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Do irrigation programs make poor rural communities in Bolivia less vulnerable to climatic and other shocks?

¿Los programas de riego hacen que las comunidades rurales pobres de Bolivia sean menos vulnerables?

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Abstract[1]

Using a combination of quantitative and qualitative methods, this paper evaluates the effectiveness of Bolivia's national irrigation programs –PRONAR and PRONAREC– in reducing the vulnerability of agricultural communities. We propose two practical indicators to measure vulnerability, and develop an explicit Theory of Change that not only explains how irrigation systems are expected to reduce vulnerability, but also highlights where things might go wrong. We then make a propensity score matched difference-in-differences estimation that compares the change in vulnerability of households in cantons that have benefitted from

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irrigation projects during the period 2002 to 2012, with the changes in similar households in cantons that have not benefitted from one of the national irrigation programs. The quantitative analysis is complemented by a qualitative analysis based on interviews and focus groups with past and present program officials and program beneficiaries in the highlands, the valleys and the lowlands of Bolivia.

Key words: Vulnerability, resilience, adaptation, irrigation, Bolivia.

Resumen

Usando una combinación de métodos cuantitativos y cualitativos, este estudio evalúa la efectividad de los programas nacionales de riego en Bolivia –PRONAR y PRONAREC– en la reducción de la vulnerabilidad de las comunidades agropecuarias. Proponemos dos indicadores prácticos para medir empíricamente la vulnerabilidad, y desarrollamos una Teoría de Cambio que detalla cómo el riego podría afectar la vulnerabilidad de los hogares agropecuarios. Procedemos a hacer una "propensity score matched difference-in-differences estimation," que compara los cambios en vulnerabilidad entre los hogares en cantones beneficiarios de un programa nacional de riego entre 2002 y 2012 y los hogares similares en cantones que no se han beneficiado de programas de riego. Se complementa el análisis cuantitativo con un análisis cualitativo basado en entrevistas y grupos focales con oficiales actuales y anteriores, así como beneficiarios en el altiplano, los valles y las tierras bajas de Bolivia.

Palabras clave: Vulnerabilidad, resiliencia, adaptación, riego, Bolivia.

Classification/Clasificación JEL: Q15, Q25, Q54.

1. Introduction

The constant cycle of droughts, floods, frost and hail, insufficient rainfall and erratic weather conditions in large parts of Bolivia result in high risks for agricultural production. The situation is aggravated by a lack of provisions that can cushion the damage caused by these contingencies (shortage of irrigation infrastructure, lack of water and soil conservation methods, lack of warning mechanisms, among others). This makes agriculture in these regions excessively vulnerable to adverse weather conditions.

Irrigation programs can potentially alleviate some of this vulnerability. Previous evaluations of Bolivia's national irrigation program, PRONAR, indicated that farmers had significantly increased their income through higher production volume and more employment, and also improved their food security from 10-20% to 60-80% (MACA-BID-GTZ, 2003). A more recent evaluation has shown that improving irrigation and micro-irrigation systems is a worthwhile investment, with satisfactory to good production results for the participating families. The improved systems also show a high degree of sustainability so that the investment has a sustained economic impact (BID, 2007).

However, other studies have found that the impact of irrigation on vulnerability may not be that simple. For example, Eakin (2003), which analyzes the impact of irrigation systems in poor, highland communities in Puebla, Mexico, finds that the provision of irrigation may actually increase vulnerability for a number of reasons. First, irrigation permits extending the growing season outside the rainy season, but in Puebla, as in the Bolivian Altiplano, the dry season is colder, so the farmers who sow early or late are at increased risk of losing their crops to frost. Second, irrigation may permit growing commercial crops for sale in nearby cities, but then market and price volatility become an added risk. Farmers were found to be much more likely to lose/abandon crops due to low prices than due to adverse climate and pests, showing market risk is an important factor. Third, the inclusion of additional farmers and additional agricultural land due to irrigation meant increased agricultural supply and thus lower prices, therefore adversely affecting the initial group of farmers.

The aim of this paper is to carry out a mixed quantitative and qualitative analysis of the effects of the irrigation projects carried out in Bolivia within the two national irrigation programs, PRONAR and PRONAREC, on the vulnerability of beneficiary communities.

