004. Technological change and depletion in the offshore oil and gas industry. Journal of Environmental Economics and Management 47, 388-409.
[77] Maponga, O., Ngorima, C.F., 2003. Overcoming environmental problems in the gold panning sector through legislation and education, the Zimbabwean experience. Journal of Cleaner Production 11, 147–157.
[78] Martínez, E., Wolf, E., Pinzón, J., Pineda, J., 2007. Resultados y experiencias exitosas de proyectos relacionados con el manejo del mercurio en la minería de oro en Colombia con fines preventivos. Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Bogotá.
[79] Moav, O., Neeman, Z., 2012. Saving rates and poverty: The role of conspicuous consumption and human capital. The Economic Journal 122, 933-956.
[80] Mol, J., Ouboter, P., 2004. Downstream effects of erosion from small-scale gold mining on the instream habitat and fish community of a small neotropical rainforest stream. Conservation Biology 18, 201-214.
[81] Molano, A., 2011. ¡Al tren del oro!. El Espectador Sep./3/2011. [Accessed 1/31/2012, http://www.elespectador.com/impreso/opinion/columna-296689-al-tren-del-oro#].
[82] Moreno-Sánchez, R., Maldonado, J., 2010. Evaluating the role of co-management in improving governance of marine protected areas: An experimental approach in the Colombian Caribbean. Ecological Economics 69, 2557-2567.
[83] Moxnes, E., van der Heijden, E., 2003. The effect of leadership in a public bad experiment. Journal of Conflict Resolution 47, 773-795.
[84] Navia, J., 2005. Oro y Muerte en Minas de Segovia. El Tiempo Jun./26/2005. [Accessed 12/11/2012, http://www.eltiempo.com/archivo/documento/MAM-1626293].
[85] Ostrom, E., 1998. A behavioral approach to the rational choice theory of collective action. The American Political Science Review 92, 1-22.
[86] Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences 104, 15181-15187.
[87] Ostrom, E., 2010. Revising theory in light of experimental findings. Journal of Economic Behavior & Organization 73, 68-72.
[88] Ostrom, E., Janssen, M., Anderies, J.M., 2007. Going beyond panaceas. Proceedings of the National Academy of Sciences 104, 15176-15178.
[89] Pantoja, F., Alvarez, R., Rodriguez, A., 2005. Methods to reduce mercury pollution in small gold mining operations. Revista de Metalurgia 41, 194-203.

[90] PEA - Programa Expedición Antioquia 2013-, 2010. Sistemas productos territoriales para el desarrollo de Antioquia. Gobernación de Antioquia, Universidad de Antioquia, Universidad de Medellín, Universidad EAFIT, Escuela de Ingenieros de Antioquia, ITM, Medellín, Colombia.
[91] Pinzón, J., Contreras, R., Bernardy, C., 2003. A new still for the prevention of mercury poisoning in small-scale gold mining by amalgam extraction. Geofísica Internacional 42, 641-644.
[92] Prieto, G., 2010. Mercurio y minería de oro. INGEOMINAS al día, 10, 18-21.
[93] Prieto, G., Gonzalez, M.L., 1998. Diagnosis of environmental problems related to vein gold mining in Colombia. Lecture Notes in Earth Sciences 72, 185-191.
[94] Pyndick, R., 1981. Models of resource markets and the explanation of resource price behavior. Energy Economics 3, 130-139.
[95] Romero, S., 2011. In Colombia, new gold rush fuels old conflict. New York Times March 3/3/2011 [Accessed 3/3/2011, http://www.nytimes.com/2011/03/04/world/americas/04colombia.html].
[96] Seeling, A., 2003. Report on field research into the socio-economic and social impact of artisanal and small-scale mining in Peru, in: Hilson, G. (Ed.), The Socio-economic Impacts of Artisanal and Small-scale mining in Developing Countries. A.A. Balkema Publishers, Lisse, The Netherlands, pp. 597-632.
[97] Shen, L., Gunson, A.J., 2006. The role of artisanal and small-scale mining in China's economy. Journal of Cleaner Production 14, 427-435.
[98] Shoko, D., 2003. Small-scale mining and alluvial gold panning within the Zambezi Basin: an ecological time bomb and tinderbox for future conflicts among riparian states, in: Chikowore , G., Manzungu, E., Mushayavanhu, D., Shoko, D., (Eds.), Managing Common Property in an Age of Globalisation. Weaver Press, Zimbabwe, Chapter 4.
[99] Siegel, S., Veiga, M., 2010. The myth of alternative livelihoods, artisanal mining, gold and poverty. International Journal of Environment and Pollution 41, 272-288.
[100] Spiegel, S., 2009. Socioeconomic dimensions of mercury pollution abatement: Engaging artisanal mining communities in Sub-Saharan Africa. Ecological Economics 68, 3072-3083.
[101] Spiegel, S., Veiga, M., 2005. Building capacity in small-scale mining communities: health, ecosystem sustainability, and the Global Mercury Project. EcoHealth 2, 361-369.
[102] Stavins, R.N., 2001. Experience with market-based environmental policy instruments. Discussion Paper 01–58, Resources for the Future.
[103] Sterman, J. D., 2000. Business Dynamics: System Thinking and Modeling for a Complex World. Irwin McGraw-Hill, Homewood, USA.
[104] Sterner, T., 2003. Policy Instruments for Environmental and Natural Resource Management. RFF Press, Washington.
[105] Swain, E., Jakus, P., Rice, G., Lupi, F., Maxson, P., Pacyna, J., Penn, A., Spiegel, S., Veiga, M., 2007. Socioeconomic consequences of mercury use and pollution. Ambio 36, 45-61.
[106] Teschner, B.A., 2012. Small-scale mining in Ghana: The government and the galamsey. Resources Policy 37, 308-314.
[107] Thaler, R.H., Shefrin, H.M., 1981. An economic theory of self-Control. Journal of Political Economy, 89, 392-406.

[108] Tilton, J.E., 1992. Mineral wealth and economic development: An overview, in: Tilton, J.E. (Ed.), Mineral Wealth and Economic Development. Resources for the Future, Washington, pp. 1-18.
[109] Tirado, V., García, M.A., Moreno, J., Galeano, L.M., Lopera, F., Franco, A., 2000. Alteraciones neuropsicológicas por exposición ocupacional a vapores de mercurio en El Bagre (Antioquia, Colombia). Revista de Neurología 31, 712-716.
[110] Tomicic, C., Vernez, D., Belem, T., Berode, M., 2011. Human mercury exposure associated with small-scale gold mining in Burkina Faso. International Archives of Occupational and Environmental Health 84, 539-546.
[111] Tschakert, P., 2009. Recognizing and nurturing artisanal mining as a viable livelihood. Resources Policy 34, 24-31.
[112] van Huyck, J.B., Battalio, R.C., Beil, R.O., 1990. Tacit coordination games, strategic uncertainty, and coordination failure. American Economic Review 80, 234-248.
[113] van Vuuren, D.P., Strengers, B.J., De Vries, H.J.M., 1999. Long-term perspectives on world metal use–a system-dynamics model. Resources Policy 25, 239-255.
[114] Veiga, M., 1997. Introducing New Technologies for Abatement of Global Mercury Pollution in Latin America. UNIDO/UBC/CETEM/CNP.
[115] Veldhuizen, R. Van, Sonnemans, J., 2011. Nonrenewable resources, strategic behavior and the Hotelling Rule: An Experiment. CREED Working Paper, University of Amsterdam.
[116] Vera, L.D., 2010. Construction d’une certification verte dans le secteur minier artisanal, une analyse à partir de l’approche des conventions et de l’ordre négocié. Le cas Oro verde. PhD Thesis, University of Montreal, Canada.
[117] Vergara, O., 2005. Minería y Dinámicas Regionales en Colombia. Universidad Externado de Colombia, Bogotá.
[118] von Humboldt Institute, 1999. Viabilidad de los instrumentos económicos para mitigar efectos negativos sobre la biodiversidad: La contaminación por mercurio en la región de La Mojana. Biosintesis 16, Colombia.
[119] West, R., 1972. La Minería de Aluvión en Colombia durante el Periodo Colonial. Universidad Nacional de Colombia, Bogotá.

Chapter 3
--
Phasing out mercury through collective action in artisanal gold mining: Evidence from a framed field experiment

Abstract
Several millions of people in the world are engaged in the extraction of gold with artisanal mining methods. However, the application of conventional practices such as mercury amalgamation makes this an economic activity with a high negative impact on health and the environment. Associative entrepreneurship has been proposed as a scheme that would bring cleaner technologies to miners, in order to phase out the use mercury in the gold recovery process and reduce the harmful environmental and health effects of using of this element. In this paper we investigate to what extent miners can establish and sustain an association of these characteristics. This is done by conducting a framed threshold public good experiment with miners. We test the effect of two different institutional arrangements on associative entrepreneurship: (i) exclusion, and; (ii) the interaction between internal communication and the intervention of a non-coercive authority –co-management–. Our subjects consist of artisanal and small-scale gold miners in Antioquia, Colombia. We found that miners made contributions that allowed the acquisition of the technology. However, this provision was not sustained and exhibited an oscillating pattern. We found that co-management led to high provision rates and players could achieve a long-lasting efficient level of individual contributions; but, on the contrary, exclusion did not trigger this kind of collective action. Policy implications of our results and avenues for further experimental research are discussed.

1. Introduction

Several millions of people in the world are engaged in the extraction of gold with artisanal mining methods (Spiegel and Veiga, 2005).[1] For most of them gold extraction is the most attractive or the unique livelihood activity (Siegel and Veiga, 2010). However, the application of conventional practices, mercury amalgamation being the most representative, makes artisanal and

---

[1] In this paper, the terms "artisanal mining" and "small-scale mining" are used interchangeably.

small-scale gold mining (ASGM) an activity with a high negative impact on health and the environment.[2] Even though cleaner, more productive, and financially viable technologies are available to miners (Pantoja et al., 2005; Hilson, 2006), mercury amalgamation and other rudimentary techniques continue to be massively used techniques for gold recovery in ASGM.

Technology choice for the gold recovery process in ASGM can be characterized as a social dilemma. The dilemma involves a trade-off where miners may tend to maximize short-run individual profits by choosing the cheapest and easy-to-handle available technique –mercury amalgamation–. However, in the long-run, the entire community, which includes him, is worse off than with the choice of a cleaner and more productive technology. In this context, the dilemma that artisanal gold miners face is not found in the extraction and availability of this non-renewable resource or in its depletion. Instead, the dilemma concerns the pollution resulting from the gold recovery process; i.e., a public-good dilemma.[3]

In order to tackle mercury pollution, there have been interventions in the form of training programs or environmental campaigns. Incentives to access alternative technologies have been also proposed or undertaken in different places. In fact, United Nations in 2002 launched the Global Mercury Project which is a capacity-building initiative, created with aim of "removing barriers to the adoption of cleaner practices of small-scale gold mining" (Spiegel and Veiga, 2005, p. 362). However, interventions must go beyond the presentation of technical solutions to the problems of mining and processing, and attention to economic and social issues should also be paid (Jennings, 2003). For instance, a complementary form of intervention would be in the promotion or strengthening of collective action through miners associations (Kazilimani et al., 2003).

By either collective action or associative entrepreneurship, in this paper we mean the creation of associations between small-scale gold miners to get more environmental-friendly technologies, in order to overcome the social dilemma that is present in the gold recovery process. The promotion of associative entrepreneurship has been on the policy agenda of governments and independent agencies working to improve the quality of life of ASGM communities (Saldarriaga-Isaza et al., 2013). This type of association allows not only to improve the relationship with the state, but also it would enable miners to accumulate the financial capital required to obtain cleaner and more productive technologies that are beyond the budget of most miner families (Hentschel et al., 2002; Hinton et al., 2003; Hilson and Potter, 2003; Heemskerk and Oliviera, 2004; CDS, 2004; Ghose and Roy, 2007; Spiegel, 2009). This financial capital is difficult to obtain from the

---

[2] More than a few effects on human well-being attributable to mercury pollution have been actually documented: neurological disorders ranging from loss of eyesight to tremors and paralysis, kidney damage and lung damages, and effects on the reproductive system (Tirado et al., 2000; Hilson and Pardie, 2006; Tomicic et al., 2011).

[3] In a public-good dilemma –pollution control in this case– people find it costly to contribute to the provision of the public good and prefer others to pay for its provision instead. If everybody follows this (equilibrium) strategy, the public good is underprovided or not provided, and pollution persists. However, the entire community may be better off if everyone contributes (Ostrom, 1998).

financial system, which perceives small-scale mining as a risky activity (Chaparro, 2003). This fact, added to the low tendency of miners to save money for investing (Saldarriaga-Isaza et al., 2013) would partially explain the low rate of adoption of cleaner technologies. Thus, associative entrepreneurship is therefore an option for small-scale miners to increase their financial capital.

In addition to the environmental benefits, alternative technologies would bring more productivity to miners that employ them in the gold recovery process. Hereinafter these additional profits will be referred to as private benefits in order to differentiate them from the public good benefits associated with the use of the cleaner technology. Despite of the advantages of associative entrepreneurship, aspects such as lack of communication and organization would hinder miners to reach those gains (Hinton et al., 2003). In this sense, it is then necessary to explore the effectiveness of institutions in fostering collective action that promote the adoption of cleaner technologies. Some of the main institutions that have been proven to have effects on collective action for the sustainable management of common-pool resources and public goods are as follow: external regulation (e.g., Cardenas et al., 2000; Dickinson, 2001); face-to-face communication (e.g., Ledyard, 1995; Ostrom, 2010), and; information disclosure (e.g., Ledyard, 1995; Smith, 2010).

In this paper we analyze the effect of two different institutional arrangements on associative entrepreneurship in ASGM using a framed field experiment. One of the institutions that we investigate is co-management. This institution is understood as the interaction between internal communication among community members and an external non-coercive party (Moreno-Sánchez and Maldonado, 2010). Moreno-Sánchez and Maldonado (2010) showed in a field experiment with fishermen of a marine protected area in Colombia, that co-management may perform better than other institutions such as only using internal communication among community members or only having an external (coercive) regulation.

External coercive regulation in ASGM may be unfeasible, due to widespread illegality and lack of operational resources for enforcement (Saldarriaga-Isaza et al., 2013). Thus, considering the difficulties of carrying out external coercive regulation, and the current policy context in which some external organizations are trying to encourage better practices in ASGM, we test the effect that co-management may have on associative entrepreneurship in ASGM and whether the effects of co-management found by Moreno-Sánchez and Maldonado hold in the case of ASGM.

Another institution we are interested in testing is the option that once a better technology is acquired and the public good is provided (lower mercury emissions), non-contributors are excluded from the private benefits that the technology providing the public good also generates. An institutional arrangement such as the exclusion from the benefits of a public good of those individuals who fail to meet a predetermined minimum contribution requirement, may lead to increases in contributions to the public good (Swope, 2002; Kocher et al., 2005; Croson et al., 2007; Bchir and Willinger, 2008). In general, the exclusion from the benefits of a public good reduces the individual incentives to free-ride, and generates Pareto-efficient outcomes. However, Swope (2002) argued that in environments in which individuals fail to coordinate their contributions, exclusion can decrease both contributions and welfare. Czap et al. (2010), for instance, found that subjects contributed more to the non-excludable compared to the excludable public good arguing therefore that in their case exclusion of non-contributors crowded out other-oriented preferences.

There are examples of goods that can be non-rival but somehow excludable in their consumption (Swope, 2002; Kocher et al., 2005): public facilities with controlled access such as parks and museums; or television broadcasts. In our case, we are not interested on the exclusion from the positive externalities stemming from the utilization of a cleaner technology. In ASGM this kind of exclusion may actually be unfeasible or costly. Instead, we focus on the exclusion from the private benefits an artisanal gold miner might obtain from the alternative technology: more productivity in the gold recovery process. The cleaner and more productive technology could be used in a centralized processing facility (Hilson, 2006), or done in a community-based development project. The exclusion of non-contributors would avoid this group of miners to benefit of recovering more gold in the ore beneficiation process. However, the exclusion would not avoid that these miners enjoy the benefits stemming from an improved environmental quality.

With the alternative technology, a subject might be tempted to free-ride; i.e., not to contribute but to enjoy the benefits of both a better environmental quality given by the lower mercury levels and higher profits given by the higher efficiency of the new technology in the recovery process. Assuming that those who do not contribute may be excluded from the benefits of getting higher profits, the incentives to free-ride would be only linked to the enjoyment of the benefits of a better environmental health. We would therefore expect the free-riding rate to decline under a scheme where it is possible to exclude free-riders from the enjoyment of the private benefits of a more efficient technology.

In order to get the more productive and cleaner technology for gold recovery, miners should contribute to a common fund to raise the minimum financial capital required to buy such technology. Given that there is neither exclusion nor rivalry in the positive externalities derived from the adopted technology for recovery of this mineral, we propose to carry out a framed threshold public good game (TPGG). In general, public good games are a useful tool for the analysis of organizational processes that entails dilemmas such as environmental protection or teamwork (Ledyard, 1995; Camerer and Weber, 2013). Participants in our experiments are artisanal and small-scale miners from the Northeastern region of the Department of Antioquia, Colombia. This is a region of particular interest. The mercury emissions to the environment registered there makes of this region the world’s highest per capita emitter of mercury from gold mining (Cordy et al., 2011).

The paper is organized as follows. In Section 2 we describe the hypotheses we want to test and the economic experiment. Then, in Section 3 we describe the experimental protocol and the study site. In Section 4, we present our main findings and results which mainly suggest that under co-management miners can achieve an efficient level of contributions that holds up until the end of the game. However, in the framework of our experiment, we do not find evidence that the exclusion may foster collective action in ASGM. Our conclusions as well as policy recommendations and avenues for further research are presented in Section 5.

2. Threshold Public Good Games: An Economic Experiment for ASGM

We run a framed field experiment in which artisanal gold miners must decide whether to contribute to the acquisition of cleaner and more productive equipment. In section 3 we offer a brief description of the equipment that was mentioned in the experiment.

In a TPGG, a minimum amount of money must be raised (provision point or threshold) for provision of the public good to occur (van de Kragt et al., 1983). Examples of threshold public goods are dikes and bridges, at a large scale; and at the organizational level some kind of initial investments in organizing the fundraising have to be made before any voluntary provision of a public good is possible (Schram et al., 2008). In the field, TPPGs has been used before to analyze contributions for the construction of a bridge in a Vietnamese village (Pham, 2011).

We have found two main approaches in the TPGG literature. There are games that restrict participants to binary (all-or-nothing) contributions (van de Kragt et al., 1983), and in others participants can contribute any desired amount of their endowment (Marks and Croson, 1998, 1999; Cadsby and Maynes, 1999). For the latter case, Cadsby and Maynes (1999) showed that permitting continuous contributions tends to increase the contributions to and facilitates provision of the public good.

For our experiment, we consider the results of Cadsby and Maynes (1999) and Cadsby et al. (2008) who consider a continuous TPGG with two institutional factors: a money-back guarantee (refund) and a no rebate rule if the level of contributions exceeds the threshold (T). On the one hand, if someone contributes but T is not reached, his contribution is refunded. According to Cadsby and Maynes (1999), this guarantee of getting money back may encourage contributions to and provision of the public. On the other hand, if the total amount of tokens contributed exceeds T, no one is paid back the exceeded amount. Marks and Croson (1998) found that no rebate and proportional rebate rules generate similar contributions, which are not statistically different from the Nash equilibrium level that is Pareto-efficient. However, Marks and Croson

(1998) also showed that the no rebate rule may be preferable to a proportional rebate rule in terms of equity and variability of contributions.[4]

In a TPGG there is not dominant strategy for any participant (Ledyard, 1995), but multiple efficient Nash equilibria in which the public good is provided, and inefficient equilibria in which it is not (Cadsby et al., 2008). Among the set of Nash equilibria there are two that are symmetric. One of these is a free-riding equilibrium (Cadsby and Maynes, 1999) in which everybody contributes nothing. Moreover, there is an equitable Pareto-efficient equilibrium, in which every one of the n participants contributes T/n such that the public good is provided. Both the free-riding equilibrium and the cost-sharing equilibrium may be focal points (Schelling, 1960) around which participants might tacitly coordinate and make their decisions of how much to contribute. Additionally, within the set of efficient Nash equilibria and under a no rebate rule, excess contributions are welfare reducing; i.e., group earnings are decreasing for group contributions beyond the provision point (Marks and Croson, 1998).

In order to test the effect of our two institutions of interest: (i) co-management and (ii) exclusion from private benefits derived from technology adoption, we use a 2x2 experimental design as presented in Table 3.1.

Table 3.1. Summary of Experimental Design.

		Exclusion from the benefits of more productivity No	Yes
Co-management	No	*Treatment 1* [T1]	*Treatment 2* [T2]
	Yes	*Treatment 3* [T3]	*Treatment 4* [T4]

Our control treatment, Treatment 1 (T1), is a standard TPGG with continuous contributions. In this treatment there is money-back guarantee if T is not reached and a no rebate if the level of contributions exceeds the threshold. Taking into consideration the fact that in the gold recovery process it is unlikely to see associations of miners (Hinton et al., 2003; Saldarriaga-Isaza et al., 2013), with this base case we can test our first hypothesis:

H1: *Sustained collective action does not emerge as a solution to the social dilemma faced by households engaged in ASGM.*

[4] There are several rules that can be used in a TPGG. Utilization rebate, proportional rebate, and no rebate rules are some of them (Marks and Croson, 1998). Spencer et al. (2009) discuss other different rules and found that in the provision of a threshold public good, a proportional rebate rule may be more useful among a set of rebate rules. However, in their analysis they do not consider the no rebate rule case.

In T1 each of the n members of a group has an initial endowment (E) of which he chooses to contribute $c_i \in [0,E]$ to the group account. If the sum of contributions is lower than T, the contribution is paid back to participants, the public good is not provided and hence the public and private benefits from the new equipment are not delivered. In this case each participant's payoff (U_i) equals the initial endowment:

$$\text{If } \sum_{i=1}^{n} c_i < T, \text{ then } U_i = E \qquad (3.1)$$

If the sum of contributions is higher than or equal to T, the technology is acquired with the consequent provision of the public and private benefits from the technology adoption. In this case the individual's payoff is composed by three factors: (i) the individual's earning from the private account that represents his private consumption in the experimental environment, which is given by $E - c_i$; (ii) the reward R, which represents the benefits of an improved environmental quality, and; (iii) ρ that represents the private profits from technology adoption. Both R and ρ are not excludable. In this case each participant's payoff is represented as follows:

$$\text{If } \sum_{i=1}^{n} c_i \geq T, \text{ then } U_i = E - c_i + R + \rho \qquad (3.2)$$

Provided that this game is representing a public-good dilemma, we must assume that $E<T<n.E$. Also, to be incentive compatible and socially efficient, it is necessary that $n.(R+\rho)>T$ (Cadsby et al., 2008). In our experiment we chose the following parameterization: E=25, T=60, n=5, R=16, ρ=8. This choice of the parameters is in line with previous TPPG experiments like Cadsby et al.'s (2008), in which the base step return, $n.(R+\rho)/T$ in this case, has been usually set at 2.[5]

Our second hypothesis is about excluding non-contributors from the private benefits of the alternative technology; thus, we design and implement treatment 2 (T2) for testing it. Our second hypothesis is as follows:

H2: *The exclusion of those miners who do not contribute to the provision of a cleaner and more productive technology from the private benefits* (*more productivity*) *derived from the technology that reduces a public bad* (*mercury pollution*), *triggers collective action.*

In T2, an individual may obtain the productivity return (ρ) only if he contributes to the project and the project is actually carried out. Those who do not invest in the project are excluded from

[5] According to Cadsby et al. (2008), the base step return is the best predictor of contributions in threshold public good games.

these profits, but still they receive the benefit of the positive externality (*R*). In this treatment the subject receives the payoff:

$$\text{If } \sum_{i=1}^{n} c_i < T, \text{ then } U_i = E \qquad (3.3)$$

$$\text{If } \sum_{i=1}^{n} c_i \geq T, \text{ then } U_i = E - c_i + R + \rho$$

where ρ=8 only if $c_i > 0$, and $\rho = 0$ otherwise; i. e. the parameters are the same as in T1. With this change in the conditions of the experiment, the free-riding equilibrium should change from contributing nothing to contributing one token.[6] With this treatment we can also know whether miner's preference for the technology is more due to its private benefits or it is social preferences that lead him to contribute to the amelioration of the public good.

In order to test the effect of co-management, we expand T1 to consider another mechanism for the management of this nonrenewable resource. Both the current policy context in which some external organizations are trying to encourage better practices in ASGM, and Moreno-Sánchez and Maldonado's (2010) results, lead us to our third hypothesis:

H3: *The intervention of a third party* (*co-management*) *is needed to promote a larger and well established association of miners that allows them to access to cleaner and more productive technologies.*

In our co-management treatment (T3) every group had the opportunity to talk up to five minutes with an external advisor, following Moreno-Sánchez and Maldonado (2010). The task of the advisor was to persuade miners to invest in the new technology, with the aim of reducing the emissions of mercury and avoiding the harmful effects of mercury pollution. More about the protocol of this treatment is presented in the next section.

Finally in our Treatment 4 we explore the interaction between the two institutional settings described and implemented in T2 and T3. Bowles and Polanía-Reyes's (2012) survey of behavioral experiments shows that interventions aimed at influencing behavior by altering the economic costs or benefits of some targeted activity –i.e., economic incentives– may undermine or trigger social preferences. Therefore, with T4 we want to test whether the effects of co-management are crowded in or crowded out by exclusion from the private benefits stemming from the cleaner technology.

[6] The level of minimum contribution in T2 was chosen to be simply above zero. Czap et al. (2010) pointed out that this condition removes strategic considerations in the game. Thus, even if a risk averse subject attaches a low probability of success for reaching the provision point, he would rationally contribute one token.