The paper contributes to the literature on irrigation and vulnerability by developing a quantitative measure of vulnerability and comparing changes in vulnerability, as measured by our indicators, in Bolivian agricultural communities that have benefitted from one of the national irrigation programs (PRONAR and PRONAREC) between 2002 and 2012 with the changes in vulnerability in communities that never benefitted from these programs.

The rest of the paper is organized as follows: Section 2 presents the methodological approach, including the definition of key concepts, the choice of indicators, the Theory of Change, the econometric strategy and the supplementary qualitative analysis. Section 3 describes the data collection process, including the construction of treatment and control groups and the construction of intermediate indicators as well as vulnerability indicators. Section 4 presents the results of both the quantitative and the qualitative analysis, and Section 5 discusses the results and provides policy recommendations.

2. Methodology

2.1. Definition of key concepts

Vulnerability, resilience and adaptation are very complex and multifaceted concepts which have been defined in a variety of ways, applied to many different types of systems and situations, and have been the subjects of numerous debates (*e.g.*, Béné *et al.*, 2012; Ionescu *et al.*, 2009; Kelly & Adger, 2000).

For the purpose of the present paper, we consider resilience to be the opposite of vulnerability. Thus, we are not thinking about resilience in the original way as a physical property (the property of a material that enables it to resume its original shape or position after being bent, stretched, or compressed), nor as the term widely used in ecology (the ability of an ecosystem to return to its original state after being disturbed), but rather as a new and emerging concept characterizing socio-economic systems (Andersen *et al.*, 2014).

Resilience is a desirable state for a household or a community, as it reflects a "capacity to anticipate, cope with, resist, and recover from the impacts of a shock." In contrast, vulnerability is an undesirable state which reflects the "inability to anticipate, cope with, resist, and recover from the impacts of a shock." Obviously, there is a continuum of states in between reflecting lower or higher degrees of resilience. We consider adaptation to be "the process of taking deliberate actions to become more resilient (or less vulnerable) in the face of adverse shocks or stresses."

Notice that in this conceptualization, we consider not only specific vulnerability to climate change, but rather general vulnerability to shocks and stresses of all types, including currently adverse climates and recurrent extreme weather events.

Since vulnerability is an undesirable state, households will naturally try to take deliberate actions to become less vulnerable. In developed countries, buying insurance is a common way of protecting against some of the potential threats. However, not all shocks can be insured against, and insurance also comes at a significant cost, which poor and vulnerable households may not be able to afford. The population in OECD countries spends on average more than US$ 3,000 per person per year on insurance[2], which corresponds to almost 10% of GDP (Andersen & Cardona, 2013). In developing countries insurance is rare, but an alternative strategy for coping with risk is livelihood diversification (Ellis, 2000; Ellis and Freeman, 2005). The resilience of livelihoods to disruption from particular shocks is higher the greater the diversity of income (Adger, 1999).

Governments can support households and communities in their effort to become less vulnerable, and it would be of high interest to governments and donors alike to understand which kind of projects and investments are effective at moving households and communities in the direction of less vulnerability and more resilience. The present project proposes a simple, but widely applicable, methodology for measuring vulnerability.

2.2. Indicators of vulnerability

Although vulnerability is a complex and multi-dimensional concept, we aim to quantify it in the simplest possible way, because simplicity makes the indicators more likely to be widely adopted and thus useful for the purpose of comparisons across time, countries, regions and projects.

We will argue that the level of vulnerability of a household/community can be usefully summarized by just two SMART (Specific, Measurable, Achievable, Relevant and Timely) indicators.

Per capita income is the first indicator, since it is widely agreed in the literature that poor households and poor regions are much more sensitive to shocks, especially climatic shocks, than richer households or regions (*e.g.*, Stern, 2006; IPCC, 2007; Verner, 2010). *Per capita* income is already a widely calculated and used indicator, so this dimension is easy.