We implement both within and between subjects design. The within subjects design is implemented to analyze the effect of the institutional settings, in which every subject played the game for 17 periods: 8 initial periods of the base case (stage 1), and 9 periods in which subjects played one of 4 treatments as follows:

- T1: players continued playing the base case.
- T2: Exclusion treatment.
- T3: Co-management.
- T4: Exclusion and co-management.

This means that participants can be classified in four groups as follows: those who played the baseline and treatment with exclusion of the private benefits from technology adoption (T1-T2), those who played the baseline and the treatment with co-management (T1-T3) and those who played the baseline and the treatment with both co-management and exclusion of private benefits from technology adoption (T1-T4). Additionally, there were players who played T1 over all periods.

3. Experimental Procedure

All subjects recruited for this experiment were from the same subject pool: artisanal gold miners from the municipalities of Segovia and Remedios, in the Northeastern region of the Department of Antioquia, Colombia. This is the region with more production of gold in Colombia (UPME, 2012), and the largest world's mercury polluter per capita from artisanal gold mining according to Cordy et al. (2011).[7]

The experiment was a multi-period game but the number of periods was not indicated to participants in order to avoid end-of-game effects.[8] At the end of each period, using a piece of paper each participant was privately informed about total group contributions and of his payoff according to those contributions. This was done to avoid any bias that might arise from several groups in the same session being able to compare their contributions. The length of the experiment was about 2 hours.

[7] Remedios' total population is estimated at 23500, and total population in Segovia amounted to about 37500 inhabitants in 2012. The economy and culture of both towns revolve around gold mining at different scales of production. People directly engaged in ASGM in this zone are estimated in 13000 miners (UPME, 2006).
[8] Whilst one-shot games may eliminate the possibility of reputation effects and the strategic behavior that can exist in repeated-play experiments (Spencer et al., 2009), repeated games offer the possibility of learning. Despite of the examples included and training periods, the repetition of the game offer to players the possibility of getting familiarized with the game, including what the other subjects are like and their strategies (Ledyard, 1995; Cadsby and Maynes, 1999). Additionally, although with a threshold there are multiple equilibria, so the convergence question is fuzzy (Ledyard, 1995), repetition may allow the experimenter to see if players converge to certain type of equilibria (Cadsby and Maynes, 1999). Lastly, in the framework of our experiment, the acquisition of the technology may imply not only to contribute just once for buying it, but also several other times for its maintenance.

With the same population, the experiment was run using a classroom and in-situ in the mines. For the classroom experiments, players were recruited through a public call with the help of mining leaders and existing miners associations, flyers distributed in mines and processing plants, and messages that were transmitted from a local radio station. The total number of miners that attended this call was 35. The experimental sessions with these participants were run in classrooms of an education center in Segovia, the 23rd and 24th of November of 2012.

One week later, in order to increase the sample size of our experiment we also run sessions directly in some of the mines; which is the in-situ experiment. Due to security reasons, in this opportunity we just got 4 out of 25 phone calls to mine managers answered. By the time the experiment was run, illegal armed groups were extorting mine managers by making phone calls. Fifty miners could additionally be recruited with this strategy, totalizing eighty-five subjects for the complete experiment. In the parametric analysis we included a dummy variable to identify the possible effect of this procedure. Table 3.2 reports the number of players by treatment.

Table 3.2. Number of players by treatment.

Treatment	*No.*
Baseline	10
Exclusion	30
Co-management	20
Exclusion & Co-management	25

In each session we randomly formed up to four groups of five members each. In each five-person group every member knew both the size of the group and who the other members were, and made individual decisions of how much of his endowment, expressed in tokens, would allocate to a private account and a group account. Instructions were read aloud by the experimenter in all experimental sessions. All the individual decisions were private and confidential, and were made anonymously. In the initial sessions, to guarantee the confidentiality of their decisions players were seated back-to-back. To facilitate and ensure understanding of the game, three hypothetical examples were provided. Also, there were three training periods in which participants made decisions that did not affect their final payment.

The instructions of our framed experiment adhered to the basic language of the instructions developed by Isaac et al. (1984) (see instructions in Appendix A). These instructions have been commonly utilized in several other experiments about public good games with provision point (Croson and Marks, 2000, 2001; Marks and Croson, 1998, 1999; Cadsby et al., 2008). As part of the framework of these instructions, we introduced a statement that described the kind of equipment that has been promoted among miners and processing facilities to phase-out mercury: continuous mills and methods of gravimetric concentration. These specific technologies are recognized for being cleaner than mercury amalgamation, and more productive than the traditional ball mills currently employed in the gold recovery process (García and Molina, 2011).

The protocol of the co-management treatment (T3) adhered to the instructions of Moreno-Sánchez and Maldonado (2010). In this treatment, the conversation with the external advisor is based on a predesigned guideline, but not a script that the advisor must always read (see the guideline provided to the advisor in Appendix B).[9] The advisor, a representative of the Global Mercury Project, was asked to persuade miners to invest in the new technology, with the aim of reducing the emissions of mercury and avoiding the harmful effects of mercury pollution. After this discussion, the group had five minutes to converse among themselves. The advisor was not allowed to listen to this conversation. After this, group members made their final decisions in private and under strict confidentiality for the first period of the second stage of the game. Additionally, based on Moreno-Sánchez and Maldonado (2010), the external advisor was given one minute to talk with the group for each successive period of the game, thereafter, the group members had one minute to talk.

Payments to participants in the experiment were done individual and privately. Every participant was identified with a number that was provided in a slip of paper at the beginning of the experiment. To collect his payment, the player should give back this slip of paper individually at the end of the session, receiving in exchange a sealed envelope with his payment. In the game, each token gained by a miner was converted into 72 Colombian pesos. This value was computed bearing in mind participants' average opportunity cost of time and the maximum and minimum amount of tokens each participant could gain in the game. The total payment to each individual could vary between COP$35000 and COP$60000.[10]

At the end of each session, and before the payment was done, we asked every player to fill out a survey. The answers to these questions were meant for interpretation of the results of the experiment. Besides some specific socioeconomic and demographic information such as education and income levels, we also asked questions about perceptions miners have about the gold recovery process.[11] Additionally, attitudes towards risk, trust and two personality traits (empathy and self-control) were measured in this survey. Previous literature suggests that these four attributes may affect contributions to public goods (Kocher et al., 2011, 2012; Czap and Czap, 2010; Czap et al., 2010). The attributes were measured as follows:

[9] According to Moreno-Sánchez and Maldonado (2010), this way of communication allows the advisor to express his ideas about what kind of strategy is better for the group. These authors argue that such as source of variance may be relevant when thinking about the policy implications of the implementation of co-management.

[10] The exchange rate at the time of the experiment was approximately 1US$ equals 1815 Colombian pesos.

[11] Anderies et al. (2011) suggest that the best time to gather debriefing data that help to interpret individuals' decisions during the experiment is right after decisions have been made but before their consequences are known to the participants.

- *Risk*: Dohmen et al. (2011) and Ding et al. (2010) have found that a simple risk question may predict results of risk measures obtained in economic experiments.[12] We followed Dohmen et al. (2011) and asked participants in our experiment to indicate their willingness to take risks on an eleven point scale, with zero indicating complete unwillingness to take risks, and ten indicating complete willingness to take risks. The question was as follows: "How do you see yourself: 'Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?'."

- *Trust*: Naef and Schupp (2009) and Ben-Ner and Halldorsson (2010) argue that survey measures of trust are significantly correlated with the measure of trust obtained in a trust game. Considering these results, we asked subjects to answer to the statement for measuring trust found in surveys like the General Social Survey: "Generally speaking, would you say that most people can 'be trusted or that you can't be too careful in dealing with people?'."

- *Self-control* and *empathy*: In the questionnaire, each subject specified his level of agreement to several statements taken from the International Personality Item Pool inventory (Goldberg et al., 2006), using a 5-item Likert scale, ranging from the highest of "Completely Agree" to the lowest of "Completely Disagree". The scores for each personality trait are calculated as the mean of these answers.

4. Results and Discussion

4.1 General description

Table 3.3 summarizes the descriptive statistics of socioeconomic and demographic characteristics of participants in the game. Perceptional characteristics and attitudinal variables are included. In general, there are not differences between subjects who participated in the experiments.[13] These participants were adults with low education, earnings between 1 and 2 local minimum wages, most of them living in either Segovia or Remedios for more than two decades. Despite the fact that a big proportion of miners know methods for gold recovery different to mercury amalgamation, few of them employ such methods. Those who stated a reason for not employing those alternative methods said that it is because they cannot afford that kind of equipment. Furthermore, even though most of the participants stated that training programs for better practices in mining are useful, few of them have taken part in those sessions.

[12] See, for example, Holt and Laury (2002) for an economic experiment in which risk is measured.
[13] In our comparisons we follow the standard procedure of testing the null hypothesis of equality versus a hypothesis of strict inequality. We performed a t-test of difference in means and the Mann-Whitney-Wilcoxon (MWW) Z-test. Both tests coincided with each other in their results. In this paper we only present the results for the MWW test.

Figure 3.1 shows average group contributions across treatments. Consistent with previous TPGGs (Croson and Marks, 2000), the oscillating pattern around the efficient Nash equilibrium outcome (60 tokens) is observed in the baseline (see T1 and periods 1 to 8 in T2, T3 and T4). This pattern is less evident when co-management is applied (T3); in fact, from periods 9 to 17 in T3 players try to coordinate their actions on the efficient contribution level of 60 tokens. Regarding exclusion (T2), the oscillating pattern observed in the baseline remains, even when it is combined with co-management (see periods 9 to 17 in Figure 3.1). We can also discern the differences between these treatments in Figure 3.2. This figure shows an example of individual contributions in a chosen group of miners that played T3 and another group that played T4.

In order to gain more insights from these results, in the next two subsections we provide tests of the hypotheses above. Firstly, we discuss the provision of the public good in the game and the effect of the mechanisms on contributions. In the analysis of contribution decisions we then do a multivariate analysis in order to understand the decisions of players in this type of game.

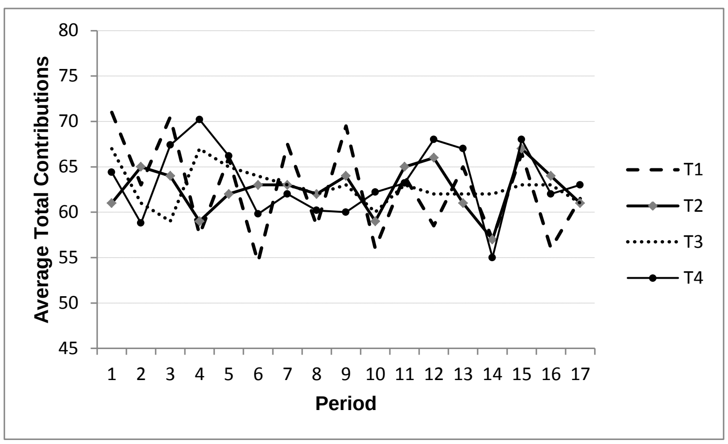


Figure 3.1. Average group contributions in treatments.

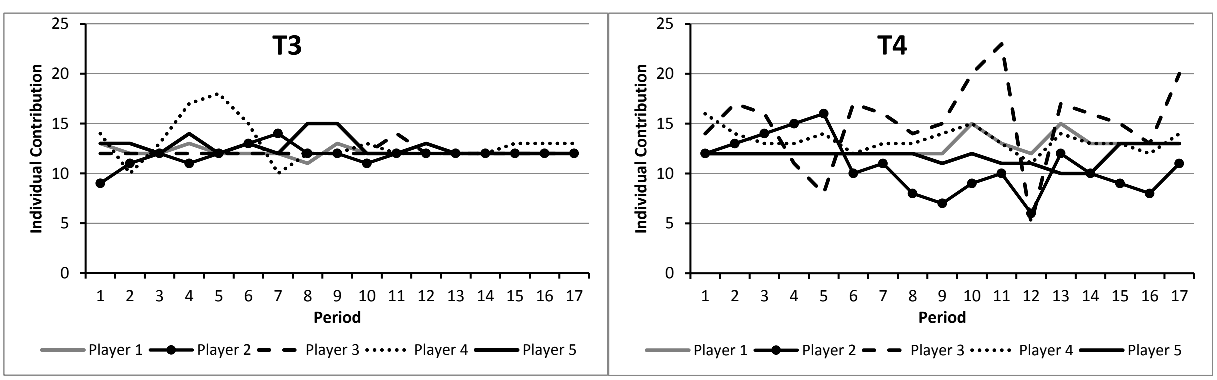


Figure 3.2. Example of individual contributions in treatments T3 and T4.

Table 3.3. Description and test of differences between treatments of socioeconomic and perception variables.

	Pooled data			Mean				Differences					
Variable	**Mean**	**Min**	**Max**	**T1**	**T2**	**T3**	**T4**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**
Socioeconomic Variables													
Age (years)	32.39 (10.6)	16	58	30.6 (11.2)	31.4 (8.5)	37.6 (12.7)	28.4 (8.5)	n.s.	n.s.	n.s.	*	n.s.	***
Education[a]	3.59 (3.6)	1	7	4.4 (1.8)	2.8 (1.5)	3.92 (1.9)	4 (1.7)	**	n.s.	n.s.	**	**	n.s.
Income[b]	3.42 (3.4)	1	8	3 (2.91)	3.1 (1.38)	3.28 (2)	4 (1.1)	n.s.	n.s.	*	n.s.	**	**
Residence Time in Town (years)	22.6 (13.1)	1	57	23.4 (9.2)	25.7 (11.9)	21.5 (14.7)	19.8 (13.1)	n.s.	n.s.	n.s.	n.s.	*	n.s.
Perception Variables													
Knowledge of alternative methods for gold recovery? (1 yes 0 no) (*Know_new_tech*)	0.76 (0.47)	0	1	0.8 (0.45)	0.73 (0.45)	0.72 (0.46)	0.84 (0.37)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Limitations in access to better equipment? (1 yes 0 no) (*Limitation_in_access)*	0.52 (0.5)	0	1	0.6 (0.55)	0.6 (0.49)	0.52 (0.5)	0.4 (0.5)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Have you operated alternative methods for gold recovery? (1 yes 0 no) (*Have_used_ tech*)	0.4 (0.49)	0	1	0.6 (0.55)	0.4 (0.49)	0.4 (0.5)	0.36 (0.49)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Have you participated in any training session for better practices in ASGM (1 yes 0 no) (*Participation_in_training*)	0.44 (0.5)	0	1	0.4 (0.24)	0.3 (0.09)	0.48 (0.5)	0.52 (0.5)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Is this training useful? (1 yes 0 no) (*Participation_is_useful*)	0.98 (0.15)	0	1	1 (0)	1 (0)	0.92 (0.28)	1 (0)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Have you or anyone you know suffered any mercury-related disease? (*Health_effects*)	0.53 (0.5)	0	1	0.2 (0.45)	0.63 0.49)	0.52 (0.51)	0.48 (0.51)	*	n.s.	n.s.	n.s.	n.s.	n.s.
Attitudinal variables													
Risk	6.58 (2.72)	0	10	8.8 (1.3)	5.9 (2.36)	6.63 (3.21)	6.88 (2.65)	**	n.s.	n.s.	n.s.	n.s.	n.s.
Can people be trusted? (1 yes 0 no) (*Trust*)	0.39 (0.49)	0	1	0.2 (0.45)	0.37 (0.49)	0.5 (0.51)	0.36 (0.49)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Empathy	3.45 (1.15)	1	5	4.4 (0.5)	3.2 (1.36)	3.99 (0.66)	3.13 (1.1)	**	n.s.	***	**	n.s.	***
Self-control	2.6 (0.9)	1	5	3.5 (0.97)	2.5 (1.1)	2.67 (0.55)	2.48 (0.8)	*	*	*	n.s.	n.s.	n.s.

[a] Education is measured in levels depending whether primary, secondary, technical or college education had been completed or not.
[b] Income is measured in levels ranging from half a minimum wage to six minimum wages.
*** significant at 1%, ** significant at 5%, * significant at 10%, [n.s.] non-significant. Standard deviations in parentheses.

4.2 Successful provisions and treatment effects

Table 3.4 summarizes the proportions of successful provisions and percentage of efficient Nash equilibrium outcomes in the four treatments. In all treatments, and consistent with results of other TPGGs made in the lab (Croson and Marks, 2000), the provision occurs frequently. In the stage 1, more than 80% of the times the threshold is reached, except in the baseline where the provision rate is 57%. In stage 2, the provision rate falls to about 70% which can be explained by decreasing contributions, and the Nash equilibrium of 60 tokens is barely reached by groups. In contrast, under the co-management treatment (T3) the public good is provided most of the time and players try to coordinate their actions in order to reach the efficient outcome.

Table 3.4. Proportion of successful provisions by stage.

Stage	Treatment			
	Baseline	T2	T3	T4
Stage 1	57.14%	85%	82.1%	86.7%
Stage 2	75%	78.9%	92.5%	69%
Difference	17.85%	-6.1%	10.36%	-17.7%
MWW test	0.45	0.314	1.1	1.08
% of Efficient Nash Equilibria	2.9	3.3	52.5	0

In all treatments, the difference in the provision rates between stages 1 and 2 is not statistically significant. Individual contributions are always close to or around 12; therefore, a test of means may not show the whole effect that each treatment has on the decisions taken by players in the experiment. To complement this analysis, in this section we also present an analysis of the standard deviations of contributions. In Tables 3.5 and 3.6 we present the results of these analyses, respectively.

In general, there is a difference of the contributions done by players in T3 with those done in other treatments. Table 3.5 shows that average contributions in T3 tend to be more closely to the cost-sharing equilibrium (12 tokens), while average contributions in the other treatments are greater than 12. Contrary to linear public good games in which monotonically increasing contributions are preferred over low contributions levels, the goal in a threshold public good is to reach the provision point. Contributions beyond the provision point are not efficient and welfare decreasing for the group (Marks and Croson, 1998). Therefore, for the case of ASGM, we can argue that efforts to achieve associative entrepreneurship with long-term perspective can be more efficient with an institutional arrangement such as co-management. Moreover, the effect that exclusion has on individual contributions appears to be worthless and not different from the baseline. In the latter case, players fail to achieve a long-lasting collective action.

Table 3.5. Average contributions for each treatment and non-parametric test for differences in means.

Treatment	Mean	P-value of the MWW test				
		T1 – T2	T1 – T3	T1 – T4	T2– T4	T3– T4
Baseline (T1)	13.34	0.7173	0.0038***	0.6008	0.4707	0.0735*
Exclusion (T2)	13.52					
Co-management (T3)	12.67					
T2 & T3 (T4)	13.04					

***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively.

Table 3.6 shows that the average standard deviation of the contributions per period is significantly lower when co-management occurs, even lower than the case in which exclusion is applied (*p-value*<0.001). Nonetheless, when exclusion and co-management are combined (T4), the standard deviation is much higher than in treatments T2 and T3 (*p-value*<0.001). In fact, results from Tables 3.5 and 3.6 suggest that when players can communicate with each other in the group and can count on the support of a third party, decisions are much closer of being optimal: everyone chooses a fair contribution, including original free-riders, and the public good is regularly provided. This result might be partially explained by members of the group who played the role of leaders. In co-management we could observe that one or two individuals in the group tried to point out the features of the social dilemma and suggested the way of better dealing with it: to make fair contributions to buy the technology. Our finding is comparable to Moxnes and van der Heijden's (2003) who showed that the actions of a leader may persuade other members of the group to desist from making investments in a public bad.

We also observe that the aforementioned effect of co-management is undermined when combined with exclusion. This finding is consistent with other studies of behavior in common-pool resources dilemmas. Ostrom (2006), for instance, provides an overview of this literature and shows the critical importance of communication and endogenous rule formation on the sustainable management of these resources, and the adverse effect that coercive rules may have on such management. Moreover, we find that although the threat of being excluded from the total benefits of the alternative technology does increase mean contributions, such a raise is not significant either from a statistical viewpoint or for the provision of the technology.

Table 3.6. Average standard deviations of individual contributions per period for each treatment and non-parametric test for differences in standard deviations.

Treatment	Mean of s.d.	P-value of the MWW test				
		T1 – T2	T1 – T3	T1– T4	T2– T4	T3– T4
Baseline (T1)	2.69	0.0000***	0.0000***	0.2776	0.0000***	0.0000***
Exclusion (T2)	2.04					
Co-management (T3)	1.42					
T2 & T3 (T4)	3.2					

***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively.

Our results thus indicate that under co-management subjects can engage in a well-established association that remains during periods. Under this association not only the technology is acquired and the public good provided, but also each player supports this provision on equal terms. The independent effects that communication among members and the intervention of an external party have on individual contributions cannot be disentangled from these results. Nonetheless, considering Moreno-Sánchez and Maldonado's (2010) result and ours, co-management can be thought as a suitable rule to achieve sustained and successful provision of threshold public goods.

With respect to the exclusion treatment, results from our paper would not support previous findings from other experiments (Swope, 2002; Kocher et al., 2005; Croson et al., 2007; Bchir and Willinger, 2008). Even though the threat of exclusion may initially trigger individual contributions (see Figure 3.1), such a rise is not sustained and the oscillating pattern observed in the baseline carries on. This effect is observed even when this mechanism is combined with co-management. In other words, although co-management alone lead the miners to better manage the production process and their resources, the pressure generated in the exclusion case, would make it difficult to subjects to reach the coordination needed to achieve a sustained efficient outcome.

4.3 Individual contributions

We performed a parametric analysis by modeling individual contribution for each period. Given that there are observations of individual contributions for several periods, data are treated as a panel. The estimated model considers the fact that the dependent variable only takes discrete values, and that the individual specific constant terms of the model are randomly distributed across the cross-sectional units, where the sample units are drawn from a population (Greene, 2000).[14] Hence, we use the Poisson regression with random-effects. The Poisson regression assumes that the mean and the variance of the count variable are the same. Alternatively, the negative binomial model allows for over-dispersion. We estimated both type of models and we observed that the results coincided with each other, what suggest that there is no problem of over-dispersion. Of these two only the estimations of the Poisson model are reported. Additionally, we ran an OLS random effects regression.

[14] In other public good experiments authors such as Carpenter (2007) and Spencer et al. (2009) have estimated two-limit Tobit models because the individual contributions have been assumed as a variable that is double-censored (from above and below). To consider individual contributions as a censored variable means, for instance, that a player would be willing to make contributions greater than which is allowed, and that those censored values are not observed. However, the conditions of the game actually limit the range of values that this variable can take. Therefore, the censoring assumption does not seem to be plausible inasmuch as the values that the level of individual contributions can take are perfectly observable in the experiment. We also ran a two-limit Tobit model and got results that mismatch results from Poisson and OLS models. For instance, significant parameter estimates for treatment effects are negative, meanwhile for trend is positive.

The explanatory variables are socioeconomic and demographic characteristics, perception variables, and attitudinal variables. Dynamic and treatment variables are also included in the behavioral model. The dynamic variables include the total contributions of the other four members of the group in the previous period ($\Sigma_{j\neq i,\ t-1}$), the difference between group contribution and the threshold also in the previous period (Difference_{t-1}), interactions among these two variables, and a variable that captures the time trend (*Trend*). The inclusion of the dynamic variables is mainly intended to capture how individual behavior may depend upon past group behavior; i.e., to evaluate whether subjects show reciprocity or altruism across the game (Croson, 2006). Moreover, to test the impact of the different rules on individual contributions we introduce three categorical variables (T2, T3, T4), which take binary values; one if the player was exposed to the treatment, and zero otherwise. The estimations results, which were estimated in STATA™, are presented in Table 3.7.

From the estimations, Poisson and OLS specifications generate similar results. Consistent to results of section 4.2, T3 and T4 do not have a statistically significant effect on the level of contributions. Conversely, the threat of exclusion (T2) can raise contributions somewhat, but as we mentioned above, such a rise is not long-lasting. Nonetheless, the main effect of the treatments can be seen in the variability of contributions overtime. In Table 3.8 we present the results of an OLS model with the standard deviations of individual contributions as dependent variable. In this case, all institutional arrangements, except T4, are statistically significant in downgrading the variability of contributions, that is, in putting players to agree each other on what the best level of contributions is. Such effect is stronger with co-management (T3).

Table 3.7. Results of specifications of random effects models.

Variable	Poisson panel model		OLS panel model	
	Coef.	t-value	Coef.	t-value
Trend	-0.009**	-2.43	-0.131***	-2.77
T2	0.069	1.62	1.411***	2.85
T3	0.019	0.44	0.355	0.71
T4	0.033	0.77	0.719	1.41
$\Sigma_{j\neq i,\ t-1}$	-0.019***	-5.72	-0.515***	-11.2
Difference_{t-1}	0.0001	0.03	0.196***	2.89
$\Sigma_{j\neq i,\ t-1}$ * Difference_{t-1}	0.0003***	3.82	0.004***	3.55
Residence Time	0.002	0.9	0.012	1.01
Age	0.001	0.61	0.023	1.3
Income	0.02	1.37	0.199**	2.37
Education	-0.012	-0.78	-0.049	-0.49
Know new tech.	0.106**	2.01	0.92**	2.41
Limitation in access	0.018	0.4	0.393	1.34
Have used tech.	-0.108**	-2.15	-1.064***	-2.93
Participation in training	0.016	0.33	0.22	0.74
Participation is useful	-0.046	-0.25	-0.924	-0.83
Health effects	-0.137***	-3.12	-1.716***	-6.02
Risk	0.012	1.4	0.113**	2.16
Trust	0.054*	1.69	0.715**	2.5
Empathy	-0.006	-0.23	-0.085	-0.51
Self-control	0.025	0.67	0.387	1.48
Mine	0.015	0.26	0.008	0.02
Constant	3.356***	12.01	36.343***	13.78
Observations	85		85	
Wald chi2(k)	88.58***		356.34***	

*** significant at 1%, ** significant at 5%, * significant at 10%.

Table 3.8. OLS model of treatment effects on standard deviation of c_i.

Variable	Coef.	t-value
T2	-0.327*	-1.83
T3	-1.697***	-7.86
T4	0.106	0.51
Trend	0.084***	5.18
Constant	3.117***	14.63
Wald chi2(k)		93.95***

*** significant at 1%, ** significant at 5%, * significant at 10%.

With respect to the dynamic variables, the negative sign of *Trend* denotes that individual contributions are decreasing over time, which is consistent with other linear and threshold public good games (Ledyard, 1995; Croson and Marks, 2000). Moreover, we found that the previous tokens contributed by the other members of the group have an effect on the individual decisions. In linear public good games, the positive sign of the coefficient of contribution of others has been interpreted as reciprocity, whereas the negative sign as altruism (Croson, 2006). Thus, the negative sign of the coefficient of this variable ($\Sigma_{j\neq i,t-1}$) in our experiment would indicate altruism instead of reciprocity. However, in this case we must bear in mind that each subject also has the goal of reaching the threshold so that the technology can be bought and the public good provided. Hence, the positive sign of the interaction term of others' previous contributions ($\Sigma_{j\neq i,t-1}$) and the difference between past total contributions and T ($Difference_{t-1}$) suggests that given a difference between Σ_{t-1} and T, higher contributions of other players trigger higher allocations of tokens to the group account. In other words, in this game players reciprocate.

This notion of reciprocity can be supported with the following statement that one of the participants wrote down in a section for observations in the final questionnaire:

"*Initially I decided to allocate cost-sharing contributions and see what the other partners did. There were always partners who contributed few, but I kept trying contributing more tokens so the technology could be provided and obtain its benefits. However, later on I decided to reduce my contributions in order to send the message that everybody should make similar contributions, and that reducing contributions is not profitable for the group*." (Player 3, Session 6, T2).

Econometric analysis is also consistent with literature according to which the level of trust in others someone has positively determine social capital and cooperation, and therefore subject's concern for the provision of the public good (Czap and Czap, 2010; Czap et al., 2010; Kocher et al., 2011).

Some studies have shown that risk-averse individuals might make lower contributions to the public good if they anticipate others' contributions as low. A decision of this kind would compensate for the risk of others not contributing (Kocher et al., 2011). Evidence of this relationship can be found, for instance, in the study by Charness and Villeval (2009). These authors showed that subjects who invest more in a risky asset are more willing to cooperate in a public good game. Similarly, Sabater-Grande and Georgantzis (2002) and Kocher et al. (2012) found that risk-aversion relates negatively with the frequency of collusive outcomes in social dilemma situations. This positive correlation between risk-love and cooperation is, however, unclear from our parametric analysis. The coefficient of this variable is significant in the OLS model (*p-value*<0.005), whereas in the Poisson model is not significant at all. Our result are consistent with Kocher et al.'s (2011), who did not get any significant effect of their measure of risk on contributions in a one-shot public good game.

Czap and Czap (2010, p. 2035) suggest that the subject's decision to contribute to the provision of a public good would depend on his "ability to walk in the shoes of those who suffer from the problem, i.e. on empathy." In addition to this personality trait, self-control would also be related to contributions to public goods (Czap and Czap, 2010; Czap et al., 2010; Kocher et al., 2012). According to this literature, more impatient subjects may exhibit less levels of cooperation in the presence of a social dilemma. In our experiment, however, personality traits such as empathy and self-control did not have any effect on the contributions miners made.

Finally, our results suggest that knowledge of alternative technologies a priori (*Know_new_tech*) has positive implications for the contributions to the common fund. However, the negative sign of *Have_used_tech* suggest that lack of operation of or familiarity with any of this equipment (see Table 3.3) make less likely that miners contribute to the acquisition of the technology. Lastly, a counterintuitive result that we got from these estimations is that when someone has or knows someone else has suffered mercury-related diseases (*Health_effects*), his contributions marginally decreases.

5. Conclusion

In this paper we explored the role of two institutional arrangements on associative entrepreneurship in order to phase out mercury in ASGM, via a framed experiment with miners from Colombia. In this experiment, we have found empirical support for our first hypothesis, which states that sustained collective action does not emerge as a solution to the social dilemma faced by households engaged in ASGM. In the baseline, we obtained that total contributions exceeded the provision point, but this provision was not sustained and exhibited an oscillating pattern.

In contrast, co-management effected collective action in the experiment. We combined communication among members and the intervention of an external party; such combination led to a rise in the provision rate and a better coordination of players that allows them to attain an efficient level of individual contributions. This finding supports hypothesis H3: co-management encourages a larger and well established association of miners that allow them to access to cleaner and more productive technologies.

We also tested the effect of exclusion from private benefits of the alternative technology on fostering a well-established collective action (H2); experimental results did not support this hypothesis. Despite the fact this arrangement led to an initial increase in contributions, they rapidly fell followed-up by the oscillating pattern observed in the baseline. The extent to which the size of the private benefits affects the impact of this institutional arrangement on associative entrepreneurship is a question that is left for future research.

To some extent miners are aware of the harmful effects of employing mercury in the gold recovery process. Switching to cleaner technologies can be, however, hampered if miners do not develop trust by, for instance, communication among them. Communication and the support from external parties could help to break out the vicious cycle miners are trapped due to, among other things, mercury utilization. Thus, the external intervention can take several forms: training in the operation of new equipment, education programs, and other policies that focus on the access and switch to better practices, and campaigns to foster social capital.

In this study we tested alternative rules in a TPGG. To our knowledge, in the literature this is the first economic experiment that is done with communities involved in ASGM, and one of the few TPPGs done in the field. This study opens the door for further field research with a topic that has received little research in the economic literature; but very important for the economic activity of many miners. This is particularly relevant nowadays when efforts to phase-out mercury from ASGM and other sources of mercury pollution worldwide are taking place (Qiu, 2013). Rather than thinking on coercive policies such as ban on the mercury trade, other policies could be implemented or at least assessed using, for instance, the methods that experimental economics offers.

Further research is needed to test other mechanisms and institutions that help these mining communities to improve their production process and alleviate poverty. For instance, the role of leaders might be essential in persuading other subjects to change behavior in the context of the public-good dilemma (Moxnes and van der Heijden, 2003). Leaders' tendencies to adopt better practices might encourage fellows of his social network to do the same. Such tests might be done by using experimental economics.

Other real life components that could drive decision-making in a public-good dilemma are access to credit, and norms such as how others would treat people who do not contribute, how individuals care about other's income, and the armed conflict that surround these communities. Alpizar et al. (2005), for instance, show evidence that the income of others affects one's own subjective well-being and then human decision making. There is also experimental evidence that shows that inequality affect decisions in public-good dilemmas (see, e.g., Cárdenas et al., 2002). In general, there are many other factors that drive behavior in common-pool resources experiments (see, e.g., Ostrom, 2010). In this sense, there is broad space for future research not only in the analysis of decision-making in artisanal gold mining but also in the assessment of institutions to improve the well-being of these communities.

References

[1] Alpizar, F., Carlsson, F., Johansson-Stenman, O., 2005. How much do we care about absolute versus relative income and consumption? Journal of Economic Behavior & Organization 56(3), 405-421.

[2] Anderies, J., Janssen, M., Bousquet, F., Cardenas, J., Castillo, D., Lopez, M.C., Tobias, R., Vollan, B., Wutich, A., 2011. The challenge of understanding decisions in experimental studies of common pool resource governance. Ecological Economics 70, 1571-1579.

[3] Ben-Ner, A., Halldorsson, F., 2010. Trusting and trustworthiness: What are they, how to measure them, and what affects them. Journal of Economic Psychology 31(1), 64-79.
[4] Bchir, M., Willinger, M., 2008. Provision of club goods in the lab, in: Hartani, T., Douaoui, A., Kuper, M. (Eds.), Economies d'eau en systèmes irrigués au Maghreb. Actes du quatrième atelier régional du projet Sirma, Mostaganem, Algérie. Cirad, Montpellier, France, pp. 1-20.
[5] Bowles, S., Polanía-Reyes, S, 2012. Economic incentives and social preferences: Substitutes or complements? Journal of Economic Literature 50(2), 368-425.
[6] Cadsby, C., Maynes, E., 1999. Voluntary provision of threshold public goods with continuous contributions: experimental evidence. Journal of Public Economics 71(1), 53-73.
[7] Cadsby, C., Croson, R., Marks, M., Maynes, E., 2008. Step return versus net reward in the voluntary provision of a threshold public good: An adversarial collaboration. Public Choice 135(3-4), 277-289.
[8] Camerer, C., Weber, R., 2013. Experimental organizational economics, in: Gibbons, R., Roberts, J. (Eds.), Handbook of Organizational Economics. Princeton University Press, Princeton, pp. 213-262.
[9] Cardenas, J.C., Stranlund, J., Willis, C., 2000. Local environmental control and institutional crowding-Out. World Development 28(10) 1719-1733.
[10] Cárdenas, J.C., Stranlund, J., Willis, C., 2002. Economic inequality and burden-sharing in the provision of local environmental quality. Ecological Economics 40, 379-395.
[11] Carpenter, J.P., 2007. Punishing free-riders: How group size affects mutual monitoring and the provision of public goods. Games and Economic Behavior 60, 31-51.
[12] CDS -Centre for Development Studies-, 2004. Livelihoods and Policy in the Artisanal and Small-Scale Mining Sector -An Overview. University of Wales Swansea, UK.
[13] Chaparro, E., 2003. Small-scale mining: a new entrepreneurial approach. CEPAL, Serie Recursos Naturales e Infraestructura No. 9.
[14] Charness, G., Villeval, M.C., 2009. Cooperation and competition in intergenerational experiments in the field and the laboratory. American Economic Review 99(3), 956-978.
[15] Cordy, P., Veiga, M., Salih, I., Al-Saadi, S., Console, S., Garcia, O., Mesa., L.A., Velásquez-López, P., Roeser, M., 2011. Mercury contamination from artisanal gold mining in Antioquia, Colombia: The world's highest per capita mercury pollution. Science of the Total Environment 410-411(1): 154-160.
[16] Croson, R., 2006. Theories of commitment, altruism and reciprocity: Evidence from linear public goods games. Economic Inquiry 45(2), 199-216.
[17] Croson, R., Marks, M., 2000. Step returns in threshold public goods: A meta- and experimental analysis. Experimental Economics 2(3), 239-259.
[18] Croson, R., Marks, M., 2001The Effect of recommended contributions on the voluntary provision of public goods. Economic Inquiry 39(2), 238-249.
[19] Croson, R., Fatas, E., Neugebauer, T., 2007. Excludability and Contribution: A Laboratory Study in Team Production. Working Paper, University of Texas-Dallas.
[20] Czap, H.J., Czap, N.V., 2010. An experimental investigation of revealed environmental concern. Ecological Economics 69(10), 2033-2041.

[21] Czap, H.J., Czap, N.V., Bonakdarian, E., 2010. Walk the talk? The Effect of voting and excludability in public goods experiments. Economics Research International 15, 1-15.
[22] Dickinson, D.L., 2001. The carrot vs. the stick in work group motivation. Experimental Economics 4, 107-124.
[23] Ding, X., Hartog, J., Sun, Y., 2010. Can We Measure Individual Risk Attitudes in a Survey? Discussion Paper No. 4807, IZA, Germany.
[24] Dohmen, T., Huffman, D., Schupp, J., Falk, A., Sunde, U., Wagner, G., 2011. Individual risk attitudes: Measurement, determinants, and behavioral consequences. Journal of the European Economic Association 9(3), 522-550.
[25] García, O., Molina, J., 2011. Avances en la solución de impactos ambientales causados por la minería aurífera artesanal en el Nordeste de Antioquia, in: Barrezuela, E., Domínguez-Cuesta, M. (Eds.), Técnicas Aplicadas a la Caracterización y Aprovechamiento de Recursos Geológico-Mineros. Red Minera XXI, CYTED, Instituto Geológico y Minero de España, pp. 40-50.
[26] Ghose, M., Roy, S., 2007. Contribution of small-scale mining to employment, development and sustainability – an Indian scenario. Environment, Development and Sustainability 9(3), 283-303.
[27] Goldberg, L.R., Johnson, J.A., Eber, H.W., Hogan, R., Ashton, M.C., Cloninger, C.R., Gough, H.C., 2006. The international personality item pool and the future of public-domain personality measures. Journal of Research in Personality 40(1), 84-96.
[28] Greene, W.H., 2000. Econometric Analysis. Prentice-Hall, New Jersey.
[29] Heemskerk, M., Oliviera, M., 2004. Perceptions of Small-Scale Gold Miners on Self-Organization and Formalization in Suriname, South America. GMD Project, Suriname.
[30] Hentschel, T., Hruschka, F., Priester, M., 2002. Global Report on Artisanal and Small-Scale Mining. International Institute for Environment and Development, London, UK.
[31] Hilson, G., 2006. Abatement of mercury pollution in the small-scale gold mining industry: Restructuring the policy and research agendas. Science of the Total Environment 362(1-3), 1-14.
[32] Hilson , G., Pardie, S., 2006. Mercury: An agent of poverty in Ghana’s small-scale gold-mining sector?. Resources Policy 31(2), 106-116.
[33] Hilson, G., Potter, C., 2003. Why is illegal gold mining activity so ubiquitous in rural Ghana? African Development Review 15(2-3), 237-270.
[34] Hinton, J., Veiga, M., Veiga, A., 2003. Clean artisanal gold mining: a utopian approach?. Journal of Cleaner Production 11(2), 99–115.
[35] Holt, C., Laury, S., 2002. Association risk aversion and incentive effects. American Economic Review 92(5), 1644-1655.
[36] Isaac, M., Walker, J., Thomas, S., 1984. Divergent evidence on free-riding: An experimental examination of possible explanations. Public Choice 43(2), 113–149.
[37] Jennings, N., 2003. Addressing labour and social issues in small-scale mining, in: Hilson, G. (Ed.), The Socio-Economic Impacts of Artisanal and Small-Scale Mining in Developing countries. A.A.Balkema Publishers, Lisse, The Netherlands, pp. 140-148.
[38] Kazilimani, E., Bukali da Graça, F., McMahon, G., 2003. Artisanal mining baseline survey of Mozambique, in: Hilson, G. (Ed.), The Socio-Economic Impacts of Artisanal and Small-Scale Mining in Developing Countries. A.A.Balkema Publishers, Lisse, The Netherlands, pp. 218-243.

[39] Kocher, M., Sutter, M., Waldner, V., 2005. Exclusion from Public Goods as an Incentive System. An Experimental Examination of Different Institutions. Working Paper, University of Innsbruck, Germany.
[40] Kocher, M., Martinsson, P., Matzat, D., Wollbrant, C., 2011. The role of beliefs, trust, and risk in contributions to a public good. Working Papers in Economics No 482, University of Gothenburg, Sweden.
[41] Kocher, M., Martinsson, P., Myrseth, K., Wollbrant, C., 2012. Strong, Bold, and Kind: Self-Control and Cooperation in Social Dilemmas. Working Papers in Economics No 523, University of Gothenburg, Sweden.
[42] Ledyard, J., 1995. Public goods: A survey of experimental research, in: Roth, A., Kagel, J. (Eds.), Handbook of Experimental Economics. Princeton University Press, Princeton, pp. 111-194.
[43] Marks, M., Croson, R., 1998. Alternative rebate rules in the provision of a threshold public good: An experimental investigation. Journal of Public Economics 67(2), 195-220.
[44] Marks, M., Croson, R., 1999. The effect of incomplete information in a threshold public goods experiment. Public Choice 99(1-2), 103-118.
[45] Moreno-Sánchez, R., Maldonado, J., 2010. Evaluating the role of co-management in improving governance of marine protected areas: An experimental approach in the Colombian Caribbean. Ecological Economics 69(12), 2557-2567.
[46] Moxnes, E., van der Heijden, E., 2003. The effect of leadership in a public bad experiment. Journal of Conflict Resolution 47, 773-795.
[47] Naef, M., Schupp, J., 2009. Measuring Trust: Experiments and Surveys in Contrast and Combination. Discussion Paper No. 4087, IZA, Germany.
[48] Ostrom, E., 1998. A behavioral approach to the rational choice theory of collective action. American Political Science Review 92(1), 1-22.
[49] Ostrom, E., 2006. The value-added of laboratory experiments for the study of institutions and common-pool resources. Journal of Economic Behavior & Organization 61(1), 149-163.
[50] Ostrom, E., 2010. Revising theory in light of experimental findings. Journal of Economic Behavior & Organization 73(1), 68-72.
[51] Pantoja, F., Alvarez, R., Rodriguez, A., 2005. Methods to reduce mercury pollution in small gold mining operations. Revista de Metalurgia 41, 194-203.
[52] Pham, N., 2011. Prosocial Behavior, Social Interaction and Development: Experimental Evidence from Vietnam, PhD thesis, Economic Studies, University of Gothenburg, no. 195.
[53] Qiu, J., 2013. Tough talk over mercury treaty. Nature 493, 144-145.
[54] Sabater-Grande, G., Georgantzis, N., 2002. Accounting for risk aversion in repeated prisoners' dilemma games: an experimental test. Journal of Economic Behavior & Organization 48(1), 37-50.
[55] Saldarriaga-Isaza, A., Villegas-Palacio, C., Arango, S. (2013). The public good dilemma of a non-renewable common resource: A look at the facts of artisanal gold mining. Resources Policy 38(2), 224-232.
[56] Schelling, T.C., 1960. The Strategy of Conflict. Harvard University Press, Cambridge, MA.

[57] Schram, A., Offerman, T., Sonnemans, J., 2008. Explaining the comparative statics in step-level public good games, in: Plott, C., Smith, V. (Eds.), Handbook of Experimental Economics Results, Vol. 1. Elsevier, Amterdam, pp. 817-824 .
[58] Seigel, S., Veiga, M., 2010. The myth of alternative livelihoods: artisanal mining, gold and poverty. International Journal of Environment and Pollution 41(3-4), 272-288.
[59] Smith, V.L., 2010. Theory and experiment: What are the questions?. Journal of Economic Behavior & Organization 73(1), 3-15.
[60] Spencer, M., Swallow, S., Shogren, J., List, J.A., 2009. Rebate rules in threshold public good provision. Journal of Public Economics 93(5-6), 798-806.
[61] Spiegel, S. 2009. Socioeconomic dimensions of mercury pollution abatement: Engaging artisanal mining communities in Sub-Saharan Africa. Ecological Economics 68(12), 3072-3083.
[62] Spiegel, S., Veiga, M., 2005. Building capacity in small-scale mining communities: Health, ecosystem sustainability, and the Global Mercury Project. EcoHealth 2(4): 361-369.
[63] Swope, K., 2002. An experimental investigation of excludable public goods. Experimental Economics 5(3), 209-222.
[64] Tirado, V., García, M.A., Moreno, J., Galeano, L.M., Lopera, F., Franco, A., 2000. Alteraciones neuropsicológicas por exposición ocupacional a vapores de mercurio en El Bagre (Antioquia, Colombia). Revista de Neurología 31(8), 712-716.
[65] Tomicic, C., Vernez, D., Belem, T., Berode, M., 2011. Human mercury exposure associated with small-scale gold mining in Burkina Faso. International Archives of Occupational and Environmental Health 84(5), 539-546.
[66] UPME –Unidad de Planeación Minero Energética-, 2006. Alteraciones neurocomportamentales en personas expuestas a mercurio en la actividad minera del oro en el municipio de Segovia (Antioquia). Ministerio de Minas y Energía, Colombia.
[67] UPME –Unidad de Planeación Minero Energética-, 2012. Sistema de Información Minero Colombiano: producción de oro por departamento. [Accessed 8/29/2012, http://www.upme.gov.co].
[68] van de Kragt, A., Orbell, J. Dawes, R., 1983. The minimal contributing set as a solution to public goods problems. American Political Science Review 77(1), 112-122.

APPENDIX A

Instructions Used in the Economic Experiment

The following instructions correspond to the baseline (T1) of our experiment. These instructions are based on the instructions used in the experiments of Marks and Croson (1998, 1999).

INSTRUCTIONS

WELCOME! The following activity (that we call experiment) is a different and fun way of participating in a study about people's decision making. Various agencies have provided funds for this research. The amount of money you earn during this session will depend on the decisions you make and on the decisions made by the other participants; that is why it is important you pay attention to these instructions. At the end of today's session, you will be paid in cash privately. This experiment is different to what other individuals in this community have played. Therefore, the comments that you have heard from other people do not necessarily apply to this activity.

It is important that you remain silent and do not look at other people's work. If you have any questions or need assistance of any kind, please raise your hand and an assistant will come to you. If you talk, laugh, exclaim out loud, etc., you will be asked to leave and you will not be paid. We expect and appreciate your cooperation. It is expected that this session last for about 2 hours.

In this experiment we will use "tokens" that will be converted to money at the end of the experiment. Every token that you have at the end of the experiment will be converted to $72 Colombian Pesos. You will make your choices individually, and no one will be told what your choices are. To ensure the confidentiality of your decisions, at the beginning when you entered to the room you received as slip of paper with a number. This number will be your identification during the experiment. At the end of the activity when you are being paid, you must give this slip of paper back and in exchange you will be given a sealed envelope with your number. This envelope will contain the money you win.

GENERAL DESCRIPTION

This experiment recreates a situation in which a group of people must make decisions on how to manage their natural resources. For this group we are referring to gold management in Northeastern Antioquia.

In this area, some institutions have been promoting alternative techniques and technologies that reduce the use mercury and the effects this element has on the environment and human health, and that improve the profits that can be obtained in the gold recovery process.

In this activity you are assigned to a decision group that consists of five (5) people. This experiment consists of several periods. In every period, everyone in the group will be given a balance of tokens. All participants receive the ***same*** initial balance of tokens every period.

Each period, you and the other group members will be asked to allocate your tokens between two types of accounts. The first type of account is a **Private Account**. Every individual has his own Private Account. Any token you allocate to your Private Account will give you a guaranteed earning of exactly one token; that is, if you allocate one token to the Private Account your earning of this account is the same token. The second type of account is a **Group Account**. There is only one Group Account for the entire group. Your earnings from the Group Account depend on the **total** number of tokens that the group allocates to the Group Account according to the Payoff Table. Both accounts are explained below.

You have a Payoff Table. With this table you can calculate the tokens you will receive every period as total earnings, assuming the decisions made by you and of the other members of the group. The way you can use this table is explained later.

Finally, we want you to know we do not pretend to evaluate if your decisions are correct or wrong; therefore, in this experiment there are not good or bad decisions.

YOUR BEGINNING BALANCE OF TOKENS

Each period, you and every other member of the group will be assigned a balance of 25 tokens. Thus, the group will have a total of 125 tokens.

PRIVATE ACCOUNT

Every period in this experiment you will be asked to make simultaneous decisions about how many tokens to allocate to your Private Account and how many tokens to allocate to the Group Account. Your allocations must add up to 25 tokens. Every group member has his own Private Account. Your Private Account guarantees you earnings of $72 per token. The other members of the group receive the same earnings from their Private Accounts.

If you chose to allocate all of your 25 tokens to the Private Account and 0 tokens to the Group Account, your period earnings from your Private Account would be 25 tokens

If you chose to allocate 9 tokens to your Private Account and 16 tokens to the Group Account, your preliminary earnings from your Private Account would be 9 tokens. The Group Account is discussed below.

GROUP ACCOUNT

Every group of 5 people has one **Group Account** for the entire group. Every member of the group can allocate tokens to the group account. What are the tokens collected in the Group Account going to be used for? This account will be used to collect the necessary funds to obtain the alternative technology for the gold recovery process. With this technology lower levels of mercury pollution can be achieved, as well as increasing the recovery of gold in this process.

In each period, each group member will decide how many tokens to allocate to the group account. In this exercise, each person can decide to assign zero tokens to the group account, allocate part of the 25 tokens that were assigned initially or allocate all. In this common fund we will collect the necessary funds to buy a technology that allows reducing mercury pollution of the gold recovery process, and increase the recovery of this process. In this experiment this technology is referred to ***continuous mills*** and ***methods of gravimetric concentration***.

And is it always possible to buy the technology from the Group Account? No, it is only possible to have the technology if the five members of the group are able to raise a total of **60 tokens** in the Group Account, in that period. This required number of tokens is called the **Group Account Requirement**. It represents the minimum level of collection of tokens in the group account to cover the cost to acquire the alternative technology. If the **Group Account Requirement** is achieved and the technology acquired, the earnings from the **Group Account** will be divided equally among the five group members. These earnings represent the improved environmental quality and the higher profits due to more recovery of gold. Because in the real life these benefits could be enjoyed by everyone, no matter who allocates the tokens to the group account, in this game every player will receive tokens from the Group Account even if he decided to allocate nothing to this account.

What happens if the group does not meet the 60 tokens that are the group account requirement? If group's total allocation to the Group Account is less than the Group Account Requirement of 60 tokens, then the group will not earn anything from the Group Account. The tokens that you had allocated to the Group Account will be returned to you and will be automatically put into your Private Account.

What happens if the group does exactly meet the 60 tokens? If the total number of tokens allocated to the Group Account is equal to or greater than 60, then the group receives **120 tokens** from the Group Account for the first 60 tokens allocated. This means that you will receive 24 tokens from the Group Account what represents your benefits from the purchase of the new technology in that period and only for that period.

What happens if the group managed to gather more than 60 tokens? If your group's total allocation to the Group Account is greater than the 60 token Group Account Requirement, the extra tokens are not returned to the members of the group in any way. Thus, the group receives no benefit from allocating more than a total of 60 tokens to the Group Account.

It is not compulsory for you to spend any amount of tokens to the acquisition of the alternative technology. The money allocated to you (represented by the number of tokens) is yours and you are completely free to decide what to do with these tokens during this exercise. In this experiment, even if you do not want contribute or want to do it in a small amount, if the alternative technology is purchased (that is, the Group Account Requirement is reached), you will enjoy the benefits of the Group Account during that period of the game. The enjoyment of the benefits of purchasing the alternative technology applies only for the period during which the technology is acquired.