However, if the income of a household comes from only one source, the household is vulnerable to any shock that might adversely affect that income source. For example, if a household depends almost exclusively on one commercial crop, they may earn quite a good income most years, but they will be vulnerable to a pest attack, a drought, or a drop in the output price. Thus, we propose that the second crucial dimension of vulnerability should be a

2 OECD: http://www.oecd-ilibrary.org/finance-and-investment/average-insurance-spending-per-capita_20755066-table3

diversification indicator, because the greater the diversity of income, the greater the resilience of livelihoods to disruption from particular sources (Adger, 1999). Several other authors have pointed out the importance of diversification. For example, Koren and Tenreyro (2013) develop a theoretical model in which diversification dampens the adverse effects of activity-specific negative shocks by limiting the direct impact of a negative activity-specific shock and facilitating substitution away from the negatively affected activity.

Andersen & Cardona (2013) argue that diversification is the opposite of income concentration, so a simple and logical way of constructing a Diversification Index, *DI*, is simply one minus the widely used Herfindahl-Hirschman Index of Concentration:

$$DI = 1 - \sum_{i=1}^{N} p_i^2 \tag{1}$$

where N is the total number of income sources and p_i represents the income proportion of the *i*-th income source. The value of the index is zero when there is complete specialization (100% of total household income comes from one source only) and approaches one as the number of income sources increases and no single source dominates household incomes.

The advantage of using the Diversification Index, instead of just the number of different livelihood sources, is that the index is not very sensitive to the grouping of small income sources together with bigger ones. For example, if a household had three income sources, contributing 90%, 9% and 1%, respectively, the Diversification Index would be 0.1818. If we lump together the last two sources, for example because they are highly correlated or because no detailed data exist, the index changes only marginally to 0.1800. This is a reduction of less than 1% in the Index, whereas the reduction in number of livelihood sources would be 33%. This property of robustness to alternative classifications is important as we will necessarily have to make some assumptions about how to classify and group different income sources together (Andersen & Cardona, 2013).

This measure of diversification has also been proposed by other authors. Fiszbein (2013), for example, uses it to measure agricultural diversification in the United States in 1860 and shows that diversification has positive long run impacts on GDP. Andersen, Aston & Cardona (2014) uses the same measure and shows that the level of income diversification has increased significantly for rural, peri-urban and central-urban households in Bolivia over the last decade.

Standard household surveys contain all the information necessary to estimate this index for the households of interest, as demonstrated in Andersen & Cardona (2013). The Diversification Index can be calculated at all scales from household to country level, and can be calculated for any sub-group of interest.