CALCULATING YOUR PERIOD EARNINGS

Your "period earnings" are the sum of your earnings from your Private Account and your earnings from the Group Account. Each period, your earnings for the period are added to your previous earnings to keep a running total of your cumulative earnings. Thus, your earnings for the experiment are the sum of all of your period earnings. Recall that every token you have at the end of the experiment will be converted to $72 Colombian pesos. To make these things clearer, below we show you some examples.

THE RECORD SHEET

The **Record Sheet** gives you a place to record certain pieces of information. It is here that your period earnings will be recorded. You have been also provided a sample Record Sheet which is green. Please make sure you can find where the following pieces of information are recorded on your sample Record Sheet. The numbers below correspond to the column of the Record Sheet where this information can be found:

(1) Period Number
(2) Group Account Requirement
(3) Your Allocation Choices: Group Account
(4) Your Allocation Choices: Private Account
(5) Total Group Account allocation
(6) The Fraction *You* Allocated to the Group Account
(7) Extra Tokens
(8) Your Earnings: Group Account
(9) Your Earnings: Private Account
(10) Total Period Earnings
(11) Cumulative earnings

You have been given a stack of blue **Reporting Sheets** that will be used during the experiment. Each one looks like the example below. Please make sure you can locate the Reporting Sheets.

REPORTING SHEET

Player No.: ________ Room No.: ________

Period No.: ________

Your Allocation Choices

number of tokens to Group Account	________	+	number of tokens to Private Account	________	= 25 tokens

Each period, you will denote your allocations on the portion of the sheet entitled Your Allocation Choices. You need to make sure that your allocations add to 25 tokens. After finishing, you will turn the Reporting Sheet over and put it in the corner of your desk. The Reporting Sheets will be collected by an assistant. An assistant will add up the allocations to the Group Account. Items (3) - (9) on the Record Sheet will be reported to you on a slip of paper.

We will use the sample Record Sheet you have been given (the green one) to go through three examples of how to calculate your period earnings. The information you will receive for the first two examples (periods) is reported to you on a sample Reporting Sheet, similar to the one above and the ones you will use in the decision-making periods. This information for the first two examples is recorded on your sample Record Sheet. For example 3, you will be asked to fill out the sheets yourself, and an assistant will also be filling out the entries on the whiteboard. Please follow along on your sample Record Sheet as we go through the three hypothetical periods.

Hypothetical Example 1:

REPORTING SHEET

Subject No.: ____ Room No.:

Period No.: __1

Your Allocation Choices

number of tokens to Group Account __13__ + number of tokens to Private Account __12__ = 25 tokens

Assume you allocate 13 tokens to the Group Account and 12 tokens to your Private Account. This is recorded on the Reporting Sheet above and columns (3) and (4) of the sample Record Sheet. Assume that the group's total allocation to the Group Account is 40 tokens. This implies that the other four group members allocated a total of 27 tokens to the Group Account. You now have enough information to fill out columns (5), (6), (7), (8) and (9) on the sample Record Sheet. In Column (5) it is noted that the total Group Account Allocation is 40 tokens. The group did not meet the Group Account Requirement of 60 tokens. Therefore, there are no extra tokens allocated to the Group Account. This is noted in column (6).

Columns (7) and (8) record your period earnings. Since the group did not reach the Group Account Requirement, the 13 tokens you allocated to the Group Account are returned to you and are automatically allocated to your Private Account. This means that all 25 of your tokens are now allocated to your Private Account and your earnings from the Group Account are 0 tokens. The earning of 0 tokens from the Group Account is placed in column (7). The 25 tokens you earn from your Private Account are placed in column (8) of the sample Record Sheet.

Your total earnings for period 1 are determined by adding together the entries in (7) and (8). Thus, 25 is placed in column (9). You can verify this in the Payoff Table:

		My allocation to the Group Account 13
THEIR ALLOCATION TO THE GROUP ACCOUNT	⋮	⋮
	27	25

Hypothetical Example 2:

REPORTING SHEET

Subject No: ____ Room No.:

Period No.: __2

Your Allocation Choices

number of tokens to Group Account	__10__	+	number of tokens to Private Account	__15__	= 25 tokens

Assume you allocate 10 tokens to the Group Account and 15 tokens to your Private Account. These numbers are entered in the Reporting Sheet above and in columns (3) and (4) of the sample Record Sheet. Assume the group's total allocation to the Group Account is exactly 60 tokens, implying that the other four group members allocated a total of 50 tokens. The total Group Account allocation is noted in column (5) of the sample Record Sheet. Since the group exactly reached the Group Account Requirement, there are no extra tokens as noted in column (6).

Your earnings are determined as follows: You receive 24 tokens from the Group Account because the technology could be acquired. This number is placed in column (7) of the sample Record Sheet. You earn 15 tokens from your Private Account which is noted in column (8). Adding together your earnings from the Group Account and your Private Account gives you a total period earning of 39 tokens. You can verify this in the Payoff Table:

		My allocation to the Group Account 10
THEIR ALLOCATION TO THE GROUP ACCOUNT	⋮	⋮
	50	39

This is noted in column (9) of the sample Record Sheet.

Hypothetical Example 3 has <u>not</u> been recorded on the Reporting Sheets in the Instructions or the sample Record Sheet. Please fill in the relevant information as we work through Hypothetical Example 3. The information will also be filled in on the whiteboard.

Hypothetical Example 3:

REPORTING SHEET

Subject No: ____ Room No.:

Period No.: 3

Your Allocation Choices

number of tokens to Group Account ____ + number of tokens to Private Account ____ = 55 tokens

A new period begins. Assume you allocate 17 tokens to the Group Account and 8 tokens to your Private Account. Please record this information on the Reporting Sheet above and on the sample Record Sheet in columns (3) and (4). Assume your group's total allocation to the Group Account is 69 tokens. The Group Account total of 69 should be recorded on the Record Sheet in column (5). Since the group exceeded the Group Account Requirement of 60 tokens, there are 9 extra tokens. This is recorded in column (6). Your earnings are calculated as follows: You receive 24 tokens from the Group Account. This should be recorded in column (7). You also earn 8 tokens from your Private Account. This should be recorded in column (8). Your total period earnings add up 32 tokens:

		My allocation to the Group Account 17
THEIR ALLOCATION TO THE GROUP ACCOUNT	⋮	⋮
	52	32

Please record this in column (9) of the sample Record Sheet.

QUESTIONNAIRE

At this point, each of you will fill out a short questionnaire to ensure that everyone knows how to calculate his or her period earnings. Upon completion, the questionnaires will be collected and checked. Please put your subject number (not your name) on your questionnaire. The questionnaire looks like the sample Record Sheet you have been working with. There are six sample periods for which you are given a hypothetical choice of Group Account allocation and Private Account allocation. You will also be given a Total Group Account Allocation. You will be asked to fill in the empty entries on the Record Sheet and answer several questions.

If you have any questions while working through the questionnaire, please raise your hand and an assistant will come to you. When you finish, please turn the questionnaire over and place it in the corner of your desk. An assistant will collect the questionnaire and will bring it to the front of the room for checking. If there are any questions at this time, please raise your hand. If there are no questions, you may begin the questionnaire.

INFORMED CONSENT SHEET

Everyone in this session has received an **Informed Consent Sheet**. This sheet is a requirement for the universities that undertake studies with the participation of people. In this format we inform to you about confidentiality and handling of the information we collect in these activities, you sign if you agree to participate, certifying that they were informed of the project and the handling of the information. Please read this sheet before signing. The information on this form is confidential and no one will have access to this but the researcher of this study. Your participation is completely voluntary. You can leave the activity at any time. However, if you leave you will not receive any payment.

If you agree to participate, please complete and sign the **Informed Consent Sheet**.

PERIOD INFORMATION

You have been given an **Information Sheet** that summarizes what you have been told above. The **Information Sheet** informs you of all of the relevant information for the periods of the experiment. Please make sure you can find where the following pieces of information are listed on the Information Sheet:

1) Group Account Requirement
2) Your Balance of tokens
3) Every other Group Member's Balance of Tokens
4) Total Number of Tokens Belonging to Group
5) Your Share of the Group Account Earnings
6) Every Other Group Members' Share of the Group Account Earnings
7) What Tokens in the Group Account earn:
8) What Tokens in Your Private Account earn:

SUMMARY OF A SINGLE PERIOD

A single period proceeds as follows:

- You have been given a set of blue **Reporting Sheets**, one for each period.

- You will tear off the Reporting Sheet for the relevant period and you will indicate your choice of allocations to the Group Account and your Private Account. Please make sure your allocations add to 25 tokens. These decisions effect only on the ongoing period.

- You will also denote your choices on your Record Sheet.

- When you are done filling out your Reporting Sheet, you will turn it over and place it in the corner of your desk. The Reporting Sheets will then be collected by one of the assistants.

- The Group's total allocation to the Group Account will be determined and the information on the Record Sheet will be calculated for you. This information will be returned to you on a slip of paper. You may choose to perform your own calculations on the Record Sheet using the Payoff Table. Or, you may choose to copy the information that you have received onto the Record Sheet.

- An experimenter will collect the slips of paper before you receive the one for the next period. At this point the period is over and a new period will begin.

- Note that you will never be told the allocation choices made by other group members, and they will not be told anything about your choices.

SUMMARY OF THE INSTRUCTIONS

- You are assigned to a decision group that consists of five people.
- This session will consist of several decision-making periods.
- Each period, you and every other member of your group will be assigned a balance of 25 tokens. Thus, the group will have a total of 125 tokens.
- You will be asked to make simultaneous decisions about how many tokens to allocate to your Private Account and how many tokens to allocate to the Group Account. The Group Account will be used to collect the tokens needed to buy a technology that reduces the use of mercury and increases the recovery of gold.
- Your decisions and those of each of the members of the group will be completely anonymous. All information you provide is confidential and no one will have access to it, except the researcher of this study.
- Your allocations must add up to 25 tokens.
- Your **Private Account** guarantees you that each token put there is yours.
- There is one **Group Account** for your entire decision group. The earnings from the **Group Account** will be divided equally among the five group members.
- Every period the <u>group only benefits from the Group Account if at least 60 tokens are allocated to the Group Account.</u>
- If the group's total allocation to the Group Account is <u>less than the Group Account Requirement of 60 tokens</u>, then the group will not earn anything from the Group Account. The tokens that you had allocated to the Group Account will be returned to you and will be automatically put into your Private Account.
- If the total number of tokens allocated to the Group Account is <u>equal to or greater than 60</u>, then the group receives **120 tokens** from the Group Account for the first 60 tokens allocated. Tokens allocated in excess of 60 are addressed below. The 120 tokens will be <u>divided equally</u> between the 5 members in the group. **Thus, your share would be 24 tokens.**
- If your group's total allocation to the Group Account is <u>greater than the requirement of 60 tokens</u>, the extra tokens <u>are not returned to the members of the group in any way</u>.
- Your "period earnings" are the sum of your earnings from your Private Account and your earnings from the Group Account.
- At the end of this session you will be paid in cash, depending on the number of tokens you have at the end of the game. Each token you have at the end of the experiment will be converted into 72 Colombian pesos.

During the experiment, you may want to keep the Instructions open to this Summary page. This will allow you to refer to it quickly and easily if you need.

This ends the instructions. If you still have any questions at this time, please raise your hand. One of the assistants will come to you. If at any time during the experiment you have a question, please raise your hand and an assistant will come to you. If there at no questions at this time please put the sample Record Sheet in your envelope.

At this point we will begin the experiment. You are reminded that you must remain silent during the experiment. At the end of the experiment you will be paid your earnings in cash. If there are no questions, you may begin period 1 by filling out the Reporting Sheet for period 1. When you are finished, turn it over and place it on the corner of your desk.

The following instructions correspond to the exclusion treatment (T2) of our experiment.

NEW INSTRUCTIONS

DEAR PARTICIPANT! At this point game's instructions change a little. These changes are related to the profits from the Group Account once the technology is acquired. Please pay attention to these changes.

From now on, if in a given period the group collects 60 tokens and the technology is acquired, there are some benefits that are equally assigned to the five group members. These benefits are assigned no matter how many tokens each member assigned. Those benefits represent the improvement in environmental quality due to the use of the cleaner technology. However, the benefits associated to more recovery of gold will be only received by those who share the cost of the new technology.

As before, if the total number of tokens in the group account is lower than the Group Account Requirement (60 tokens), then the alternative technology cannot be acquired and the group gains nothing from the Account Group during that period. The tokens that you have assigned to the Account Group you are automatically placed on your Private Account.

If the total number of tokens assigned to the Group Account equals 60 then the technology is acquired and the group receives **80 tokens** from the Group Account; i.e., each member is given 16 tokens from the Group Account, which represents the gains due to improved environmental quality.

Additionally, if the technology is acquired and you deposited tokens in the Group Account, you can enjoy the profits of more gold recovery in beneficiation process, receiving 8 additional tokens. The total benefits from the Group Account during that period would be 24 tokens. However, if you do not contribute to the Group Account and the technology is acquired, you just receive the 16 tokens which correspond to the benefits that each member gets from the Group Account.

Just as before, if total allocation of your group is larger the Group Account Requirement (60 tokens), extra tokens are not returned to the members of the group.

For the calculation of the earnings from the Group Account henceforth we will use **Payoff Table 2**, which we deliver in this moment. In exchange we ask you to return the table that you utilized since the beginning of the game.

To make these changes clearer here there are two examples.

Hypothetical Example 4:

REPORTING SHEET

Subject No: ____ Room No.:

Period No.: 4

Your Allocation Choices

number of tokens to Group Account 16 + number of tokens to Private Account 9 = 25 tokens

Assume you allocate 16 tokens to the Group Account and 9 tokens to your Private Account. Assume the group's total allocation to the Group Account is 69 tokens, implying that the other four group members allocated a total of 52 tokens. Therefore, you receive 24 tokens from the Group Account; 16 tokens because of the provision of the technology and 8 more because the technology is acquired and you shared the cost of that acquisition. You also earn 9 tokens from your Private Account. Your total earnings for the period and add 33 (see Payoff Table 2):

		My allocation to the Group Account 16
THEIR ALLOCATION TO THE GROUP ACCOUNT	⋮	⋮
	52	33

Hypothetical Example 5:

Assume you allocate 0 tokens to the Group Account and 25 tokens to your Private Account. Assume also that the group's total allocation to the Group Account is 62 tokens.

In this case you receive 16 tokens from the Group Account because the technology could be acquired, but you do not receive any additional token because you did not contribute to the acquisition.

From your Private Account you earn the 25 tokens you have assigned to this account. By adding the profits from the Private Account and the Group Account you get a total earning of 41 tokens. You can check this result in Payoff Table 2.

		My allocation to the Group Account 0
THEIR ALLOCATION TO THE GROUP ACCOUNT	⋮	⋮
	62	41

APPENDIX B

Guideline Provided to the External Advisor in the Treatments with Co-management

The following guideline adhered to the instructions of Moreno-Sánchez and Maldonado (2010).

We thank you for having accepted the invitation to participate in the economic experimental games we are performing with artisanal gold miners from Segovia and Remedios. The purpose of this experiment is to analyze the behavior of these miners in the management of the production process of gold in the region of Northeastern Antioquia.

This experiment is a different way in which you and mining communities can participate in a study that is related to the gold recovery process in Segovia and Remedios.

This experiment recreates a situation in which a group of five people, who are small-scale gold miners in their daily life, make decisions similar to real ones about recovering gold.

You have been chosen to participate in the experiment because of your experience working with communities on environmental-education issues and sustainable techniques. You will participate in one of the rules that we have designed for the game. The rule is called co-management and groups of five participants will be playing it. Co-management rule consists of the following: at the beginning of the second stage, and for five (5) minutes, you will have the opportunity of having an open talk with group members. During the talk you will try to convince individuals that the best decision for the group (in terms of benefits) and for the whole region (in terms of environmental conditions) is *to contribute to the Group Account in order acquire the technology that reduces the use of mercury in the gold beneficiation process*. This decision jointly will allow better environmental and health conditions, and more recovery of gold, which in turn will benefit each of them through ensuring better living and economic conditions.

In this experiment, the technology that we are considering is continuous mills and methods of gravimetric concentration such *mesa alemana* and *canalones*.

In addition to this basic information you can give them information that you consider relevant about why they should reduce the use of mercury in the gold beneficiation process. The group of five will listen to your talk and then they will have five additional minutes to have an internal and confidential talk about the information you have provided to them about the game, the payoffs, ways of playing, similarities between the game and real world and about the relevance of better environmental conditions. During their confidential talk you will not be allowed to stay with players. You and the group will be allowed to have a discussion and a question and answer period.

In subsequent periods you will have the opportunity to talk one (1) minute with members of each group, then of which participants can talk to each other up to one (1) minute confidentially (without your presence).

Please note that during the talks you will not be allowed to impose your role as representative of the Global Mercury Project, not make promises or threats, since the purpose of this rule is to examine political strategies or alternative management rules in the area, based on communication between authorities, developers and communities, and within communities.

The idea of this rule is that you, as a member of the Global Mercury Project, responsible for providing environmental and technical education, provide information about the importance of having a good environmental quality, in particular, a mercury-free environment. Individuals will then make decisions according to the information and their internal discussion.

For academic purposes, the talk between you and the group will be recorded. Notice that all the information that you give during the game will be treated as strictly confidential and will be used for research purposes only.

Chapter 4

--

Chipping in for a cleaner technology across subject pools: evidence from a framed threshold public good game with students and miners

Abstract

This paper investigates the external validity of a framed threshold public good game with features of a public good dilemma that is faced by artisanal gold miners in developing countries. By using the same experimental design we analyze whether the decisions made by university students in this context-enriched situation converge to what miners do in the same framed experiment. This work contrasts with previous literature in which the comparison between lab and field has considered context-free situations. The results show behavioral convergences between students and miners in three treatments, and divergence in one treatment. In terms of the achievement of efficient outcomes, the performance of university students was better than miners. Similarly to previous literature, these results show that the external validity of lab experiments must be taken cautiously.

1. Introduction

This paper analyzes the behavioral differences between university students and artisanal gold miners in Colombia in a framed field experiment. In this analysis we use a threshold public good game that is framed according to the public-good dilemma faced by artisanal gold miners in many developing countries (Saldarriaga-Isaza et al., 2013a). The social dilemma is characterized by the conflict between the individual's interest in using a polluting and cheaper technique in the gold recovery process, and the social interest on acquiring a cleaner production technology. One way of coping with this dilemma is by establishing an association where miners can raise the financial capital required to buy a cleaner technology. To this end we test the effect of three institutional designs on the rate of technology adoption and compare the results with a control treatment where the threshold public good game is implemented. We ran the experiment with both, university students and with miners in the field. With this analysis we explore to what extent the effects of different treatments coincide across two different subject pools. The aim of this analysis is to contribute to the debate of the external validity of laboratory experiments.

One of the main assumptions of experimental economics is that the behavioral patterns observed in the laboratory are likely to be observed in real life as long as certain *ceteris paribus* conditions hold. However, the so-called general principle of induction (Friedman and Sunder, 1994), parallelism precept (Smith, 1976, 1982), or external validity (Guala, 2005) has been subject of debate since the early stages of experimental economics. For instance, in the 1990s, P. Bohm was one of the first scholars calling attention of the differences that there might be between laboratory experiments and experiments in the field (Dufwenberg and Harrison, 2008).

Some scholars defend the idea that the main purpose of any experiment is to test a theory, model or conjecture (Smith, 1982; Plott, 1991), rather than to reproduce a real-world system. If a theory is meant to describe or explain certain regularities of a real-world system, and an economic experiment does not succeed in rejecting the propositions of that theory, then we should expect that the theory provides causal relationships that explain that reality (Bardsley et al., 2010). Nonetheless, the mere fact that a theory (model) is refuted in the laboratory does not mean that the theory is entirely wrong but that a test of its applicability in a certain domain failed (Guala, 2005).

Opposite, there are skeptics scholars about the external validity of experimental economics, who have indeed used the features of universality or completeness claimed by some economic experimenters to express their concerns about laboratory experimentation in economics (Guala, 2005). In general, it has been argued that human actions are context dependent and are defined partly in relation to other phenomena and partly by people's perceptions of those relationships. Under this perspective, the "same conditions, same effect" argument for external validity, or the *ceteris paribus* assumption, might not seem appropriate (Bardsley et al., 2010).

The evidence with regard to this debate is not conclusive (Guala, 2005). For instance, experimental economics has proven to be useful in the correct design of mechanisms for the allocation of telecommunication licenses (Guala, 2005). The accurate matching between the price trajectory in laboratory experiments and the bidding trajectory observed in license auctions is, according to Guala (2005), a clear example that when certain conditions hold, the data-generating processes both in the experiment and the real-world ought to be the same. Likewise, Kagel (1995) in the analysis of auction markets, and Fehr and Gächter (2008) in their study on wage markets, found not only a correspondence between laboratory and field data, but also that theory predictions are confirmed by that data.

In contrast, results reported by Carpenter et al. (2005) and Carlsson et al. (2012) indicate differences in the offers that students and workers made in ultimatum and dictator games. Carpenter et al. (2005) point out that those differences are driven by the social framing of participants, and suggest that the external validity of lab experiments should be taken cautiously. Similarly, Anderson et al. (2012) performed a study of other-regarding preferences across subject pools; they found large differences between college students and non-student adult subjects.

The external validity of public goods experiments conducted either in the lab or in the field has been also questioned. Laury and Holt (2008) and Voors et al. (2012), for instance, found respectively that the behavior shown by players in a laboratory experiment and in field experiment is weakly correlated with actual behavior in a real (natural) public good dilemma situation. These authors cast doubt on the external validity of economic experiments and point out the need of doing further research to gather more evidence on the external validity of decisions made in context-free situations.

In this paper, we conduct a framed threshold public good game in order to analyze the behavioral differences between lab and field experiments. Besides including the characteristics of an artefactual experiment, in the framed experiment an abstract context is substituted by a field context (Harrison and List, 2004). In our experiment, we modify the abstract environment of a context-free threshold public good game (TPGG) and consider a framework which is given by the purchase of a technology that cannot be individually afforded. With the acquisition of the technology, participants get rewards that represent reductions of mercury pollution resulting from the process of recovering gold in artisanal mining, and also the growth in productivity during this process.

Smith (1979) argues that the embellishment of instructions with well-intentioned attempts of gaining realism in an experiment may not be convenient. This would change the sources of valuation in the experiment from just one, the monetary reward, to several ones. As Murphy and Cardenas (2004) point out, some experimentalists suggest that experiments should not be framed in any particular context to avoid that this influences results; but there is no consensus on this. We might say that in the real-world the decisions people make are motivated by several sources of valuation all working at the same time. Or recalling Bardsley et al.'s (2010) idea, human actions are context dependent and defined partly in relation to other phenomena.

We contribute to this debate of the external validity of laboratory experiments by examining whether the decisions that university students and miners make in a context-enriched situation match up. This is done by comparing the decisions made by university students and artisanal gold miners in the framed economic experiment. Our work contrasts with previous literature in which the comparison between lab and field has considered context-free situations (see, e.g., Carpenter et al., 2005; Laury and Holt, 2008; Carlsson et al., 2012). Moreover, in order to offer more insights into the problem of external validity, we also compare our results with previous TPGGs conducted in the lab.

The remainder of this paper is organized as follows. In Section 2 we describe the experimental design and the mechanisms we tested in the experiment. Then, in Section 3 we report the experimental results and in Section 4 we focus our discussion on the external validity of our lab experiments. In general, we find behavioral convergences and divergences between students and miners. In Section 5 we conclude.

2. Experimental Design[1]

The experiment conducted in the lab and the field was framed according to the social dilemma faced by artisanal gold miners in many developing countries (Saldarriaga-Isaza et al., 2013a). In this economic sector, a widespread practice employed to recover gold is to amalgamate gold using mercury. The outcome of the entire process is mercury pollution, as well as posing a health risk to the communities living in zones where this activity is carried out (Saldarriaga-Isaza et al., 2013a).

One way of coping with this public good dilemma is by switching to technologies that are not only cleaner but also more productive than the amalgamation technique using mercury. However, the cost of this technology might be beyond the budget of a single miner. As an option, miners could join efforts by making individual contributions to a common fund in order to raise the minimum financial capital required to buy the technology. But given that there is not rivalry in the positive externalities derived from the adopted technology, and that it is not possible to exclude people from these public benefits, some individuals might be tempted to free ride.

In this context, one of the institutional arrangements that might foster collective action, and that are assessed in our experiments, is the intervention of a non-coercive external party that provides either technical assistance or any other kind of guidance in the process of switching to alternative technologies. This kind of intervention, namely co-management, might be needed for miners to get organized under an association scheme by which miners can raise the financial capital necessary to acquire and maintain better technologies (CDS, 2004; Chaparro, 2003; Saldarriaga-Isaza et al., 2013a).

In addition to co-management, we assessed the effect of an institutional arrangement in which those miners who do not contribute to the acquisition of the technology are excluded from using the technology and therefore from obtaining additional profits due to more productivity in the gold recovery process. It is expected that under the threat of exclusion the free-riding rate declines by pushing original strong free-riders (i.e., those contributing nothing) to contribute at least one token.

[1] A complete description of the economic experiment can be found in Saldarriaga-Isaza et al. (2013b).

All subjects were exposed to the same experimental protocol. By keeping the difference between the laboratory and field experiments to a minimum (Carlsson et al., 2012), we can make clear comparisons of the behavior of students and miners. The instructions of our framed experiment adhered to the basic language of the instructions developed by Isaac et al. (1984) (see instructions in Appendix A of Chapter 3). These instructions have been commonly utilized in other multi-period laboratory experiments of public goods with provision point (Croson and Marks, 2000, 2001; Marks and Croson, 1998, 1999; Cadsby et al., 2008).

Each period, players participating in the experiment were asked to decide between allocating c_i tokens of an initial endowment (E) to a common fund in order to buy a new technology of cost T, and keeping $E - c_i$ in his private account.[2] The latter represents the private consumption of the subject in the experiment. In this multi-period game, each player was randomly assigned in a five-person group. In each round, the payoff the individual received (U_i) was computed according to the equation:

$$
\begin{aligned}
U_i &= E && \text{if} \quad \sum_{i=1}^{n} c_i < T \\
U_i &= E - c_i + R + \rho && \text{if} \quad \sum_{i=1}^{n} c_i \geq T \qquad (4.1)
\end{aligned}
$$

In equation (4.1), R is the benefit of an improved environmental quality, and ρ represents the profits for more productivity in the gold recovery process. To represent a public-good dilemma situation, we assume that $E<T<n.E$. The parameterization of the game was as follows: E=25, T=60, n=5, R=16, ρ=8. According to equation (4.1), each individual cannot increase his benefits in the game unless the technology is acquired. In the case of exclusion, $\rho = 8$ only if $c_i > 0$, and $\rho = 0$ otherwise.

Following Moreno-Sánchez and Maldonado (2010), in the co-management treatment every group had the opportunity to talk up to five minutes with an external advisor. In this treatment, players continued being paid according to equation (4.1). The task of the advisor was to persuade miners to invest in the new technology, with the aim of reducing the emissions of mercury and avoiding the harmful effects of mercury pollution. Afterward, the group had five minutes to converse among themselves without the presence of the advisor. For each successive period of the game, the external advisor was given one minute to talk with the group, following which, group members had one minute to talk.

[2] The equipment introduced in the framework of the experiment was referred to continuous mills and methods of gravimetric concentration. These technologies have been promoted among miners and processing facilities, and are recognized for being cleaner and more productive than traditional techniques such as mercury amalgamation or ball mills.

In the field, the external advisor in the co-management treatment was a representative of the Global Mercury Project, who had been working in the zone for several years supporting the introduction of alternative technologies for gold recovery. In the experiments with university students, the advisory task was done by a professor of engineering at the National University of Colombia. In the last case, it was difficult to be certain about the presence of the representative of the Global Mercury Project in the sessions done in the university facilities with students.

The experiment was performed in two stages; the first stage consisted of 8 periods in which participants played the base case according to equation (4.1). Then, depending on the session they had been cited to, in the 9 periods of the stage 2 the groups played one of four possible treatments (see Table 4.1).

Table 4.1. Summary of Experimental Design

		Co-management	
		No	Yes
Exclusion	No	Base case (T1)	Treatment 3 (T3)
	Yes	Treatment 2 (T2)	Treatment 4 (T4)

At the end of each period, each participant was privately informed in a slip of paper about total group contributions and of his payoff according to those contributions. This was done to avoid any bias that might arise from several groups in the same session being able to compare their contributions. As part of the set of instructions we provided all the participants with pay-off tables. The provision of the pay-off table aimed to minimize subject's transaction costs by facilitating the accounting process. These tables informed marginal and total pay-offs for different levels of contributions and availability of the alternative technology (example of a pay-off table is provided in Appendix C).

In each session of the lab (field) we randomly formed up to five (four) groups of five members each. In each five-person group every member knew the size of the group. All the individual decisions were private and confidential, and were made anonymously. To facilitate and ensure understanding of the game, three hypothetical examples were provided and subjects were allowed to play three training periods (without payoff).

We additionally gathered some information that provides insights about the decisions made by subjects in the experiment. At the end of each session, and before the payment was done, we asked every player to fill out a survey. In this survey we gathered some socioeconomic and demographic information, as well as information on some personality traits: risk, trust, empathy and self-control.[3] With the data we collected about these personality traits, we can make correlations between subjects' behavior in the experiment and the behavior that they claim to have in their real lives.

Payments to participants in the experiment were done individually and privately. In order to ensure anonymity, every participant was identified with a number that was handed out in a slip of paper at the beginning of the experiment. To collect his payment, at the end of the session, the player should give back the slip, individually, receiving in exchange a sealed envelope with his payment. The value of each token was calculated taking into account participants' average opportunity cost of time, and the maximum and minimum amount of tokens each participant could gain in the session. For miners and students each token was converted into 72 and 32 Colombian pesos, respectively.[4]

2.1 Subject pools

The experiments with students were conducted in October 2012 at the National University of Colombia, at the city of Medellín. This is a public university with approximately 10000 students in its campus at Medellín. The students for the experiment were recruited via an e-mail that was sent to students of economics and engineering, with an invitation to participate in an experiment. Those students who were interested in participating had to fill out an online form with contact information, as well as to select the sessions they were available to participate in. Participants were then contacted via e-mail with specific information about the single session they were selected for. A total of 185 students were recruited and allocated to one of the eight sessions we ran for this lab experiment.

For the field experiment, we made a public call to artisanal gold miners from the municipalities of Segovia (37500 inhabitants) and Remedios (23500 inhabitants), in the Northeastern region of Antioquia, Colombia. For this call we invited miners to participate in the experiments via flyers distributed in mines and processing plants and messages transmitted from a local radio station. For this process we always counted on active support of mining leaders and existing miners associations. Provided that only 35 miners could be recruited with this call, we implemented an additional strategy: to run sessions directly in some of the mines. A total of eighty-five subjects could be finally recruited from the mining population living in these two municipalities. The experimental sessions in the field were run between the 23rd of November and the 5th of December of 2012. Table 4.2 reports the number of players by treatment in both subject pools.

[3] A description of how these variables were measured is found in Saldarriaga-Isaza et al. (2013b).

[4] The exchange rate at the time of the experiments was approximately 1US$ equals 1815 Colombian pesos.

Table 4.2. Number of players by treatment.

Treatment		*Students*	*Miners*
Baseline	(T1)	50	10
Exclusion	(T2)	45	30
Co-management	(T3)	45	20
Exclusion & Co-management	(T4)	45	25

3. Results

In Table 4.3, we present the socioeconomic characteristics of participants in the experiments.[5] As expected, on average students are younger than miners, and their level of education is much higher than what is found in mining communities. Even though miners do not get high earnings from their activity (between 1 and 2 minimum wages), the average income of participants in the field experiment is higher than what students reported. In the last case, this is not a strange result provided that many of these students come from low income households and depend on parents for money and living expenses. Interestingly, these two populations appear to be quite similar in their levels of *empathy*, *self-control*, *trust* (on others), and attitudes toward *risk*.

Table 4.3. Socioeconomic characteristics by populations.

Variable	**Students**	**Miners**	**Difference**
Socioeconomic Variables			
Age (years)	21.6	32.39	10.68***
Education[a] (mean)	7	3.59	-3.41***
Income (mean)	1.81	3.42	2.32***
Female (fraction)	0.34	0.11	-0.23***
Attitudinal variables			
Risk (mean)	6.88	6.58	-0.3
Trust (mean)	0.36	0.39	0.03
Empathy (mean)	3.6	3.45	-0.15
Self-control (mean)	2.73	2.6	-0.13

[a] Education is measured in levels depending whether primary, secondary, technical or college education had been completed or not.
***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively, using the MWW test.

Figure 4.1 shows average group contributions in the treatments across the whole game. The oscillating pattern of threshold public good games (Croson and Marks, 2000) can be also observed in our experiments. In general, this oscillation occurs around the efficient Nash equilibrium outcome of the game (60 tokens). This general outcome is more visible in the base

[5] In our comparisons we follow the standard procedure of testing the null hypothesis of equality versus a hypothesis of strict inequality. We conducted a t-test of difference in means as well as the Wilcoxon -Mann-Whitney (MWW) Z-test. Both tests coincided with each other in their results. In this paper we only present the results for the MWW test.

case of the experiment; i.e, in T1 and periods 1 to 8 of T2, T3 and T4. From this result, we may argue that players from both subject pools tacitly try to coordinate their actions in order to reach the threshold and buy the technology. In this sense, the threshold can be interpreted as what Schelling (1960) called a "focal point."

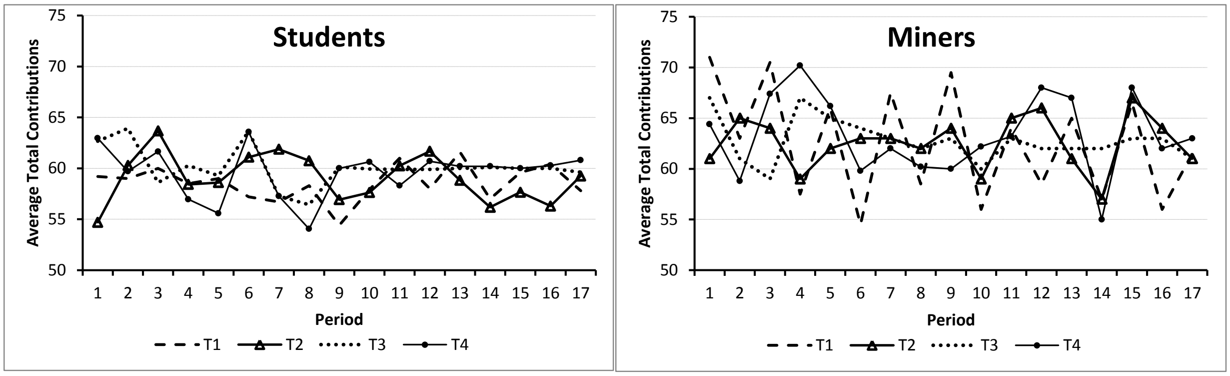


Figure 4.1. Average group contributions in treatments per period.

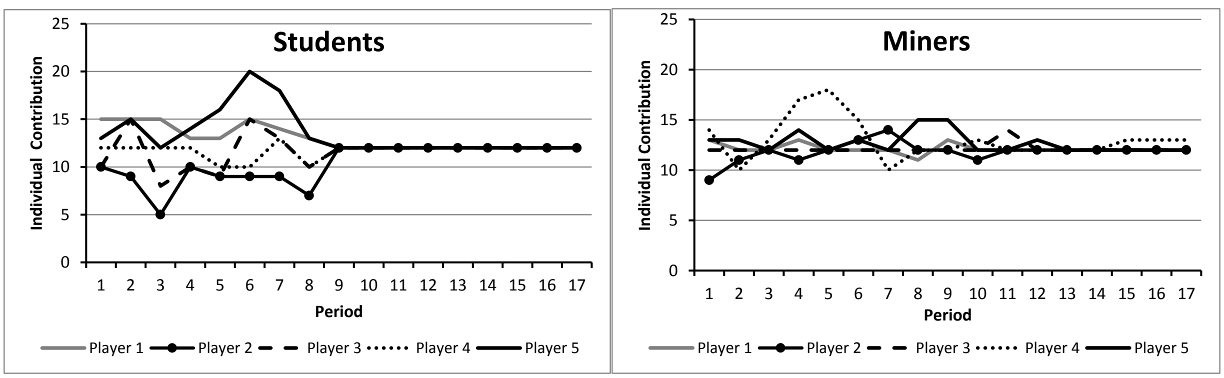


Figure 4.2. Example of individual contributions in co-managament (T3).

An interesting result can be observed in the co-management treatment (T3). From periods 9 to 17, once players can communicate each other and with the external advisor, the oscillating pattern is less evident, and even for students this pattern disappears. In this treatment (T3) students do not only continue trying to coordinate their actions but also to achieve the Pareto-efficient outcome in which everyone fairly contributes 12 tokens. This is evident by looking at Figure 4.2 which shows an example of individual contributions in a chosen group of miners and one of students. Miners, in turn, also try to coordinate their decisions but their total contributions tend to be above the efficient Nash equilibrium outcome.

By and large, by comparing charts of Figure 4.1 we detect that miners made contributions that are greater than contributions made by students. From Table 4.4 we confirm that miners on average contribute more than students in all treatments (*p-value*<0.001). This difference in contributions may account for the larger proportion of successful contributions ($\Sigma_i \geq T$) that in general miners achieved (see Table 4.5). Under co-management (T3), both miners and students try to coordinate their actions in order to reach the efficient outcome of collecting 60 tokens (see Table 4.5). This coordination leads to provision rates close to 100% in the case of students. Miners, meanwhile, only succeeded in achieving the efficient Nash equilibrium of contributing exactly 60 tokens half of the time.

Table 4.4. Average and mean standard deviations of individual contributions for each treatment.

	Average Contribution			Standard Deviation		
Treatment	Students	Miners	Difference	Students	Miners	Difference
Baseline	11.84	13.34	1.48***	1.93	2.71	0.78***
Exclusion	11.68	13.52	1.84***	1.73	2.02	0.29
Co-manag.	11.97	12.67	0.7***	0.59	1.37	0.79***
Exclu. & Co-manag.	12.03	13.04	1.01***	1.43	3.17	2.05***

***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively.

Table 4.5. Proportion of successful and efficient provisions.

		Successful Provisions (%)			Efficient Nash Equilibria (%)		
	Treatment	Students	Miners	Difference	Students	Miners	Difference
Stage 1 (Period 1 to 8)	Baseline	53.75	57.14	3.39	16.2	0	-16.2
	Exclusion	50	85	35***	5.6	0	-5.6
	Co-manag.	62.5	82.1	19.6*	22.2	7.1	-15.1
	Exclu. & Co-manag.	52.8	86.7	33.9***	9.7	2.9	-6.8
Stage 2 (Period 9 to 12)	Baseline	55	75	20*	29.4	5	-24.4
	Exclusion	55.6	78.9	23.3*	19.8	3.3	-16.4
	Co-manag.	95.1	92.5	-2.5	91.4	52.5	-38.9*
	Exclu. & Co-manag.	95.1	69	-26.1**	76.5	0	-76.5***

***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively.

From Table 4.6 we can see that the mechanisms we examined in the experiments had an effect on the average number of tokens that each individual contributed. For instance, when there is exclusion from private benefits, the fact that there is also co-management affects students and miners differently (T2-T4, T3-T4). Moreover, if there is no exclusion, co-management has the same effect on both subject pools. However, provided that in a TPGG individual (group) contributions are close to or oscillating around the threshold or the cost-sharing contribution, a test of means as shown in Table 4.6 does not show the whole effect that each treatment has on the decisions made by players in the experiment. Therefore, to complement this analysis, we also performed an analysis of the standard deviations of contributions.

Table 4.6. Test of treatment effects on average individual contributions.

	Treatment	P-value of the MWW test			
		T1 – T2	T1 – T3	T2– T4	T3– T4
Students	Baseline (T1) Exclusion (T2) Co-management (T3) T2 & T3 (T4)	0.131	0.0044***	0.0045***	0.0275**
Miners	Baseline (T1) Exclusion (T2) Co-management (T3) T2 & T3 (T4)	0.7173	0.0038***	0.4707	0.0735*

***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively.

The agreement students make in co-management is not only efficient but also equitable. In general, there is a clear effect of co-management in reducing the variability of individual contributions (see Tables 4.4 and 4.7). Notwithstanding players of both subject pools try to agree on making fairly contributions of 12 tokens, students get better outcomes in doing so. We confirm this result with students' lower standard deviation of individual contributions per period in co-management (see Table 4.4) and the trend of individual contributions shown in the examples of Figure 4.2.

When co-management is combined with exclusion (T4), the efficient and sustained outcome that players can achieve under co-management (T3) is weakened. On one side, students continue having high successful provision rates and frequent efficient outcomes, but with a standard deviation that is higher than in T3 (see Tables 4.4 and 4.7). On the other side, in T4 miners failed to produce efficient outcomes, successful provisions are even much lower than in T2, and the standard deviation of individual contributions is higher than not only in T3 but also in T2 (*p-value*<0.0001). Indeed, in T4 miners present the oscillating pattern observed in both the baseline and the exclusion treatment (T2).

Table 4.7. Test of treatment effects on standard deviations of contributions.

	Treatment	P-value of the MWW test			
		T1 – T2	T1 – T3	T2– T4	T3– T4
Students	Baseline (T1) Exclusion (T2) Co-management (T3) T2 & T3 (T4)	0.0000***	0.0000***	0.0000***	0.0012***
Miners	Baseline (T1) Exclusion (T2) Co-management (T3) T2 & T3 (T4)	0.0004***	0.0000***	0.0000***	0.0000***

***, **, and * denote statistical significance of the difference at 1%, 5%, and 10%, respectively.

Of this non-parametric analysis we can conclude that there are convergences and divergences in the behavioral patterns that miners and students show in the framed economic experiment. In order to gain more insights about the external validity of the lab experiment, we now proceed to show a parametric analysis in which we consider four sets of variables. Firstly, we include the socioeconomic and personality characteristics already described in Table 4.3. Additionally, we include three categorical variables (T2, T3, T4) which take the value of one if the player was exposed to one of these treatments, and zero otherwise. The parametric analysis also takes into account four dynamic variables: the total contributions of the other four members of the group in the previous period ($\Sigma_{j\neq i,\ t-1}$), the difference between group contribution and the threshold in the previous period (Difference_{t-1}), interactions among these two variables, and a variable that captures the time trend (*Trend*). In addition to this, we also measured some variables related to miners' knowledge of alternative technologies and perception of the effects of mercury pollution. The specification of the estimated behavioral model considers that for the dependent variable (individual contributions) we have a panel of data with discrete values. In Table 4.8 we present the estimations results of Poisson regressions with random-effects.[6]

In both subject pools socioeconomic and demographic variables do not explain individual contributions. Among the set of personality traits only *trust* in others positively affects the contributions students and miners made in the experiment. These results thus support previous findings in the literature according to which this trait would increase the subject's concern for the provision of the public good and therefore a rise in voluntary contributions (see, e.g., Czap and Czap, 2010; Czap et al., 2010; Kocher et al., 2011).

In these regressions treatment variables are not significant either. However, we should recall that in order to enhance to understanding of the effects of these treatments we should also look at the effect of these mechanisms on the variability of contributions across the game. In effect, in Table 4.9 we show that co-management contracts the variability of group contributions in both subject pools. It happens in spite of the fact that this variability tends to increase along the game. However, in miners the effect of co-management vanishes when the mechanism is combined with exclusion, whereas in students the effect of co-management surpasses that of exclusion.

[6] We also estimated a negative binomial model with random effects and an OLS random effects regression. The results of the estimations of the three specifications coincided with each other. The variable education was dropped in these estimations because the level of undergraduate education was not measured in the sample of students.

Table 4.8. The determinants of individual contributions in the TPGG (Poisson panel model).

Variable	Students		Miners		Pooled	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Trend	-0.002	0.002	-0.009**	0.004	-0.003*	0.002
T2	-0.011	0.022	0.069	0.043	0.001	0.021
T3	0.018	0.023	0.019	0.041	0.009	0.02
T4	0.029	0.023	0.033	0.043	0.03	0.021
$\Sigma_{j\neq i,\ t-1}$	-0.026***	0.003	-0.019***	0.003	-0.022***	0.002
Difference $_{t-1}$	0.028***	0.005	-0.0001	0.005	0.015***	0.003
$\Sigma_{j\neq i,\ t-1}$ * Difference $_{t-1}$	-0.0001	0.0001	0.0003***	0.0001	0.0001*	0.0004
Age	0.002	0.003	0.0012	0.002	0.001	0.001
Sex	0.002	0.017	0.037	0.07	0.006	0.02
Income	-0.005	0.005	0.003	0.014	0.0002	0.007
Risk	0.002	0.004	0.007	0.008	0.004	0.004
Trust	0.029*	0.017	0.081*	0.047	0.046***	0.018
Empathy	0.011	0.019	0.002	0.029	-0.002	0.014
Self-control	0.002	0.017	-0.015	0.035	-0.005	0.15
Constant	3.63***	0.16	3.44***	0.204	3.59***	0.012
Type (1 student 0 miner)					-0.084***	0.027
Residence time			0.002	0.04		
Know new tech.			0.106**	2.01		
Limitation in access			0.018	0.4		
Have used tech.			-0.108**	-2.15		
Participation in training			0.016	0.33		
Participation is useful			-0.046	-0.25		
Health effects			-0.137***	-3.12		
Mine			0.015	0.3		
N	185		85		270	
Wald chi2(k)	117.12***		88.5***		182.2***	

*** significant at 1%, ** significant at 5%, * significant at 10%.

Table 4.9. OLS model of treatment effects on standard deviation of c_i.

	Students		Miners	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
T2	0.057	0.117	-0.327	0.179*
T3	-2.045	0.108***	-1.697	0.216***
T4	-1.269	0.151***	0.106	0.207
Trend	0.028	0.01***	0.084	0.016***
Constant	2.52	0.099***	3.117	0.213***
Wald chi2(k)	519.64***		93.95***	

*** significant at 1%, ** significant at 5%, * significant at 10%.

For the case of linear public goods, Croson (2006) argues that when the sign of the coefficient of $\Sigma_{j\neq i,\ t-1}$ is positive, experimental subjects are reciprocators, whereas a negative sign would indicate altruism. For the case of a threshold public good we must bear in mind that subjects wish to reach the threshold with the aim of getting the public good provided. Therefore, subjects would consider not only others' previous contributions but also the difference between total contributions and T ($Difference_{t-1}$). The sign of the coefficient of this interaction term in the case of miners is positive and significant. Thus, given a difference between Σ_{t-1} and T, higher contributions of other players trigger higher allocations of tokens to the group account. From these results we can conclude that miners act as reciprocators, whereas no conclusion can be extracted for the sample of students.

In regards to the negative sign of $\Sigma_{j \neq i, t-1}$ for both subject pools, it would be an indication of strategic behavior. According to this result, when a player receives information that the rest of the group made higher contributions in the previous period, he would contribute less in the ongoing period in the expectation that they keep that level of contributions, which should be hopefully high enough to reach the threshold.

We also estimated a Poisson panel model with random effects pooling data of both samples. In these estimations, also shown in Table 4.8, besides the findings already discussed in the parametric analysis, we may confirm the results of the non-parametric analysis. Accordingly, the coefficient of the variable *Type* indicates that, conditional on socioeconomic, attitudinal and dynamic variables, players recruited from the college community on average contributed 0.09 tokens less than miners (*p-value*=0.002).[7]

4. Discussion

What do our results suggest about the external validity of TPGGs? In our framed experiments the behavior of miners and students is similar to previous multi-period context-free TPGGs made in the lab. For instance, the oscillating pattern has also been reported by Croson and Marks (2000) and Cadsby and Maynes (1999). Moreover, in the baseline of the experiments we obtained provision rates that are close to those reported by Croson and Marks (2000) and Cadsby et al. (2008). For a net reward that is equal to 12 and a step return of 2, these authors reported provision rates that vary between 0.51 and 0.59.[8] Additionally, similarly to Corson and Marks (2000), in our experiments the efficient Nash equilibrium is hardly ever achieved and contributions have a tendency to be decreasing over time, particularly in the experiments with miners.

In addition to the behavior of both samples in a threshold public good environment, we also studied the effect of the application of mechanisms aimed at encouraging collective action: co-management and exclusion from the private benefits of the alternative technology. The results

[7] In a Poisson regression model the marginal effects are estimated by computing $\hat{\beta}.\exp(\hat{\beta}'x)$, where $\hat{\beta}$ is the vector of estimated parameters (Greene, 2000).

[8] In our base case the net reward is defined as $(R+\rho - T/n)$, and the step return as $(n.(R+\rho)/T)$.

suggest that the effects of these mechanisms depend on the characteristics of subject pool. Co-management appears to have similar effects on miners and students in terms of the provision of the public good and achievement of Pareto-efficient outcomes. However, the effect of this institutional arrangement is different when it is combined with an economic incentive such as exclusion. While in students the effect of co-management prevails over the effect of exclusion, in the sample of miners the effect is completely the opposite and subjects could not agree on the best social outcome.

Given the contrasts we have found in the experiments the external validity of lab experiments must be taken cautiously. In general, scholars have arrived to the same kind of conclusion for diverse environments when comparing lab and field experimental results. Some examples are as follows: ultimatum and dictator games (Carpenter et al., 2005; and Carlsson et al.; 2012); social dilemmas (Anderson et al., 2012) including common-pool resource dilemmas (Cárdenas, 2009), and; wage markets (Fehr and Gächter, 2008).

Another part of the debate of external validity of economic experiments is focused on whether subjects behaves in natural field situations as they do in either the lab or in a field experiment. For instance, Laury and Holt (2008), Rondeau and List (2008) and Voors et al (2012) found weak correlation between the behavior people have in experiments with an artificial environment that entails a public good dilemma, and field behavior in a naturally occurring public good. A common conclusion and recommendation is that experimentalists in economics should be cautions when extrapolating their results to explain or predict behavior in the real-world.

Smith's (1976, 1982) precept of parallelism does not always hold for many reasons. Levitt and List (2007) pointed out some of them: presence or absence of moral and ethical considerations, the subject pool, the context in which the choice is embedded, the extent to which one's actions are scrutinized by others and the nature of that scrutiny, and the stakes of the game. Overall, one the main reason for this divergence is that the conditions we find in the lab are rarely, if ever, the same we find in the field.

Carpenter et al. (2005) pointed out that the behavioral differences in their sample of college students and workers might be due to the differences in the social framing of these subject pools. In our experiments, clearly the social context of both pools is different. On the one hand, participants in our lab experiments are typical university students who in most of the cases depend on their parents for living expenses and come from different regions of the country. On the other hand, miners' social context is characterized by factors such as conspicuous consumption and the stress associated to the current armed conflict present in those zones (Saldarriaga-Isaza et al., 2013a).

The level of education does make remarkable difference between these two populations. Consequences of this fact may be twofold. Firstly, better computing skills would make free-riders students to better calculate the contribution level that maximizes their individual payoff provided others' contributions. Moreover, the computing skills can lead all subjects to figure out what the best outcome for the group is – i.e., the Pareto-efficient outcome that maximizes social welfare–, especially once they can share ideas and perceptions about the game.

The familiarity that experimental subjects (miners vs. students) have with the framework of the game also impacts the decision-making process in social dilemma situations. For instance, in his comparison of students against villagers, Cárdenas (2009) detected a possible nonextraction value of standing trees in common forests, which explain the difference in the forest stocks between subject pools in a framed common-pool resource experiment. Likewise, in our comparison of students versus miners, it is more likely that miners are aware of the harmful effects of mercury pollution than what students are. Such difference in the perceptions about mercury pollution might explain why miners on average contributed more than students in the acquisition of the technology that would eventually cut emissions of this chemical element.