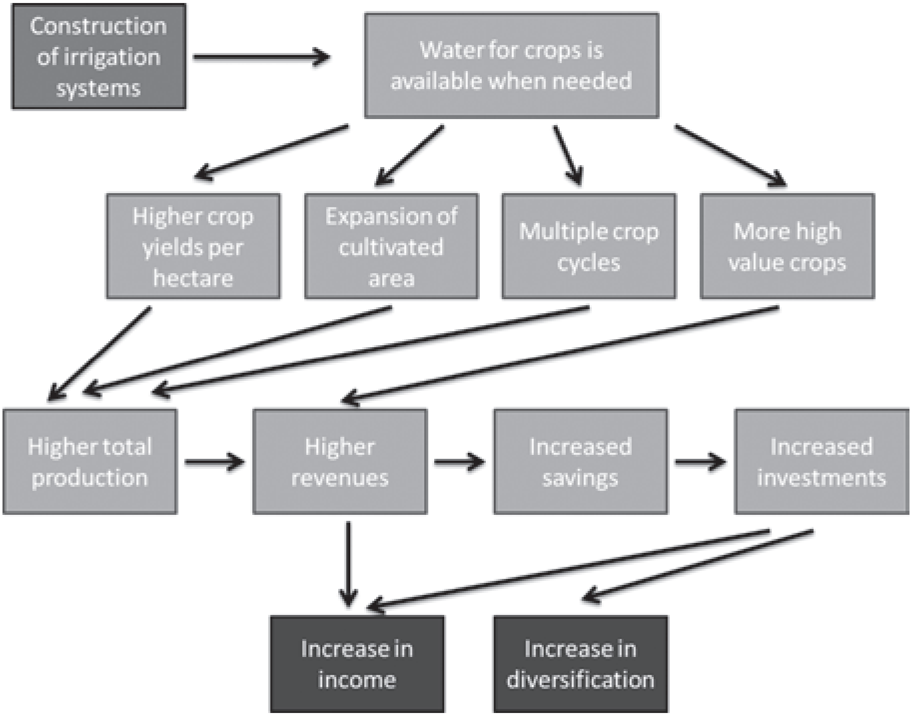
2.3. Pathways to reduced vulnerability

Rainfall in Bolivia, as well as most other places, is highly erratic and unreliable, you can never count on precipitation being available in the right quantities at the right time in the right form. Irrigation systems can partly solve this problem, by making sure that enough water is available at critical crop growing phases. Yet, naturally, they cannot solve the problem of too much precipitation or precipitation in the form of hail or snow instead of rain.

By avoiding that crops dry out, we would expect irrigation systems to increase crop yields per hectare. This has indeed been demonstrated for irrigation systems in Bolivia by the study MACA-BID-GTZ (2003). Irrigation systems may also allow the cultivation of areas that might not otherwise be suitable for crops due to lack of rain, and they may allow multiple cropping cycles over the year, as the growing season might by extended into months that would otherwise have too little or too uncertain precipitation. Finally, irrigation systems may allow farmers to invest in more expensive, high value crops as the risk of losing the crop due to drought is reduced.

If any of these intermediate results pan out, we would expect production to increase either in quantity or in value, or both. This, in turn, would likely lead to higher revenues for the farmer, allowing a higher surplus, which could then be reinvested either in farming or in other complementary activities. If so, the farmer could experience an increase in the level and/or diversification of household incomes (Figure 1).

Figure 1: A Theory of Change for irrigation systems



Source: Authors' elaboration

However, several of the arrows from the Theory of Change in Figure 1 might not be functioning optimally, in which case the final impacts on income and income diversification may be reduced or even absent. For example, the irrigation system constructed might be defective right from the beginning or become defective later due to natural disasters or lack of maintenance. If so, none of the subsequent changes can take place and you cannot expect an impact on the two vulnerability indicators.

With regards to the next line of arrows, it must be noted that water is only one of the crucial inputs in agriculture, the others being land, labor and capital (seeds and machinery). For example, if labor is scarce, which is indeed the case in many of the target areas of PRONAR and PRONAREC due to rural-urban migration, it may not be possible to expand the cultivated area or increase the number of crop cycles. Likewise, since the irrigation programs target poorer areas, households may not have the capital necessary to invest in more high value crops.

Even if a household has managed to increase production with the help of the new irrigation system, this might not result in higher incomes, because an increase in supply could cause a drop in output prices, if there is only a limited local demand for the output. PRONAR and PRONAREC by design exclude exporters and large scale farmers, who presumably can finance their own irrigation infrastructure without outside assistance, and instead target relatively disadvantaged, small-scale producers, who produce mainly for subsistence and local markets. Since local demand for agricultural products is very inelastic, the result of an increase in output can be a substantial reduction in prices, and an even more dramatic reduction in producer surplus. This price effect would be particularly worrisome in an isolated community where many producers benefit from the new irrigation system, but there is no market for the additional production.

Even if the household managed to increase production, and found a market for the additional production, so that total revenues also increased, this might not necessarily result in increased savings. Instead of saving and investing in productive activities, they might choose to spend the extra money on a refrigerator, a TV set, a wedding party, or some other expense that would fall in the category of consumption rather than savings.

If the household has surmounted all the previous potential hurdles and has managed to save money, and decided they want to invest it, they might not choose to invest it locally. They might, for example, choose to invest the extra money in a university education for their oldest son. This would be a perfectly reasonable decision, but it would mean that the son would leave the community and take the money with him, and we would thus not be able to observe an improvement in incomes or income diversification in the part of the household that remains in the community.

So, while investments in irrigation systems in poor, drought prone rural areas initially sound very convincing, there are many potential pitfalls on the road to reduced vulnerability. Whether PRONAR and PRONAREC and the beneficiary households have largely avoided those potential pitfalls and managed to significantly reduce their vulnerability with the help of irrigation systems remains an empirical question, and it is the question we try to answer in the present case study.