We also collected information on personality traits that have been said to drive decisions in public-good dilemma settings: trust in others, risk attitudes, self-control and empathy (see, e.g., Czap and Czap, 2010; Czap et al., 2010; Kocher et al., 2011, 2012). We gather this information to correlate behavior in the experiment and the behavior that participants claim to have in their real lives. Carpenter and Seki (2006), for instance, found the expected correlation between collective action in an experiment with fishing communities and variables that measure cooperation attitudes and internal and external orientation of the participants

Unexpectedly, even though we found that people from inside and outside the laboratory were statistically the same in terms of these traits, such traits did not explained contributions to the common fund except *trust*. In our opinion, this result does not indicate that those traits definitely do not affect collective action in the framework of our experiment. Instead, it would be an indication of the need of further research about how to measure these variables and their correlation with behavior in social dilemmas.

5. Conclusion

In this paper we investigate the external validity of a threshold public good game that was framed taking into account some of the features that are found in the field. This comparison between university students and artisanal gold miners in Colombia included the tests of how behavior in this framed threshold public good setting is affected by some institutional arrangements: exclusion from private benefits and co-management. The contribution to the debate about the external validity of experiments done with students is that participants in the field were recruited from a subject pool that has never been employed before in the literature of experimental economics. Moreover, we modified the artificial environment and enriched it with information concerning the social dilemma faced by many artisanal gold mining communities worldwide.

Both in the lab and the field we obtained results that are in line with previous multi-period TPGGs conducted in the laboratory: contributions have both a tendency to be decreasing and an oscillating pattern over time. However, we got mixed results in the institutional arrangements we tested. On the one hand, the effects were of different magnitude where co-management made subjects to coordinate their actions in order to achieve efficient and equitable outcomes. Additionally, in both subject pools there were no clear effect of exclusion.

On the other hand, when exclusion and co-management were combined, the effects differed between the subject pools: meanwhile students could agree on contributing a number of tokens that is a Pareto-efficient and equitable outcome, miners could not. Regarding the achievement of efficient outcomes, university students performed better than miners. To what extent the degree of education is an important driver of these differences in performance is a question for future research.

An implication of these results is that, and as other authors have suggested, we must have caveats when thinking about extrapolating lab results. Moreover, considering students' better performance in the experiment, a policy implication is that efforts focused to improve the education levels of artisanal gold mining communities might be required for a better management of natural resources.

Further research that examines the differences between lab and field experiments is needed, particularly in the analysis of other-regarding preferences and social dilemmas. Levitt and List (2007) have already pointed out that such differences might be explained, among others, by how one's actions are scrutinized by others and the nature of that scrutiny. Therefore, in the context of the public good dilemma faced by artisanal gold mining communities and the experiment we have presented in this paper, one possible branch for future research might be the investigation of social norms like, for example, how others in community would treat people who do not contribute.

References

[1] Anderson, J., Burks, S.V., Carpenter, J., Götte, L., Maurer, K., Nosenzo, D., Potter, R., Rocha, K., and Rustichini, A., 2012. Self-selection and variations in the laboratory measurement of other-regarding preferences across subject pools: evidence from one college student and two adult sample. Experimental Economics, DOI 10.1007/s10683-012-9327-7.

[2] Bardsley, N, Cubitt, R., Loomes, G., Moffatt, P., Starmer, C., Sugden, R., 2010. Experimental Economics: Rethinking the Rules. Princeton University Press, New Jersey.

[3] Cadsby, C., Maynes, E., 1999. Voluntary provision of threshold public goods with continuous contributions: experimental evidence. Journal of Public Economics 71(1), 53-73.

[4] Cadsby, C., Croson, R., Marks, M., Maynes, E. 2008. Step return versus net reward in the voluntary provision of a threshold public good: An adversarial collaboration. Public Choice 135(3-4) 277-289.

[5] Cárdenas, J.C., 2009. Experiments in environment and development. Annual Review of Resource Economics 1, 157–82.

[6] Carlsson, F., He, H., Martinsson, P., 2012. Easy come, easy go: The role of windfall money in lab and field experiments. Experimental Economics, DOI: 10.1007/s10683-012-9326-8.

[7] Carpenter, J.P, Harrison, G.W., List, J.A., 2005. Field experiments in economics: an introduction, in: Carpenter, J.P., Harrison, G.W., List, J. (Eds.), Field Experiments in Economics. Elsevier, 1-15.

[8] Carpenter, J.P, Seki, E., 2006. Competitive Work environments and social preferences: field experimental evidence from a Japanese fishing community. Journal of Economic Analysis and Policy: Contributions to Economic Analysis and Policy 5(2), Article 2.

[9] CDS -Centre for Development Studies- (2004). Livelihoods and Policy in the Artisanal and Small-Scale Mining Sector -An Overview. University of Wales Swansea, UK.

[10] Chaparro, E., 2003. Small-scale mining: a new entrepreneurial approach. CEPAL, Serie Recursos Naturales e Infraestructura No. 9.

[11] Croson, R., Marks, M., 2000. Step returns in threshold public goods: A meta- and experimental analysis. Experimental Economics 2(3), 239-259.

[12] Croson, R., Marks, M., 2001. The effect of recommended contributions on the voluntary provision of public goods. Economic Inquiry 39(2), 238-249.

[13] Croson, R., 2006. Theories of commitment, altruism and reciprocity: evidence from linear public goods games. Economic Inquiry 45(2), 199-216.

[14] Czap, H.J., Czap, N.V., 2010. An experimental investigation of revealed environmental concern. Ecological Economics 69(10), 2033-2041.

[15] Czap, H.J., Czap, N.V., Bonakdarian, E., 2010. Walk the talk? The effect of voting and excludability in public goods experiments. Economics Research International 15, 1-15.

[16] Dufwenberg, M., Harrison, G., 2008. Peter Bohm: Father of field experiments. Experimental Economics 11, 213-220.

[17] Fehr, E., Gächter, S., 2008. Wage differentials in experimental efficiency wage markets, in: Plott, C., Smith, V. (Eds.), Handbook of Experimental Economics Results. Elsevier, pp. 120-126.

[18] Friedman, D., Sunder, S., 1994. Experimental Methods: A Primer for Economists. Cambridge University Press.

[19] Greene, W.H., 2000. Econometric Analysis. Prentice-Hall, New Jersey.

[20] Guala, F., 2005. The Methodology of Experimental Economics. Cambridge University Press, NY.

[21] Harrison, G., List, J., 2004. Field Experiments. Journal of Economic Literature 42(4), 1009-1055.

[22] Isaac, M., Walker, J., Thomas, S., 1984. Divergent evidence on free-riding: An experimental examination of possible explanations. Public Choice 43(2), 113–149.

[23] Kagel, J., 1995. Auctions: a survey of experimental research, in: Roth, A., Kagel, J. (Eds.), Handbook of Experimental Economics. Princeton University Press, Princeton, pp. 501-586.

[24] Kocher, M., Martinsson, P., Matzat, D., Wollbrant, C., 2011. The Role of Beliefs, Trust, and Risk in Contributions to a Public Good. Working Papers in Economics No 482, University of Gothenburg, Sweden.

[25] Kocher, M., Martinsson, P., Myrseth, K.., Wollbrant, C., 2012. Strong, Bold, and Kind: Self-Control and Cooperation in Social Dilemmas. Working Papers in Economics No 523, University of Gothenburg, Sweden.

[26] Laury, S., Holt, L., 2008. Altruism spillovers: Are behaviors in context-free experiments predictive of altruism toward a naturally occurring public good? Journal of Economic Behavior & Organization 65, 9-29.

[27] Levitt, S., List, J.A., 2007. What do laboratory experiments measuring social preferences reveal about the real world? Journal of Economic Perspectives 21, 153–174

[28] Marks, M., Croson, R., 1998. Alternative rebate rules in the provision of a threshold public good: an experimental investigation. Journal of Public Economics 67(2), 195-220.

[29] Marks, M., Croson, R., 1999. The effect of incomplete information in a threshold public goods experiment. Public Choice 99(1-2), 103-118.

[30] Moreno-Sánchez, R., Maldonado, J., 2010. Evaluating the role of co-management in improving governance of marine protected areas: An experimental approach in the Colombian Caribbean. Ecological Economics 69(12), 2557-2567.

[31] Murphy, J.J., Cardenas, J.C., 2004. An Experiment on enforcement strategies for managing a local environmental resource. Journal of Economic Education 35(1), 47-61.

[32] Ostrom, E., 2010. Revising theory in light of experimental findings. Journal of Economic Behavior & Organization 73(1) 68-72.

[33] Plott, C.R., 1991. Will economics become an experimental science? Southern Economic Journal 57, 901-919.

[34] Rondeau, D., List, J., 2008. Matching and challenge gifts to charity: evidence from laboratory and natural field experiments. Experimental Economics, DOI 10.1007/s10683-007-9190-0.

[35] Saldarriaga-Isaza, A., Arango, S., Villegas-Palacio, C., 2013a. The public good dilemma of a non-renewable common resource: a look at the facts of artisanal gold mining. Resources Policy 38(2), 224.232.

[36] Saldarriaga-Isaza, A., Villegas-Palacio, C., Arango, S., 2013b. Phasing out mercury through collective action in artisanal gold mining: Evidence from a framed field experiment. This thesis.

[37] Schelling, T.C., 1960. The Strategy of Conflict. Cambridge, MA: Harvard University Press.

[38] Smith, V.L., 1976. Experimental economics: Induced value theory. American Economic Review 66(2), 274-279.

[39] Smith, V.L., 1982. Microeconomic Systems as an Experimental Science. American Economic Review 72, 923-955.

[40] Voors, M., Turley, T., Kontoleon, K., Bulte, E., List, J., 2012. Exploring whether behavior in context-free experiments is predictive of behavior in the field: Evidence from lab and field experiments in rural Sierra Leone. Economics Letters 114, 308-311.

APPENDIX C

Payoff Table

ASIGNACIONES DE ELLOS A LA CUENTA GRUPAL	Mi Asignación a Cuenta Grupal																									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
0	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
1	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
2	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
3	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
4	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
5	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
6	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
7	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
8	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
9	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
10	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
11	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
12	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
13	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
14	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
15	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
16	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
17	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
18	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
19	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
20	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
21	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
22	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
23	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
24	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
26	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
27	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
28	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
29	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
30	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
31	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
32	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
33	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
34	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
35	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	24
36	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	24
37	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	26	25	24
38	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	27	26	25	24
39	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	28	27	26	25	24
40	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	29	28	27	26	25	24
41	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	30	29	28	27	26	25	24
42	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	31	30	29	28	27	26	25	24
43	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	32	31	30	29	28	27	26	25	24
44	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	33	32	31	30	29	28	27	26	25	24
45	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	34	33	32	31	30	29	28	27	26	25	24
46	25	25	25	25	25	25	25	25	25	25	25	25	25	25	35	34	33	32	31	30	29	28	27	26	25	24
47	25	25	25	25	25	25	25	25	25	25	25	25	25	36	35	34	33	32	31	30	29	28	27	26	25	24
48	25	25	25	25	25	25	25	25	25	25	25	25	37	36	35	34	33	32	31	30	29	28	27	26	25	24
49	25	25	25	25	25	25	25	25	25	25	25	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
50	25	25	25	25	25	25	25	25	25	25	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
51	25	25	25	25	25	25	25	25	25	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
52	25	25	25	25	25	25	25	25	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
53	25	25	25	25	25	25	25	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
54	25	25	25	25	25	25	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
55	25	25	25	25	25	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
56	25	25	25	25	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
57	25	25	25	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
58	25	25	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
59	25	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
60	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
61	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
62	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
63	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
64	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
65	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
66	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
67	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
68	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
69	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
70	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
71	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
72	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
73	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
74	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
75	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
76	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
77	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
78	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
79	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
80	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
81	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
82	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
83	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
84	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
85	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
86	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
87	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
88	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
89	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
90	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
91	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
92	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
93	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
94	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
95	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
96	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
97	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
98	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
99	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
100	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24

Chapter 5

--

A behavioral model of collective action in artisanal and small-scale gold mining

Abstract

There is a rising global concern about mercury-usage in artisanal and small-scale gold mining because of its harmful effects on ecosystems and human health. Associative entrepreneurship has been promoted as a way of accessing to alternative techniques to deal with this mercury pollution in artisanal and small-scale gold mining. We built a behavioral simulation model to assess the feasibility of associative entrepreneurship (collective action) in the context of the public-good dilemma that gold mining communities face. The model is constructed based on results from field economic experiments, and properly replicates the observed behavioral patterns; thus, it reveals that sustained collective action is feasible when miners completely understand the social dilemma they face, but that self-organization is not possible. Features such as reciprocity and temptation to free ride partially explain why self-organization fails. In such a case, external intervention places a key role to promote programs that improve the understanding of the social dilemma faced by artisanal gold miners.

1. Introduction

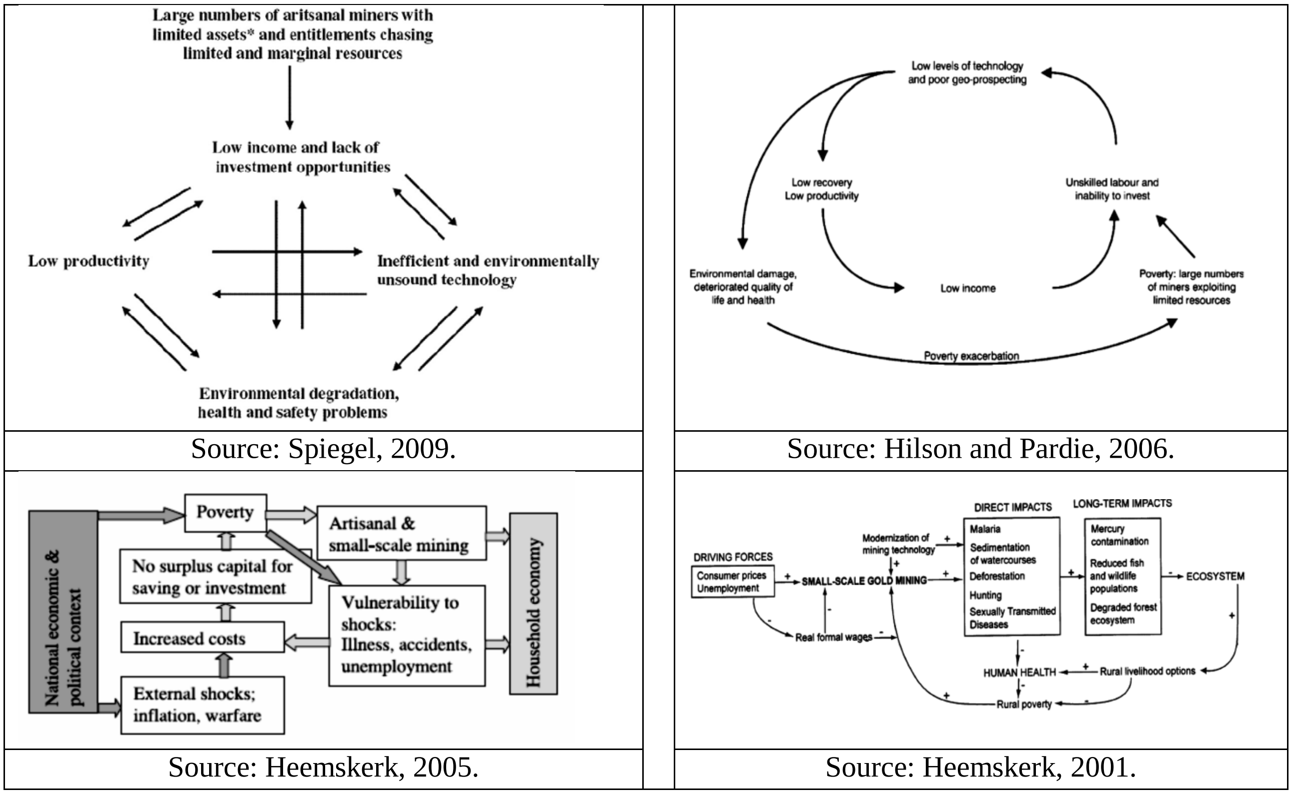
In the design and implementation of support policies for communities involved in artisanal and small-scale gold mining (ASGM), several scholars have stressed the importance of having a good understanding of the social dynamics of these communities (Hentschel et al., 2002; Hilson, 2005, 2006; Hilson et al., 2007; Sinding, 2005; Spiegel, 2009; Dondeyne et al., 2009). Poor performance of some projects aimed at regularizing and providing assistance to ASGM, has been said to be in part due to an insufficient understanding of the dynamics of target communities (Keita, 2001; Hilson, 2007).

Communities involved in ASGM face a social dilemma that is found in the way gold is recovered. In the gold recovery (ore beneficiation) process, a miner usually employs the apparently cheapest and traditional available technique –mercury amalgamation– to gain the maximum short-run benefit for himself. However, the entire community is worse off than if a cleaner and more productive technology were used. This social dilemma can be classified as a public-good dilemma and it concerns the control of pollution resulting from this process.

In a public-good dilemma people find it costly to contribute to the provision of the public good and prefer others to pay for its provision instead (Ostrom, 1998). When everybody in the community follows this type of strategy, the public good is underprovided or not provided at all, while pollution persists. However, the entire community might be better off if everyone contributes to the provision of the public good (Ostrom, 1998). In an ASGM context, cleaner technologies for gold recovery could be accessed to under an association scheme that involves entrepreneurial activities; i.e., through collective action. Nevertheless, some incentives and personality traits might hinder the emergence of such pro-social behavior.

A kind of policy aimed at dealing with mercury pollution in ASGM has been the promotion of organization of miners with an entrepreneurial criterion (Saldarriaga-Isaza et al., 2013a). In addition to improve the relationship with the state, associative entrepreneurship would enable miners to accumulate the financial capital required to obtain cleaner and more productive technologies that are beyond the budget of most miner families (Hentschel et al., 2002; Hinton et al., 2003; Hilson and Potter, 2003; CDS, 2004; Ghose and Roy, 2007; Spiegel, 2009). This financial capital is difficult to obtain from the financial system, which perceives small-scale mining as a risky activity (Chaparro, 2003). This fact, added to the low tendency of miners to save money for investing (Saldarriaga-Isaza et al., 2013a), make of associative entrepreneurship an option for small-scale miners to increase their financial capital.

In an effort to assess the feasibility of associative entrepreneurship and collective action in the context of this public-good dilemma, in this paper we propose a behavioral simulation model. This approach goes beyond the analysis done so far by some scholars who through visual models have integrated, for instance, the most relevant factors that explain poverty-traps in ASGM (Heemskerk, 2001, 2005; Hilson and Pardie, 2006; Spiegel, 2009). Even though these models represent the core relationships that drive poverty-traps in ASGM (see Figure 5.1), it is still no clear from these visual models, for instance, which the attributes that would prevent the use of cleaner technologies are, in a way that allows the design of strategies for overcoming resistance to technological change.



Source: Spiegel, 2009.

Source: Hilson and Pardie, 2006.

Source: Heemskerk, 2005.

Source: Heemskerk, 2001.

Figure 5.1. Visual models of poverty trap in ASGM.

Modeling has been established as a useful tool in the process of creating scientific explanations of how systems work and assessing alternatives to transform these systems (Morecroft, 2007). In fact, modeling by simulation has become an important methodology for theory development in the literature about organizations and to explain social phenomena (Vázquez et al., 1996; Bowles, 2004; Davis et al., 2007). The use of simulation has been previously employed in the analysis of situations that imply a social dilemma. Using the simulation method *System Dynamics*, Castillo and Saysel (2005) explained behavior of individual decision rules of communities whose livelihood depends upon the extraction of common pool fisheries, and where a common-pool resource dilemma is implied.

The paper is organized as follows. In the next section, we provide a brief discussion of the theory of collective action and our approach to model individual decision rules of artisanal gold miners, considering the aforementioned public-good dilemma. Thereafter, the behavioral simulation model and some issues on model validity are presented, followed by the simulation results and policy analysis. We use simulation methods to explain the endogenous dynamics underlying behavior of individuals involved in ASGM, in situations that involve a public-good dilemma and in which collective action is a challenge. In the final section, we conclude with a discussion of this model and provide some insights for future work.

2. Collective Action and Natural Resources

Extensive fieldwork has established that under some circumstances individuals do voluntary organize themselves to, for example, protect natural resources (see, e.g., Ostrom, 2000, 2010; Anderies et al., 2011; Cardenas, 2011). Ostrom (1998) pointed out that some of the structural variables that affect individual's decisions in situations involving social dilemmas are the size and heterogeneity of the group of participants, discount rates, and the level of information available to participants. Besides these variables, face-to-face communication (cheap-talk) is another factor that affects the individual attributes that finally shape behavior in a social dilemma condition (Ledyard, 1995; Ostrom, 1998; Anderies et al. 2011). Such individual attributes are trust, reciprocity and reputation (Ostrom 1998, 2000), which positively reinforce each other and affect the level of cooperation (extraction effort in a common-pool resource, or contributions to a public good). Such level of cooperation finally determines the benefits that individuals earn from their social interactions (see Figure 5.2).

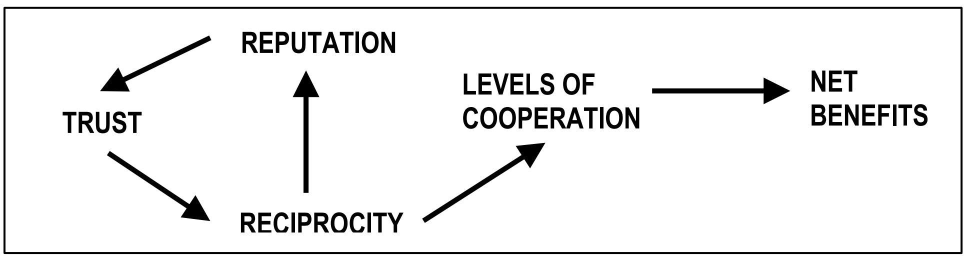


Figure 5.2. The core relationships of collective action.
Source: Reproduced from Ostrom (1998).

Laboratory experiments of public-goods provide empirical evidence of Ostrom's theory. For instance, Czap and Czap (2010) and Kocher et al. (2011) show that the level of trust in others that someone has, may positively determine the concern the subject has for the provision of the public good, and therefore his levels of donations to the provision of the public good. Ostrom (2000) and Fischbacher et al. (2001) report that certain type of player, a "conditional cooperator," may lead to relatively high levels of contributions in public good games. A conditional cooperator is someone who is willing to initiate cooperative action when he estimates others will reciprocate, and to repeat these actions as long as a sufficient proportion of the others involved reciprocate (Ostrom, 2000). However, Fischbacher and Gächter (2010) found that players in a public good game are not complete but imperfect conditional cooperators, and this feature is the explanation for the contributions to decline in finitely repeated linear public good games.

When conditional cooperators exist and individuals use reciprocity in their decisions, there is "an incentive to acquire a reputation for keeping promises and performing actions with short-term costs but long-term net benefits" (Ostrom, 1998, p. 12). Additionally, in cases where the relation between individuals is recurrent, and they have the opportunity of retaliation of those who defect, cooperation is more likely to occur (Bowles, 2004).

In addition to the effect of the structural variables on collective action mentioned by Ostrom (1998), a key ingredient for explaining the success or failure of a community in solving a social dilemma is the context. Different kind of broader contextual variables such as the resource system (Ostrom, 2007), market conditions (Castillo et al., 2011), and historical and ecological settings (Prediger et al., 2011) generate differences in the behavioral patterns and decision-making processes of resource users.

Finally, another driver of decision-making in social dilemmas is the *homo-economicus* or rational profit maximizer from the neoclassical economy. In this regard, Castillo and Saysel (2005) pointed out that some aspects of human behavior such as temptation to free-ride and profit maximization, are important drivers of individual decision-making in situations involving a common-pool resource dilemma.

In the next section we propose a model of individual decision rules of artisanal gold miners, which considers the aforementioned aspects of collective action in social dilemmas. The model is expected to improve the understating of the societal dynamics of ASGM communities. Although there are certainly other mechanisms that would explain the poverty-trap in this sector (see, e.g., Hilson and Pardie, 2006), we focus our attention on the social (public-good) dilemma as it relates to the technology trap that causes pollution from the gold recovery process to persist.

3. Modeling Approach of Decision Making in ASGM

3.1 System Dynamics Model

We develop a behavioral simulation model in order to improve the understanding of decision-making in ASGM. These methods allow describing and analyzing how complex social systems work (Sterman, 2000; Morecroft, 2007; Davis et al., 2007). The simulation model presented in this paper endogenously explains the behavior of ASGM social systems, considering the public-good dilemma studied and the most relevant aspects of the system. The interaction among these elements is captured by feedback (causal) loops diagrams which represent the structure of the socio-ecological system (Sterman, 2000).

With simulation, one can represent the tendency that sometimes economic agents have to underestimate delays and misperceive certain nonlinearities (Sterman, 1989; Moxnes, 2004). For the public-good dilemma observed in ASGM, these nonlinearities can be found in aspects such as the relationship between group's trustworthiness and willingness to cooperate (Castillo and

Saysel, 2005). Also, there might be other instances of these nonlinearities such as in the productivity (extraction per unit of effort) for a given technology, the dynamics of the resource itself and the scarcity perception of it. Additionally, in issues such as investment decisions or the perception of the unhealthy effects of pollution, the temporal difference between cause and effect can be huge (Hilson, 2006). Such delays lead to make decisions that do not consider these effects, or that consider them but when it is too late. Overall, these misperceptions lead to decisions that imply mismanagement of natural resources (Moxnes, 2004).

In order to consider the complexity underlying most socio-ecological systems, we first think of such systems as a dynamic system in which personal, social, economic, political and natural components are constantly interacting (Dudley, 2008). The model structure of our analysis is based on the core relationships of collective action proposed in Ostrom's (1998) theory of collective action, some of the main features of a model proposed by Castillo and Saysel (2005), and on the outcomes of an economic experiment conducted both in the lab (with university students) and the field (with small-scale gold miners) between October and November of 2012.