2.4. Econometric strategy

The present study uses already existing standard household survey data from 2002 (before treatment) and 2011 and 2012 (after treatment). Since these standard household surveys conducted by the National Statistical Institute (INE) do not contain direct information about whether the household has benefitted from a PRONAR/PRONAREC irrigation project, the strategy for creating treatment and control groups are the following:

- First, we divide the whole country into 1391 cantons (sub-divisions of municipalities) and mark all cantons that have a PRONAR/PRONAREC project according to Map 1. The cantons which have a completed PRONAR/PRONAREC project at the time of a specific survey, is denoted a treatment canton at that time.
- All agricultural households surveyed in a treatment canton are called treatment households, although we cannot be sure that all of them, or even most of them, have actually been direct beneficiaries of the project. The number of actually treated households constitute only about 10% of the total number of agricultural households in the treatment cantons, so, unless there are strong positive spill-over effects, any statistical relationship we find between irrigation and vulnerability will be a diluted one, biased towards zero, because it mixes a share of treated households with an even larger share of non-treated households.
- All agricultural households in cantons which never benefited from PRONAR/PRONAREC irrigation projects form a pool of control households.

Using Propensity Score Matching (Rosenbaum and Rubin, 1983), we match each treatment household with a control household that is as similar as possible in terms of a number of pre-treatment characteristics. We are looking for characteristics that may affect both the probability of getting the treatment and the outcome variables, but which cannot themselves be affected by the treatment. Thus, we consider the following variables:

- Indigenous or non-indigenous head of household
- Average annual temperature
- Average annual rainfall
- Soil quality
- Topography

Exact matching on so many variables is usually impossible, so we use Propensity Score Matching (Rosenbaum and Rubin, 1983) to reduce the dimensionality problem and obtain a single scalar which can be used to measure which household is "most similar." We use the four different matching methods of Becker and Ichino (2002). These are: i) Nearest Neighbor Matching, ii) Radius Matching, iii) Kernel Matching, and iv) Stratification Matching.

Once we have our treatment and control households both before and after the intervention, we can calculate the difference-in-differences estimate of the effects of PRONAR/PRONAREC irrigation programs on the vulnerability of agricultural households in treatment cantons.

2.5. Supplementary qualitative analysis

In order to supplement the quantitative analysis, we also carry out a qualitative analysis based on field visits, focus groups with key informants in beneficiary communities and interviews with current PRONAREC staff and former PRONAR staff. With very generous support and help from staff from PRONAREC and the Departmental Irrigation Services (SEDERI) in La Paz, Oruro, Cochabamba and Santa Cruz, we managed to carry out a series of interviews with key informants from 6 beneficiary communities spread across the highlands (Vilacollo and Rey Inca), valleys (Pirhuas, El Paso) and lowlands (Saipina and San Juan del Potrero)[3]. Communities were not chosen completely at random, but rather selected for us by PRONAREC staff according to accessibility with a very limited field work budget while trying to respond to a request for the inclusion of as wide a variety of experiences as possible (old, new, large, small, successful, conflictive, etc.).

In addition, we carried out semi-structured interviews with both current PRONAREC staff and former PRONAR staff.

All the interviews were transcribed and analyzed to identify arguments that could help determine whether each of the links in the Theory of Change was working well or not.

3 Transcripts of all interviews are annexed in a separate field work report.

3. Data collection

The empirical analysis carried out in this study relies on a combination of quantitative and qualitative data. The core of the analysis is based on pre- and post-treatment information from beneficiary and control regions. This is then supplemented with qualitative information obtained from structured interviews with PRONAREC officials and key persons in beneficiary communities.

Both pre-treatment, post-treatment and control data was obtained from existing national household surveys (MECOVI style surveys conducted by the National Statistical Institute, INE) using the following methodology:

- First a data base with key information on both PRONAR and PRONAREC projects was constructed from the project data kindly provided by the Bolivian Ministry of Environment and Water[4]. Each of the projects was assigned to one or more of the 1391 cantons (sub-divisions of municipalities) existing in Bolivia in 2001, in which the project was located, and the following variables were recorded:
  - Number of beneficiary households
  - Number of hectares of increased irrigation coverage
  - Total investment
  - Investment per household
  - Investment per hectare
  - Year of completion.
- This data base was then merged into the national household surveys from the years 2002, 2011 and 2012, permitting us to identify whether the interviewed households were located in a canton that was about to receive or had received an irrigation project through PRONAR or PRONAREC. We use both the 2011 and 2012 surveys simply to increase the total number of after-treatment observations to a reasonable number.
- In order to be able to match treatment and control households with similar climates, we also merged a municipal level data set of average annual temperature, average annual rainfall, soil

4 We would like to thank Carlos Rodriguez (Director of PRONAREC), Miguel Balcazar (BID counterpart) and Rodrigo la Fuente (PROAGRO/GIZ) for their collaboration in gathering and making this information available to us.

quality and topography into the three data sets. This data was obtained from Andersen & Nina (2007).

3.1. Construction of treatment and control groups

Using surveyed agricultural households in cantons with completed irrigation projects, we construct a post-treatment group consisting of the 342 households from the 2011 survey that were located in cantons that had at least one completed PRONAR or PRONAREC irrigation project by the time of the survey and the 272 households from the 2012 survey that fulfill the same conditions.

A matched control group is formed by the households from the 2011 and 2012 surveys which are most similar to these households, but located in cantons which had benefitted from neither PRONAR nor PRONAREC.

By "similar" we mean that the matched households should have similar characteristics in terms of a number of pre-treatment characteristics that potentially could affect both the probability of getting the treatment and the outcome variables, but which cannot themselves be affected by the treatment. Thus, we consider the following variables:

- Indigenous or non-indigenous head of household
- Average annual temperature
- Average annual rainfall
- Soil quality
- Topography

We use the four different matching methods of Becker and Ichino (2002). These are: i) Nearest Neighbor Matching, ii) Radius Matching, iii) Kernel Matching, and iv) Stratification Matching.

3.2. Construction of vulnerability indicators and intermediate indicators

Vulnerability/resilience indicators

As previously explained, the two indicators we propose to measure general vulnerability/resilience are the following:

- *Per capita* household income
- Level of household income diversification, as measured by the Diversification Index.

These indicators are calculated for all households both before and after treatment. The first indicator is already calculated by the National Statistical Institute (INE) and readily available in the three data bases. The Diversification Index is calculated by the authors in the following way:

First we identify all the different sources of livelihoods for each individual in the household surveys. Following, Andersen and Cardona (2013) we have grouped all identifiable sources into the following ten types[5]: i) primary labor income (including payments in kind, such as housing), ii) secondary labor income, iii) pension payments (including veteran benefits, incapacity benefits, and widow/orphan benefits), iv) the school incentive (Bono Juancito Pinto) including the value of school breakfast, v) the maternal health incentive (Bono Juana Azurduy), vi) remittances (and other cash transfers received from other households, including child support), vii) rental income (including interest and dividends), viii) value of other donations and exchanges in kind, ix) value of auto-consumption of own production and x) imputed rental value of own housing property.

Table 1 shows that the most common livelihood source is the rental value of own housing. About two thirds of all individuals benefit from the imputed rental value that living in a fully owned and paid house implies. However, the average value per person is not large (about US$ 26 per month), as the quality of housing is often very basic, and the value is shared between many people. The second most common income type is primary labor income, which is received by about one third of the population. The average value of this income, for those who receive it, is now above US$ 300 per month, making it the most valuable source of income. The third most common type of income is the school incentives (Bono Juancito Pinto and school meals), but they amount to only about US$ 5 per month, so it is important only for the poorest of the poor. Remittances and similar transfers from other households are both relatively common (about 7% of individuals receive remittances) and important for those who receive them (averaging about US$ 120 per month per person).

5 Some rare categories have been merged with other similar types of incomes, so that no category is so rare that less than one percent of the population receives it.