The economic experiment supports the construction of the model, which considers an ASGM framework where a cleaner and more productive technology for the gold recovery process could be accessed to under a scheme of associative entrepreneurship. The essential condition that governs this kind of association is the contribution to a common fund in order to raise the minimum financial capital to cover the cost of the technology. However, a subject might be tempted to free-ride; i.e., not to contribute but to enjoy the benefits of both a better environmental quality and the higher efficiency of the new technology in the recovery process. Under the conditions of non-exclusion and non-rivalry in the positive externalities derived from the adopted technology, a threshold public good game was carried out. In the game, players must raise a minimum amount of tokens (*T*) to cover the cost of the alternative technology.

In the baseline of the experiment, each of the 5 participants of a group had to choose which part of his endowment (*E*) of 25 tokens to contribute to a group account. This endowment was assigned at the beginning of each of the 17 periods of the game. If *T* (60 tokens) was not reached in the round, the individual's payoff was his own endowment. However, when the summation of group's contributions was equal to or greater than *T*, everyone in the group received a reward of 24 tokens which represents the benefits of both an improved environmental quality and higher productivity; benefits that are not excludable in this base case.[1]

Considering this public-good dilemma, Figure 5.3 illustrates the causal structure or dynamic hypothesis of the model. The feedback loop diagram shows the cause-and-effect relations between the variables that explain behavior in the public-good dilemma we study. In this figure,

[1] We invite the reader to see Saldarriaga-Isaza et al. (2013b, 2013c) for a complete description of the economic experiment.

the arrows indicate the causal connection between pairs of variables. When the arrow has a positive (negative) sign, it means that a change in the variable in which the link starts, generates a change in the same (opposite) direction in the other variable (*ceteris paribus*). Small parallel lines in the diagram denote delays. The dynamic hypothesis consists of four causal loops, three reinforcing loops or positive feedbacks (denoted with *R1*, *R2* and *R3* in the center of the loop), and one balancing loop or negative feedback (denoted with *B* in the center of the loop).[2] Each of these loops is described below.

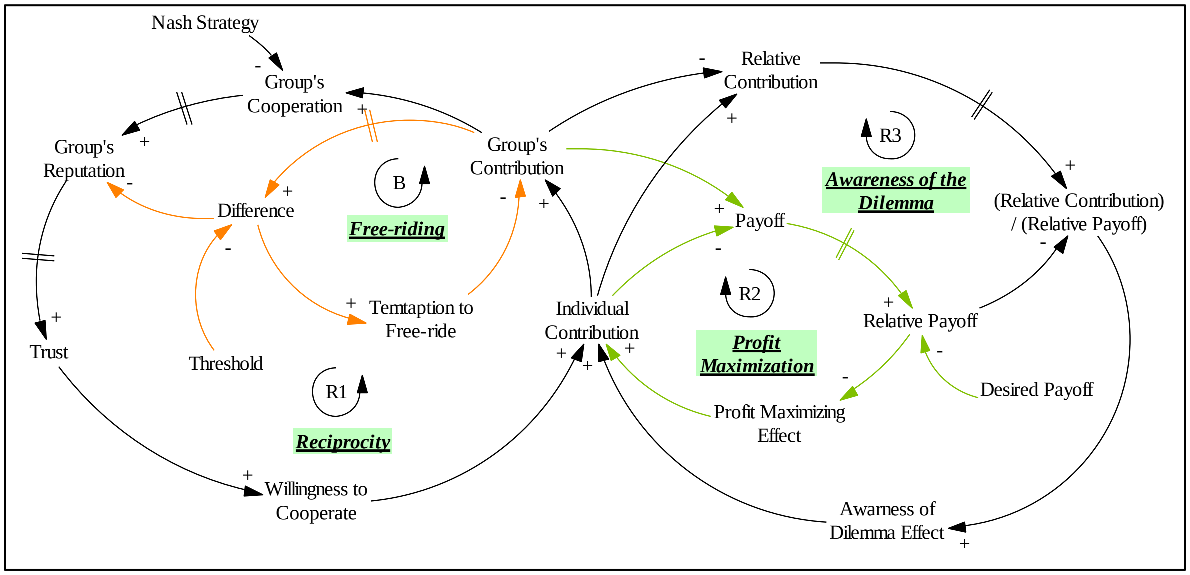


Figure 5.3. Dynamic hypothesis of the behavioral model for ASGM.

In the *reciprocity* loop (*R1*), we follow Ostrom (1998, p. 14) who defines reciprocity as the "norms individuals learn from socialization and life's experiences." In this loop, *individual's contribution* (c_i) increases *group's contribution* (Σ_i), which positively affects *group's cooperation*. The latter is defined as the total amount of donations in the group minus the symmetric free-riding equilibrium which in this game is to contribute zero tokens (Cadsby and Maynes, 1999). In other words, the higher the amount of contributions to the common fund, the more the group cooperates. Additionally, *group's reputation* to cooperate is affected by past actions (contributions) of the group. This variable is modeled as a stock or state, and it is formulated considering others' contributions ($\Sigma_{j\neq i}$) in the past and a normal (average) level of contribution of others which in this case is assumed to be an equitable donation of tokens:

$$group\text{'s } reputation_{jt} = \sum_{i\neq j} c_{i,t-1} \Big/ 48 \quad \text{for } i, j = 1, 2, 3, 4, 5 \qquad (5.1)$$

[2] See Sterman (2000) for a further explanation.

The level of *trust* the individual has on the group is clearly altered by *group's reputation* taking into account past decisions. This variable –*trust*– accumulates past group's reputation for cooperation as follows:

$$trust_{jt} = \int_0^t [group\text{'s } reputation_s] ds + trust_0 \qquad (5.2)$$

This level of trust finally affects the individual's *willingness to cooperate* (contribute) in a positive way. This relationship between *trust* and *willingness to cooperate* is represented as a nonlinear formulation in Figure 5.4.[3] In this formulation, we assume that when the levels of *trust* are high, the player reciprocates by increasing contributions to the common fund. As *trust* decreases, player's contributions decrease. In this nonlinear formulation, the player is assumed to be highly responsive to inferior levels of trust but this response slows down as trust moves toward its maximum possible value. Moreover, player's willingness to cooperate saturates at certain levels for minimum and maximum levels of *trust*.

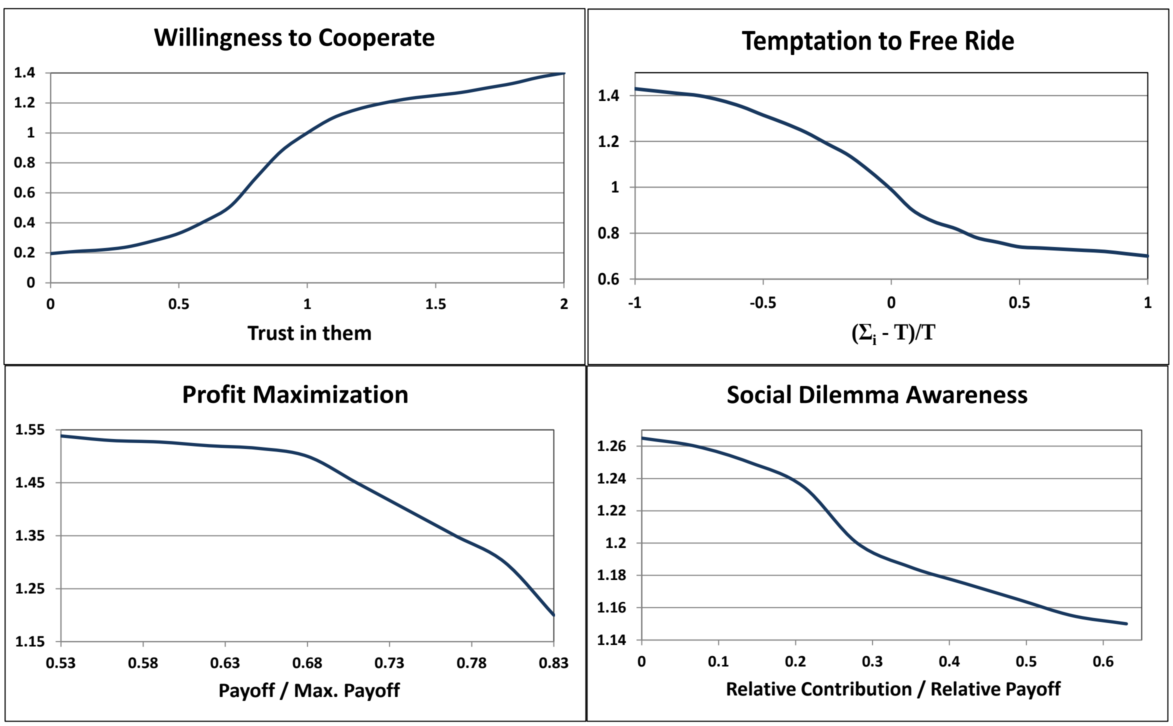


Figure 5.4. Graph Functions for Calculation of Individual Contribution.

Figure 5.3 also portrays a *free-riding* loop (*B*). In this balancing loop, the player takes into account how the difference between *group's contribution* and the threshold (*T*) has been. This difference is perceived by the player with a time delay; i.e., it corresponds to the information the

[3] Models in System Dynamics involve the use of nonlinear functions that are usually specified analytically by using table or graph functions. This kind of functions specifies the relationship between values of the independent and the dependent variables. See Sterman (2000) for further explanation.

player receives in the current period on how this difference in the previous period was. If this information indicates that the difference was positive, the player has the incentive of free riding on others by decreasing his contribution in the current decision period. Nonetheless, when total contributions drop below the threshold, the temptation disappears and individual's payoff is just his endowment. In such a case, the player would be encouraged to contribute to reach the threshold and obtain benefits from the group account. In the model, the difference between *group's contribution* and *T* is normalized taking into account the possible maximum values this difference can take according to this equation $(\Sigma_i - T)/T$. This relationship between *temptation to free ride* and this difference is modeled as a graph (table) function that is shown in Figure 5.4.

We also take into consideration that the *homo-economicus* from the neoclassical economy is present in this decision-making process. This profit maximizing behavior is represented in the reinforcing loop *R2* in Figure 5.3. According to this loop, the individual compares the average earned payoff from the previous period to the maximum payoff he could earn in a single period (49 tokens). This is modeled with a function that represents the effect of this reasoning on individual contributions, which is represented in Figure 5.4. In this function, when the average earned payoff is about the minimum that can be earned, the player would be willing to contribute more. Under this situation, contributing more would increase the chance of reaching the threshold and therefore of obtaining profits from the group account. However, as the ratio of average perceived payoff to the maximum payoff rises, the effect disappears and the player would contribute approximately the same level of tokens in the next period of the game.

As time goes by, it is also expected that each player learns about the dilemma in which he is involved. In the *awareness* loop, the player gains awareness of the public-good dilemma for higher values of the ratio of perceived relative contributions and the perceived relative payoff:

$$\frac{c_i / \sum c_i}{Payoff / Max.Payoff} \qquad (5.3)$$

When this ratio takes high values (close to 0.6), the player recognizes that by contributing few tokens relative to what others players contribute (c_i/Σ_i) is not being profitable enough; i.e., *Payoff / Max.Payoff* is low. This perception causes the individual to increase the contribution to the common fund. The social dilemma awareness, however, is better distinguished when the difference between the perceived payoff and the maximum payoff is wide (i.e., when the ratio is lower than 0.7). The learning effect decreases at an accelerated rate as the perceived payoff gets closer to the maximum possible payoff.

In summary, the decision for an association scheme that enables miners to obtain better technologies to overcome their public-good dilemma depends on several factors. The contribution decision is modeled for five representative players who make private decisions. This decision for the individual *i* is formulated as follows:

$$Contribution_i = Reference\ contribution \times Willingness\ to\ Cooperate_i \times Temptation\ to\ Free\ Ride_i \times Profit\ Maximizing\ Effect_i \,/\, Social\ Dilemma\ Awareness_i \qquad (5.4)$$

Most of these factors are nonlinear functions represented in Figure 5.4. The *reference contribution* in equation (5.4) is a parameter that was set at 12. This is the intermediate value between complete selfish donation level (0 tokens) and the maximum level the individual may donate (25 tokens).

3.2 Validation of the Model[4]

"All models are wrong, but some are useful" (Box and Draper, 1987, p. 424). In general, we cannot expect that a single system dynamics model replicates reality; however, models and their simplifications are useful to learn about how complex dynamic systems work (Sterman, 2000). In general, the validation of a system dynamics model is referred to the validity of both structure and behavior (Barlas, 1996; Qudrat-Ullah and Seong, 2010). In system dynamics, model validity is essentially seen as a building confidence process (Forrester and Senge, 1980) that involves a "variety of tests to assess the quality of both the model and the model building process" (Morecroft, 2007, p. 377). Besides tests for model structure, tests of model behavior are commonly applied to assess the adequacy of the behavior generated by the structure of the model (Forrester and Senge, 1980; Morecroft, 2007). In this sub-section we present and discuss the results of the tests we applied to our behavioral model.

3.2.1 Tests of model structure

Some of the tests mostly employed in structural validation are discussed in Forrester and Senge (1980) and Sterman (2000). A brief description of these tests is presented in Table 5.1.

In regards to the boundary adequacy and structure verification tests, the major variables of the causal loop (see Figure 5.3) are endogenously generated by the model: individual and group contributions, trust, and individual payoffs. This structure adheres to the theory of collective action of Ostrom (1998) already described in section 2, which is also supported by the results of the economic experiments reported in Saldarriaga-Isaza et al. (2013b, 2013c). Accordingly, in those experimental results the statistical significance of dynamic variables in explaining individual contributions leads to conclude that participants in the experiment reciprocated.

[4] The model in Powersim Studio™ and its complete description are available upon request.

Moreover, in the experiments, trust in others positively affected the contributions subjects made to the common fund.

Table 5.1. Tests for model structure validation.

Test	Description
Boundary adequacy:	This test asks whether the model includes all the relevant concepts for addressing the problem.
Structure verification:	Model structure must be consistent with the knowledge we have about the real system.
Parameter confirmation:	Parameters must have a meaning or a counterpart in the real world.
Dimensional consistency:	All equations in the model must be dimensionally consistent, and this dimensionality must correspond to the real system.
Extreme conditions:	This test entails assigning extreme values to selected parameters, and assessing the plausibility of model-generated behavior against what it is theoretically anticipated.
Sensitivity analysis:	Sensitivity of results to changes in the assumptions about how people make decisions.

Source: The author based on Forrester and Senge (1980), Sterman (2000) and Morecroft (2007).

Dimensional consistency was directly tested using the tool available in the software Powersim Studio™. There is no numerical data to verify the value of the parameters employed in the model. Instead, the parameters and functions of the model were calibrated taking into account the experimental results reported in Saldarriaga-Isaza et al. (2013b, 2013c).

To test the model response to extreme conditions, we first look at how the model behaves under extreme conditions of initial levels of trust. On the one hand, the most likely behavior for very low initial levels of trust is that players will try to follow the inefficient Nash strategy and make contributions near to zero tokens. In fact, Figure 5.5 shows that when the players initially distrust others they put very few tokens in the group account. As the game goes on, players learn about the dilemma and try to increase their contributions to the common fund, but the provision point is never reached. On the other hand, when players fully trust in the actions of each of the group members, contributions start high, although not at its maximum. In a threshold public good game, group contributions beyond the provision point are welfare reducing (Marks and Croson, 1998). Therefore, contributions are not expected to be much higher than certain level, which in this case is the efficient cost-sharing contribution of 12 tokens which maximizes social welfare. Other behavioral driving forces such as *profit maximization* would prevent players from wasting their available resources, making them to provide donations collectively acceptable.

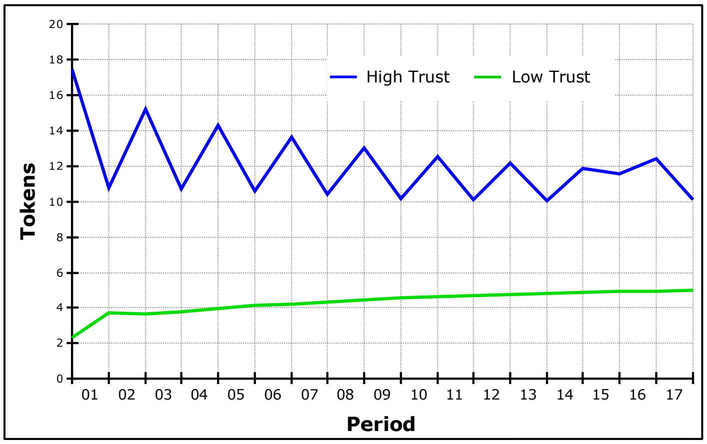


Figure 5.5. Extreme conditions test for the initial value of trust.

The results of the simulation model can be sensible to the assumptions about the way people make decisions (Sterman, 2000) or react to certain impulses. These assumptions are modeled as graph functions described in sub-section 3.1. Such relationships that are likely influential on the behavioral patterns are *willingness to cooperate* and *temptation to free ride* (Castillo and Saysel, 2005). Here we present a sensitivity analysis of the model to changes in the shape of these two graph functions.

In Figure A.1 of the Appendix D we show how the results of the model change for different possibilities of the functional forms that define the *willingness to cooperate* and different initial values of trust. When the willingness to cooperate is low and players require high levels of trust to cooperate (Castillo and Saysel, 2005), the system is not able to reach an appropriate level of individual donations that leads to the provision of the public good. This happens even when the initial level of trust is high. In contrast, players are always prone to contribute enough tokens when the willingness to cooperate is high, even when players have a low initial level of trust. In this case, individual contributions tend to increase since the beginning and stabilize in the final rounds in values close to the cost-sharing equilibrium (12 tokens).

Assuming a moderate function of willingness to cooperate, the system moves toward an inefficient equilibrium of individual contributions. Conversely, in the common case, i.e., for the graph function showed in Figure 5.4 (sub-section 3.1), neither the cost-sharing equilibrium nor the provision point are always reached, although it is more likely to be reached when players start the game with high trust. In general, the behavior of the model in this sensitivity analysis is as expected.

Some individuals can resist the temptation to free ride while others cannot (Skatova and Ferguson, 2013). These behavioral individual differences affect the opportunistic behavior players have, and hence the results of the game. For instance, let us assume that one of the players (Player A) strongly resists the temptation of free riding on others (the temptation to free ride function is concave), while the other four players are given a common temptation to free ride function (see Figure A.2 the Appendix D). In this case, player A would donate more tokens than his partners from the very beginning. The rest of the players reciprocate this behavior and at the final rounds of the game the threshold is always reached and the public good provided. In another scenario, where player A is characterized with a high temptation of free ride, the contributions of this player are quite low throughout. Other players' contributions keep close to the cost-sharing donation. However, their cooperative efforts are eroded by the elevated opportunistic behavior of player A, and the public good is hardly ever provided.

3.2.2 Tests of model behavior

The aim of testing model behavior is to assess the fit of simulation to observed data (Morecroft, 2007). In this section, we discuss the model behavior compared to the average behavior of miners and students in the framed economic experiments reported in Saldarriaga-Isaza et al. (2013c). Firstly, there is an oscillating pattern around the efficient Nash outcome equilibrium (60 tokens), usually observed in other threshold public good games (Croson and Marks, 2000); it can be detected in the baseline of the framed experiments undertaken with miners and students. However, the amplitude of the oscillation of group contributions in students is different to the behavioral pattern observed in the experiments with miners. Figure 5.6 portrays those differences.

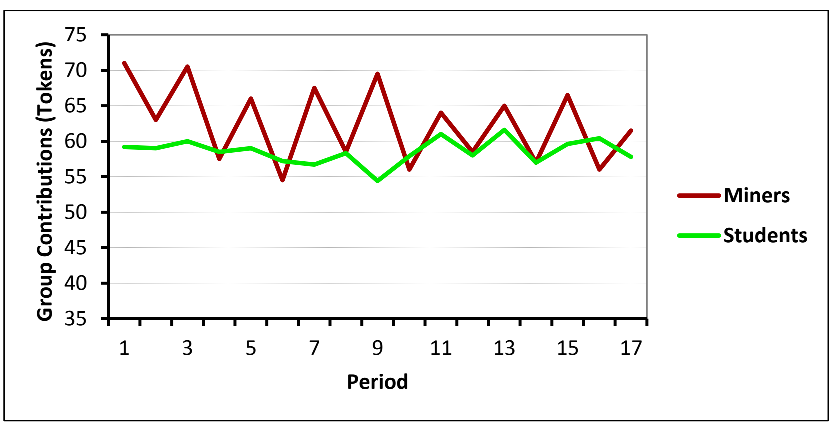


Figure 5.6. Average group contributions in the baseline of the framed experiments with miners and students.

To reproduce the behavioral patterns coming from the experiments, we modified the following characteristics of each player in the model: initial levels of trust and temptation to free-ride, and the functional forms of willingness to cooperate, temptation to free ride and profit maximization. Table 5.2 shows the characteristics of each player in both groups (students and miners). Figure 5.7 portrays the best fit between the simulations and average group contributions in the control treatment of the economic experiments. The general impression from these results is that students act more like homo-economicus (profit maximizers) than miners and try to adjust their contributions to the efficient contribution level.

Table 5.2. Characteristics of students and miners in the simulation.

Player	Initial level of trust	Initial level of free-riding	Willingness to cooperate	Temptation to free ride	Profit maximization
Students					
A	Medium	High	Common	Low	Common
B	Medium	Medium	High	Low	Common
C	Low	Low	Low	Low	Common
D	High	Medium	Medium	Common	Common
E	Medium	Medium	Common	Common	Common
Miners					
A	High	High	High	Medium[a]	Low[b]
B	Medium	Medium	Common	Common	Low
C	Medium	High	Common	Common	Low
D	Medium	Medium	Common	Common	Low
E	Medium	High	Common	Common	Low

[a] Inverse sigmoid function.
[b] Convex function.

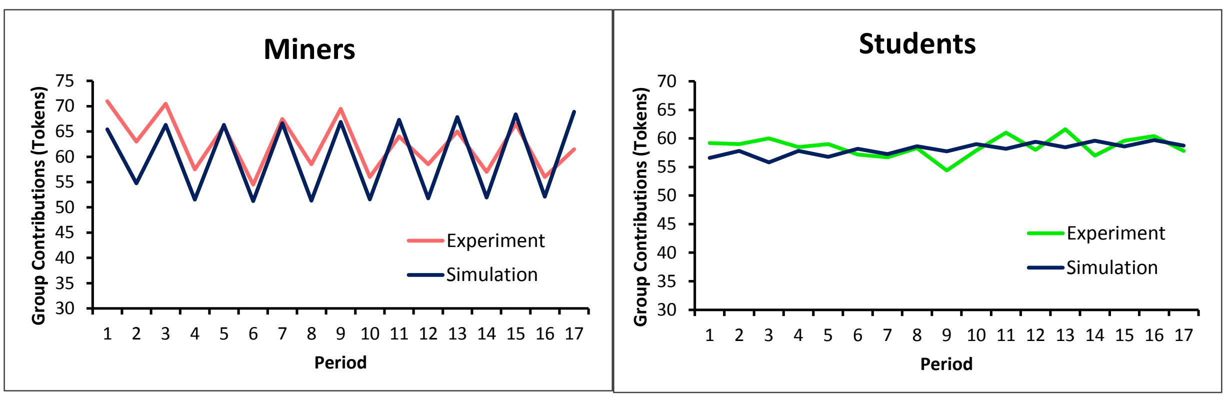


Figure 5.7. Comparison of model behavior and average group contributions in the control treatment of the economic experiments.

4. Policy Analysis

An important step for building confidence in a system dynamics model is the policy analysis and design (Barlas, 1996; Morecroft, 2007). This analysis is aimed to simulate and assess the response of the real system to a policy that has been tried, or to create new strategies to improve the performance of the real system (Forrester and Senge, 1980; Barlas, 1996; Sterman, 2000; Morecroft, 2007).

The data gathered in the economic experiments both with miners and university students show that individuals do not succeed in self-establishing a sustained collective action (see Figure 5.6). Along the base case of the experiment, players can afford the cost of the technology, but this happens only sporadically; the rates of successful provisions for both subjects pools are slightly above 50% (see Saldarriaga-Isaza et al., 2013c). In a real world situation, contributions to the common fund are required not only to buy the equipment but also to maintain it. Therefore, strategies to improve these performance patterns are required. To have individuals whose commitment to provide enough funds to the association is not permanent could have a deterrent effect on group's contributions.

In the last two decades, external organizations have presented technical mining alternatives (Veiga, 1997; Chouinard and Veiga, 2008) and persuaded artisanal gold miners to organize themselves into associative entrepreneurship. This scheme would help miners to enable them to accumulate the financial capital required to obtain cleaner and more productive technologies (Ghose and Roy, 2007; Spiegel, 2009).

Under this this policy context, one of the institutional arrangements that were examined in the economic experiments developed by Saldarriaga-Isaza et al. (2013b) was co-management. Conceptually, this mechanism is understood as the interaction between internal communication among community members and an external non-coercive party. The role of the external party was to persuade miners to invest in the new technology, with the aim of reducing the emissions of mercury and avoiding the harmful effects of mercury pollution. In addition to this persuasion, each five-person group had five minutes to converse among themselves. The average results of this treatment both in miners and students are shown in Figure 5.8. In this figure, the first eight periods correspond to the baseline; thereafter, when players communicate and interact with the external advisor, we observe that they try to coordinate their actions in order to reach the efficient outcome (60 tokens). Moreover, players tend to be more closely to the cost-sharing equilibrium by contributing 12 tokens. See for instance Figure 5.8 which portrays individual average decisions of students and miners in one of the sessions where the co-management treatment was applied.