Table 1
Importance of different livelihood types in Bolivia, individual level, 2002, 2011, 2012

Type of livelihood	% of population that benefits from this livelihood type			Average benefit per person for this benefit type (Real 2012 US$ per month)		
	2002	2011	2012	2002	2011	2012
i) Primary labor income	32.50	38.40	38.50	220.18	301.52	325.18
ii) Secondary labor income	3.60	3.30	2.80	124.13	145.97	185.23
iii) Pension payments etc.	3.90	8.27	8.70	261.31	94.75	89.52
iv) Bono Juancito Pinto	0.30	22.57	23.66	33.40	4.69	5.01
v) Bono Juana Azurduy	0.00	1.61	2.60	0.00	8.26	7.92
vi) Remittances etc.	6.57	7.63	6.70	102.71	119.86	120.79
vii) Rental income etc.	2.21	2.50	2.40	252.74	126.33	123.64
viii) Value of donations etc.	29.73	28.27	21.21	3.19	3.31	2.48
ix) Value of auto-consumption of own production	47.84	40.24	39.41	2.47	8.50	8.13
x) Value of own housing property	62.64	62.41	60.85	23.51	26.61	26.51

Source: Authors' elaboration

The next step is to calculate the number of reasonably independent livelihood sources within each household. We assume that the labor incomes of each household member are relatively independent, so that if we have a household head who works mainly as a construction worker, but also sometimes as a taxi-driver, and a spouse who works as a teacher but also sometimes as a wedding planner, this will count as four different sources of livelihood. In contrast, if they have three kids who each receive the Bono Juancito Pinto, we will count this as only one livelihood source rather than three, because they are highly correlated (for example, the government might cancel this incentive at any time, affecting all three simultaneously). All sources from iii) to x) are pooled within the household and count only as one livelihood source each (Andersen and Cardona, 2013).

With these assumptions, we can calculate all the income shares in each household and use formula (1) to calculate the Diversification Index for each household (Table 2).

Table 2
Vulnerability/resilience indicators, average for all agricultural households in Bolivia, 2002, 2011, 2012

Vulnerability/resilience indicators	2002	2011	2012
Per capita household income (current Bs. per month) (Real 2012 US$ per month)	Bs. 315 US$ 81	Bs. 819 US$ 123	Bs.799 US$ 115
Diversification Index [95% confidence interval]	0.460 [0.452-0.468]	0.518 [0.510-0.526]	0.505 [0.497-0.513]
Number of households used for calculation	2476	2713	2224

Source: Authors' elaboration

As we can see, resilience has increased significantly among agricultural households in Bolivia over the last 10 years, as both the level of income and the level of diversification have improved. Average *per capita* household income increased more than 40% in real terms from US$ 81 per month in 2002 to US$ 115 in 2012, while the average Diversification Index increased from 0.460 in 2002 to 0.505 in 2012. The question is if the irrigation programs PRONAR and PRONAREC have contributed significantly to this improvement in resilience.

Intermediate indicators

We use the Theory of Change depicted in Figure 1 to inspire the selection of intermediate indicators. Thus, the intermediate indicators of interest are the following:

- Crop yields per hectare
- Cultivated area per household
- Number of crop cycles
- Crop composition
- Total quantity of production
- Farm gate prices
- Total value of production
- Households' savings propensity
- Households' investment rate

Unfortunately, most of this information is not available from the household surveys used to calculate the final impact indicators, but partial information is gathered from other sources.

4. Results

4.1. Results of the quantitative analysis of vulnerability/resilience indicators

First we compare the average resilience indicators for agricultural households located in cantons with and without PRONAR or PRONAREC projects for the years 2002, 2011 and 2012. Table 3 shows that agricultural households in cantons chosen for irrigation programs had slightly higher average *per capita* income and slightly higher levels of income diversification than their counterparts in areas that were not chosen for PRONAR/PRONAREC. Because of this initial difference, it is important to make a difference-in-differences analysis (change over time in the difference between treated and non-treated households). No conclusions about the program can be reached by only comparing the before and after situation for treated households (because untreated households might have seen even larger improvements), or by only comparing treated and non-treated households after the intervention (because their starting points were different).

The overall averages shown in Table 3 suggest that the level of income and the level of diversification have increased by almost the same amounts in cantons with and without PRONAR or PRONAREC between 2002 and 2012, but the increase seems to be more steady (less volatile) for households in cantons with irrigation programs.