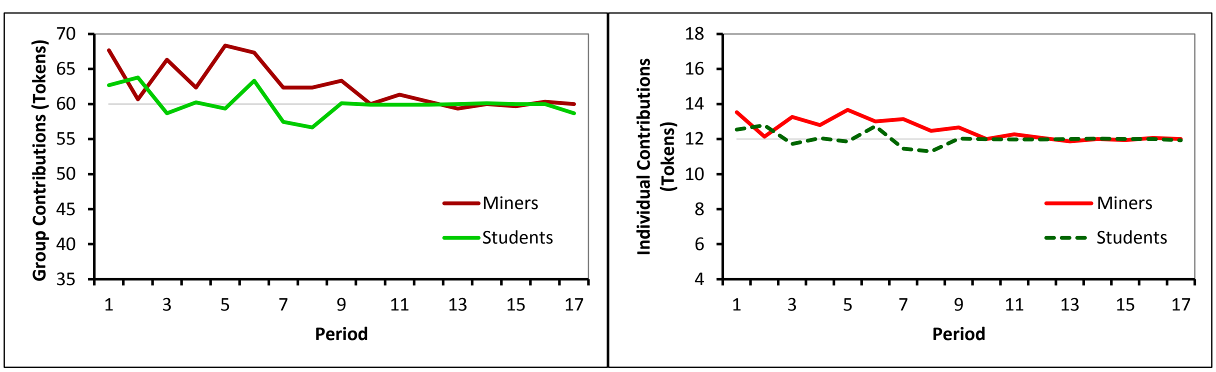


Figure 5.8. Average behavior in the co-management treatment of miners and students.

The kind of behavior observed under this treatment is explained by the *awareness of the dilemma* loop from Figure 5.3. Communication among group members and external advisor triggers commitment and trust inside the group, and additionally make players to get more aware of the public-good dilemma. During the experiments, for instance, Saldarriaga-Isaza et al. (2013b) observed that one or two miners within the group played the role of leaders. These leaders pointed out the features of the social dilemma and suggested the way of dealing with it.

To simulate the effect of this institutional arrangement on contributions as the set-up of the experiment, we introduced a graph function in the awareness loop that starts having effects from period 9. The function accelerates the rate at which each individual gets aware of the public-good dilemma. As shown in Figure 5.9, the effect of co-management is especially high when the ratio of relative contribution to relative payoff is low. In other words, when an individual himself does not perceive the dilemma, communication with an external party and with other group members triggers individual's awareness of the dilemma. The general behavioral pattern obtained from the simulation model under this treatment is portrayed in Figure 5.10.

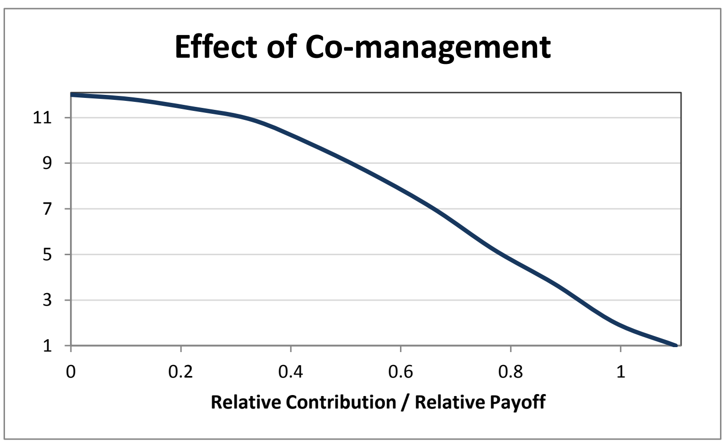


Figure 5.9. Effect of co-management of awareness of the social dilemma.

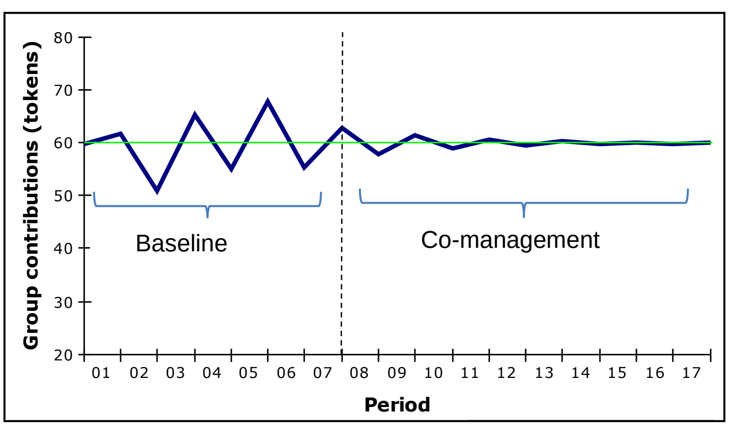


Figure 5.10. Model behavior for co-management treatment.

Spiegel (2009) points out the links that between technological development, environmental health awareness and trust-building in ASGM there is. From the sensitivity analysis in subsection 3.2.1, we see that high initial levels of trust lead to cooperation no matter the cooperative trait the subject has (see Figure A.1 in Appendix D). Moreover, simulations (subsection 3.2.2) show that the experimental results are partially explained by medium or low levels of trusts that individuals have at the beginning of the game (see Table 5.2). Therefore, from a policy viewpoint, it is important to improve the channels of communication in these communities. Better communication leads to strengthen the levels of trust, commitment and social capital which, according to Zeffane et al. (2011), are key elements within any organization. More trust and commitment, combined with the support of external agencies that increase education and provide technical assistance, guide ASGM communities to improve the gold recovery process what in the long-run may translate into more well-being.

Finally, another mechanism that was tested in the experiments of Saldarriaga-Isaza et al. (2013b) is the exclusion from the private benefits that a miner may obtain from the alternative technology if the miner does not contribute to the purchase of the technology. These private benefits correspond to the higher efficiency or more productivity in the gold recovery process if the alternative technology is obtained and used. This kind of economic incentive did not have any effect on the behavior miners showed in the experiment. However, by doing some simulations we can discern a certain design of the economic incentive in order to make it effective in terms of the objectives of the policy.

In the exclusion treatment of the experiment, the level of minimum contribution for not being excluded was chosen to be simply above zero. These results change if we consider a tougher minimum individual contribution in this exclusion case; e.g., a donation level that is at least as high as the cost-sharing contribution of 12 tokens. If we keep the characteristics of miners that were shown in Table 5.2, the simulation results show that by making this coercive requirement after period 8, contributions tend to increase such that almost in all the second stage of the game the threshold is reached although with total contributions that are welfare-decreasing (above 60), as shown in Figure 5.11. We should note that we did not obtain a significant effect when we increased the amount of the private benefits. Therefore, there is room for further research about the role of economic incentives in cooperation in ASGM.

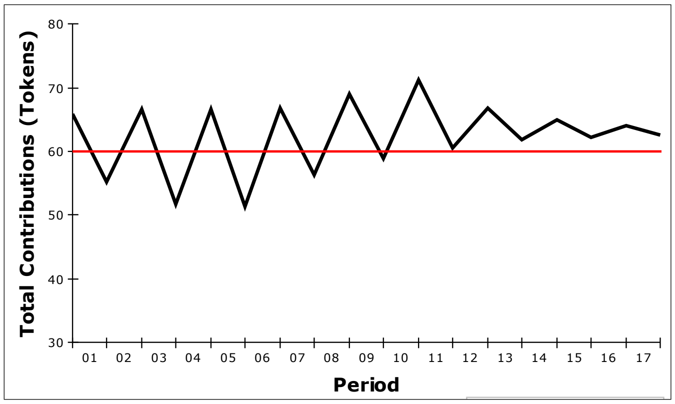


Figure 5.11. Simulation of the effect of a tougher economic incentive.

5. Discussion and Concluding Remarks

Based on Ostrom's (1998) theory of collective action in social dilemmas, in this paper I propose a behavioral simulation model to explain why communities engaged in ASGM often fail to establish a sustained association in the gold recovery process. Features such as reciprocity and temptation to free ride partially explain why this failure. Nonetheless, my simulations reveal that sustained collective action is feasible when miners increase their understanding of the social dilemma where they are involved. The better understanding can be gained, for instance, with education campaigns and interventions that foster social capital through the improvement of the channels of communication.

Previous literature has proved the usefulness of simulation methods in the study of issues that involves decision making about environmental problems (Decker, 1994; Grant and Thompson, 1997). This literature includes models developed to analyze the management of natural resources that entails social dilemmas (Castillo and Saysel, 2005; Touza et al., 2013), and indeed to support the design of policies focused on ASGM (Andriamasinoro and Angel, 2012). Likewise Castillo and Saysel's (2005) approach, in this paper we constructed a model with a structure based on Ostrom's (1998) causal theory of collective action, and supported we experimental data from the lab and the field. This approach takes into account some of the features of the local community and its environment, what according to Hilson (2007) and Speigel (2009) is a need for the analysis of issues concerning ASGM.

We intend to contribute to the understanding of social dilemmas faced by users of natural resources. For the specific case of ASGM, our paper goes beyond the analysis done so far with visual models done by scholars such as Heemskerk (2001, 2005), Hilson and Pardie (2006) and Spiegel (2009). Through a simulation model, we explored how an institutional arrangement influences associative entrepreneurship among artisanal gold miners that improves the well-being of these communities.

The design of effective policies to address environmental problems requires setting up interventions that considers the peculiarities of each problem, as well as the kind of pro-environmental behavior that policy makers desire to induce (Osbaldiston and Schott, 2012). In fact, for situations in which individuals must cope with a social dilemma, several scholars have highlighted the positive effects that face-to-face communication on collective action has (see for instance Ledyard, 1995; and Ostrom, 2010). Nonetheless, weak communication channels may actually prevent self-organization or collective action, which emerges as a solution to those social dilemmas. In those cases, ASGM being one of them, external intervention is needed. For the specific case of ASGM, we show that external parties (governments, NGOs, etc.) have a key role by promoting programs that improve the understanding of the social dilemma miners have. Also important is to set up strategies (e.g. education programs) to improve social capital and strengthen the skills that are required to attain an everlasting association.

Lokhorst et al. (2013) pointed out the effectiveness of different commitment-making strategies in altering environmental behavior. Nonetheless, these authors admit the ignorance that in the literature exists about the mechanisms by which it may happen. From our behavioral model, however, we argue that by making people more aware of the social dilemma, external interventions could lead miners to commit themselves to socially responsible mining practices. Economic incentives that alter the private benefits the individuals earn from the recovery process also work in this direction.

We observe the importance of education and capacitation. In the economic experiments university students performed better than miners. In general, students achieved more efficient outcomes than miners did (see Saldarriaga-Isaza et al., 2013c). From simulation results, we argue that a possible explanation of this behavioral discrepancy is found in the differences of education levels. Better skills make the individual to better understand particular situations, of the game in this case, and estimate the consequences of their actions considering also others' actions.

Finally, in this paper I showed the usefulness that simulation models can have in the design and support of policies targeted at natural resource-based communities, which serve to add to the existing literature (see, e.g., Castillo and Saysel, 2005; Andriamasinoro and Angel, 2012). In ASGM, further applications could be in the analysis of other aspects that explain or mechanisms to address poverty-trap in this sector. Besides the technology trap that has been analyzed in this paper, other social and economic components that call for analysis are the decisions that entail low levels of education and savings. Moreover, simulation methods and experimental economics are potential tools to be jointly employed in the design of mechanisms, including economic incentives, to overcome mercury pollution and change certain behavioral patterns that are welfare-reducing in ASGM.

References

[1] Anderies, J., Janssen, M., Bousquet, F., Cardenas, J., Castillo, D., Lopez, M.C., Tobias, R., Vollan, B., Wutich, A., 2011. The challenge of understanding decisions in experimental studies of common pool resource governance. Ecological Economics 70, 1571-1579.

[2] Andriamasinoro, F., Angel, J.-M., 2012. Artisanal and small-scale gold mining in Burkina Faso: Suggestion of multi-agent methodology as a complementary support in elaborating a policy. Resources Policy 37, 385-396.

[3] Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics. System Dynamics Review 12 (3), 183– 210

[4] Bowles, S., 2004. Microeconomics: Behavior, Institutions, and Evolution. Princeton University Press, Princeton, NJ.

[5] Box, G.E.P., Draper, N.R., 1987. Empirical Model-Building and Response Surfaces. Wiley.

[6] Cadsby, C., Maynes, E., 1999. Voluntary provision of threshold public goods with continuous contributions: experimental evidence. Journal of Public Economics 71(1), 53-73.

[7] Cardenas, J.C., 2011. Social norms and behavior in the local commons as seen through the lens of field experiments. Environmental and Resource Economics 48 (3), 451-485.

[8] Castillo, D., Bousquet, F., Janssen, M.A., Worrapimphong, K., Cardenas, J.C., 2011. Context matters to explain field experiments: Results from Colombian and Thai fishing villages. Ecological Economics 70(9), 1609-1620.

[9] Castillo, D., Saysel, A.K., 2005. Simulation of common pool resource field experiments: a behavioral model of collective action. Ecological Economics 55(3), 420- 436.

[10] CDS -Centre for Development Studies-, 2004. Livelihoods and Policy in the Artisanal and Small-Scale Mining Sector -An Overview. University of Wales Swansea, UK.

[11] Chaparro, E., 2003. Small-scale mining, a new entrepreneurial approach. Serie Recursos Naturales e Infraestructura No. 9. CEPAL, Santiago, Chile.

[12] Chouinard, R., Veiga, M., 2008. Results of the Awareness Campaign and Technology Demonstration for Artisanal Gold Miners, Summary Report. UNIDO, Vienna.

[13] Croson, R., Marks, M., 2000. Step returns in threshold public goods: A meta- and experimental analysis. Experimental Economics 2(3), 239-259.

[14] Czap, H.J., Czap, N.V., 2010. An experimental investigation of revealed environmental concern. Ecological Economics 69(10), 2033-2041.

[15] Davis, J., Eisenhardt, K., Bingham, C. 2007. Developing theory through simulation methods. Academy of Management Review 32(2), 480–499.

[16] Decker, J. (1994). The validation of computer simulations for design guideline dispute resolution. Environment and Behavior 26(3), 421-443.

[17] Dondeyne, S., Ndunguru, E., Rafael, P., Bannerman, J., 2009. Artisanal mining in central Mozambique: Policy and environmental issues of concern. Resources Policy 34, 45-50.

[18] Dudley, R., 2008. A basis for understanding fishery management dynamics. System Dynamics Review 24(1), 1-29.

[19] Fischbacher, U., Gächter, S., Fehr, E., 2001. Are people conditionally cooperative? Evidence from a public goods experiment. Economics Letters, 71(3): 397-404.

[20] Fischbacher, U., Gächter, S., 2010. Social preferences, beliefs, and the dynamics of free riding in public good experiments. American Economic Review 100(1), 541-556.
[21] Forrester, J.W., Senge, P., 1980. Tests for building confidence in system dynamics models, in: Legasto, A., Forrester, J.W., Lyneis, J. (Eds.), TIMS Studies in Managements Sciences, vol. 14. North Holland, New York, pp. 209–228.
[22] Ghose, M., Roy, S., 2007. Contribution of small-scale mining to employment, development and sustainability – an Indian scenario. Environment, Development and Sustainability 9, 283-303.
[23] Grant, W.E., Thompson, P.B., 1997. Integrated ecological models: simulation of socio-cultural constraints on ecological dynamics. Ecological Modelling 100, 43-59
[24] Heemskerk, M., 2001. Do international commodity prices drive natural resource booms? An empirical analysis of small-scale gold mining in Suriname. Ecological Economics 39(2), 295-308.
[25] Heemskerk, M., 2005. Collecting data in artisanal and small-scale mining communities: Measuring progress towards more sustainable livelihoods. Natural Resources Forum 29, 82-87.
[26] Hentschel, T., Hruschka, F., Priester, M., 2002. Global Report on Artisanal and Small-Scale Mining. International Institute for Environment and Development, London, UK.
[27] Hilson, G., 2005. Strengthening artisanal mining research and policy through baseline census activities. Natural Resources Forum 29, 144-153.
[28] Hilson, G., 2006. Abatement of mercury pollution in the small-scale gold mining industry: Restructuring the policy and research agendas. Science of the Total Environment 362, 1-14.
[29] Hilson, G., 2007. What is wrong with the Global Support Facility for small-scale mining? Progress in Development Studies 7, 235-249.
[30] Hilson, G., Hilson, C., Pardie, S., 2007. Improving awareness of mercury pollution in small-scale gold mining communities: Challenges and ways forward in rural Ghana. Environmental Research 103, 275-287.
[31] Hilson , G., Pardie, S., 2006. Mercury: An agent of poverty in Ghana's small-scale gold-mining sector? Resources Policy 31, 106-116.
[32] Hilson, G., Potter, C., 2003. Why is illegal gold mining activity so ubiquitous in rural Ghana? African Development Review 15, 237-270.
[33] Hinton, J., Veiga, M., Veiga, A., 2003. Clean artisanal gold mining, a utopian approach?. Journal of Cleaner Production 11, 99–115.
[34] Keita, S., 2001. Study on Artisanal and Small-Scale Mining in Mali. MMSD/IIED and WBCS No. 80, UK.
[35] Kocher, M., Martinsson, P., Matzat, D., Wollbrant, C., 2011. The role of beliefs, trust, and risk in contributions to a public good. Working Papers in Economics No 482, University of Gothenburg, Sweden.
[36] Ledyard, J., 1995. Public goods: A survey of experimental research, in: Roth, A., Kagel, J. (Eds.), Handbook of Experimental Economics. Princeton University Press, Princeton, pp. 111-194.
[37] Lokhorst, A.M., Werner, C., Staats, H., van Dijk, E., Gale, J., 2013. Commitment and behavior change: A meta-analysis and critical review of commitment-making strategies in environmental research. Environment and Behavior 45(1), 3-34.
[38] Marks, M., Croson, R., 1998. Alternative rebate rules in the provision of a threshold public good: an experimental investigation. Journal of Public Economics. 67(2), 195-220.

[39] Morecroft, J., 2007. Strategic Modeling and Business Dynamics. John Wiley & Sons Ltd, West Sussex, England.
[40] Moxnes, E., 2004. Misperceptions of basic dynamics: the case of renewable resource management. System Dynamics Review 20(2), 139-162.
[41] Osbaldiston, R., Schott, J.P., 2012. Environmental sustainability and behavioral science: meta-analysis of proenvironmental behavior Experiments. Environment and Behavior 44(2), 257-299.
[42] Ostrom, E., 1998. A behavioral approach to the rational choice theory of collective action. American Political Science Review 92, 1-22.
[43] Ostrom, E., 2000. Collective action and the evolution of social norms. Journal of Economic Perspectives 14 (3), 137-158.
[44] Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences 104, 15181-15187.
[45] Ostrom, E., 2010. Revising theory in light of experimental findings. Journal of Economic Behavior & Organization 73, 68-72.
[46] Prediger, S., Vollan, B., Frölich, M., 2011. The impact of culture and ecology on cooperation in a common-pool resource experiment. Ecological Economics 70(9), 1599-1608.
[47] Qudrat-Ullah, H. Seong, B., 2010. How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. Energy Policy 38(5), 2216-2224.
[48] Saldarriaga-Isaza, A., Villegas-Palacio, C., Arango, S., 2013a. The public good dilemma of a non-renewable common resource: a look at the facts of artisanal gold mining. Resources Policy 38(2), 224-232.
[49] Saldarriaga-Isaza, A., Villegas-Palacio, C., Arango, S., 2013b. Phasing out mercury through collective action in artisanal gold mining: Evidence from a framed field experiment. Chapter 3 of this thesis.
[50] Saldarriaga-Isaza, A., Villegas-Palacio, C., Arango, S., 2013c. External validity of laboratory experiments: insights from a framed threshold public good game with students and miners. Chapter 4 of this thesis.
[51] Sinding, K., 2005. The dynamics of artisanal and small-scale gold mining reform. Natural Resources Forum 29, 243-252.
[52] Skatova, A., Ferguson, E., 2013. Individual differences in behavioural inhibition explain free riding in public good games when punishment is expected but not implemented. Behavioral and Brain Functions 9(1), doi:10.1186/1744-9081-9-3.
[53] Spiegel, S., 2009. Socioeconomic dimensions of mercury pollution abatement: Engaging artisanal mining communities in Sub-Saharan Africa. Ecological Economics 68, 3072-3083.
[54] Sterman, J.D., 1989. Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. Management Science 35(3), 321-339.
[55] Sterman, J. D., 2000. Business Dynamics: System Tinking and Modeling for a Complex World. Irwin McGraw-Hill, Homewood, IL.
[56] Touza, J., Drechslera, M., Smart, J., Termansen, M., 2013. Emergence of cooperative behaviours in the management of mobile ecological resources. Environmental Modelling & Software, in press. http://dx.doi.org/10.1016/j.envsoft.2012.03.015

[57] Vázquez, M., Liz, M., Aracil, J., 1996. Knowledge and reality: some conceptual issues in system dynamics modeling. System Dynamics Review 12(1), 21-37.
[58] Veiga, M., 1997. Introducing New Technologies for Abatement of Global Mercury Pollution in Latin America. UNIDO/UBC/CETEM/CNP.
[59] Zeffane, R., Tipu, S., Ryan, J., 2011. Communication, commitment & trust: Exploring the triad. International Journal of Business and Management 6(6), 77.

APPENDIX D

Figure A.1. Sensitivity analysis of *willingness to cooperate* function and *trust*.

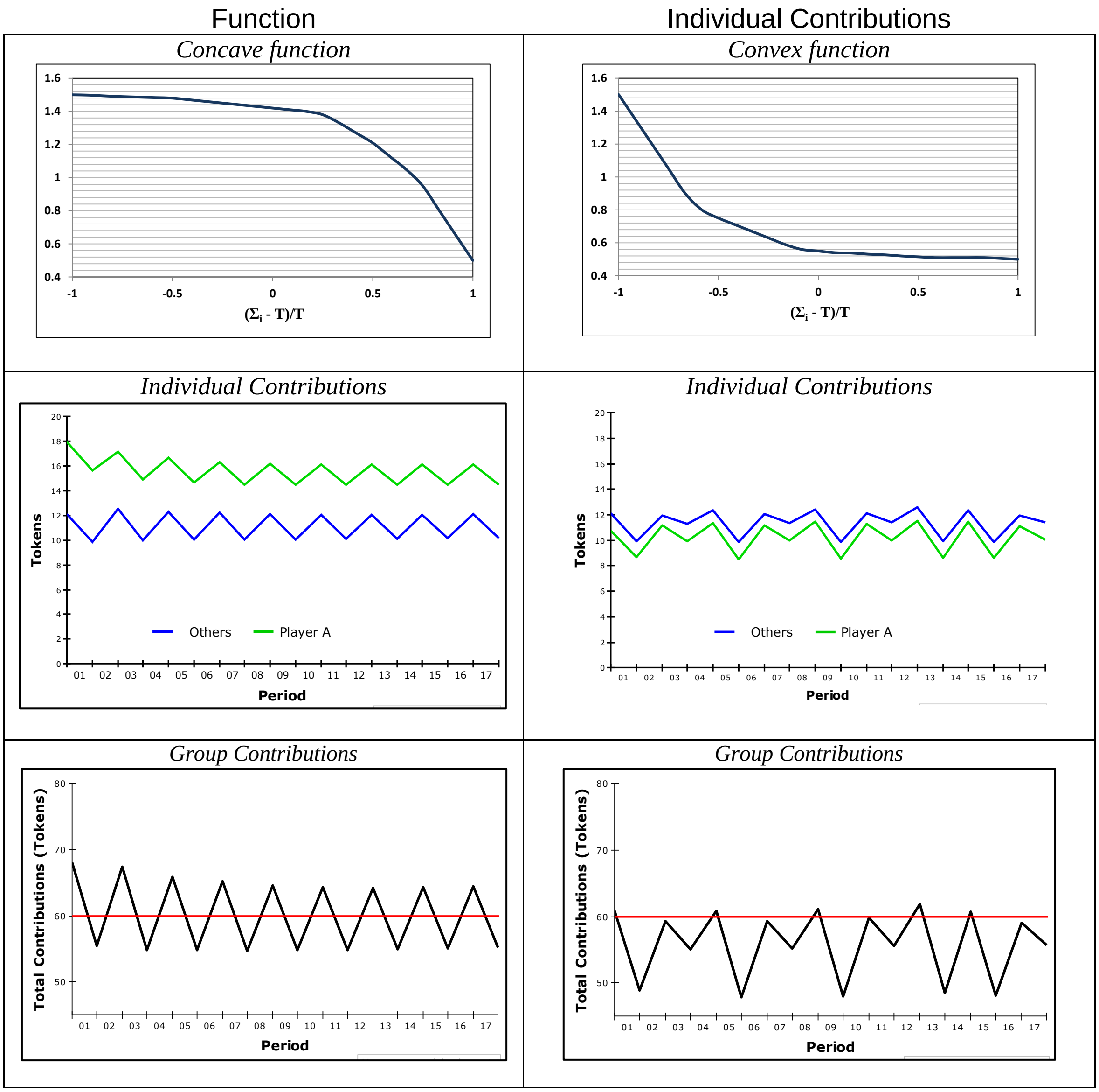


Figure A.2. Sensitivity analysis of *temptation to free ride* function.

Dissemination

Part of this thesis has been disseminated as follows:

a) Chapter 2 is published in ***Resources Policy*** Volume 38, Issue 2, pp. 224-232, (June 2013).

b) Chapter 3 was presented at the Ninth International Meeting on Experimental and Behavioral Economics (IMEBE 2013), in Madrid, Spain, April 11-13, 2013.

c) Chapter 5 was presented at the PhD Colloquium of the 31^{st} International Conference of the System Dynamics Society, in Cambridge, MA, USA, July 21, 2013.

d) Some of the main findings of this dissertation were presented at the international seminar “Minería en Latinoamérica: retos y oportunidades,” organized by Universidad de los Andes and the David Rockefeller Center for Latin American Studies of Harvard University, in Bogotá, Colombia, May 23-24, 2013. In this seminar I presented “Retos en el diseño de políticas públicas para la pequeña minería,” in the invited panel “Política pública en minería.”