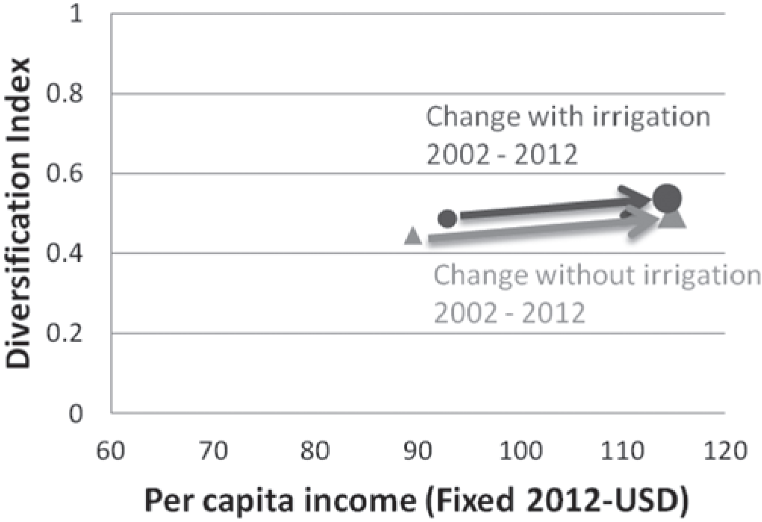
Table 3
Vulnerability/resilience indicators for agricultural households in cantons with and without PRONAR or PRONAREC irrigation projects, 2002, 2011, 2012.

		2002	2011	2012
Average income per capita (Real 2012 US$/month)	Without PRONAR or PRONAREC	89	127	115
	With PRONAR or PRONAREC	93	99	114
Average Diversification Index	Without PRONAR or PRONAREC	0.445	0.515	0.500
	With PRONAR or PRONAREC	0.486	0.534	0.539

Source: Authors' elaboration

Figure 2 illustrates the change in indicators between 2002 and 2012 for agricultural households in cantons with and without irrigation projects, respectively. The changes are very similar, but slightly more positive for agricultural households in cantons without PRONAR/PRONAREC.

Figure 2: Changes in vulnerability/resilience indicators for households located in cantons with and without irrigation projects, 2002–2012.



Source: Authors' elaboration

However, this evolution of the resilience indicators does not necessarily reflect on the effectiveness of PRONAR/PRONAREC irrigation programs, since beneficiary communities have not been randomly selected. Indeed, according to the Bolivian Vice-minister of Water and Irrigation, Carlos Ortuño, beneficiary communities have not been chosen to maximize the impacts of irrigation, but rather to benefit relatively disadvantaged small-holders (especially those with agricultural properties of less than 2 hectares). Since the indicators in 2002 are slightly better for beneficiary cantons than non-beneficiary cantons, it is likely that the poorest and most disadvantaged communities have had difficulties entering the program. The reason for this is partly that communities have to generate a project proposal and coordinate with the municipality to present a request to PRONAR/EC, and this may be complicated for the most isolated and disadvantaged communities. PRONAR also required that there should be road access to the construction site, not just to facilitate construction, but also to make sure that the resulting produce can be brought to a market.

Due to these self-selection and selection biases, it is important to control for all the pre-treatment characteristics that could have affected both the probability of receiving PRONAR or PRONAREC projects and the final outcomes as measured by the two resilience indicators.

The obvious way to control for differences in pre-treatment characteristics is to run simple Ordinary Least Square (OLS) regressions with the vulnerability indicators as dependent variables, the treatment dummy as key explanatory variable and a series of control variables.

Table 4 shows the regression results for the household income *per capita* indicator (measured in real 2012 US$ in order to make the coefficients comparable over time). Important control variables include: Number of persons in household (large households have lower *per capita* income); years of education of the head of household (more is better); age of head of household (more mature households have higher *per capita* income); indigenous status as measured by language (indigenous households have lower incomes); urban dummy (agricultural households located in urban areas have much higher incomes); altitude (households located high above sea level have lower incomes), and slope (households located in a terrain with steep slopes tend to have lower incomes). Soil quality, rainfall and the gender of the head of household were also included as control variables, but did not turn out to be systematically correlated with *per capita* income according to the regression results in Table 4.

Table 4
OLS regressions to test the treatment effect while controlling for pre-treatment characteristics, Dependent variable: Household income per capita. Sample: All agricultural households in survey

Explanatory variable	2002	2011	2012
Treatment dummy	17.563 (1.93)	-0.750 (-0.12)	5.287 (0.74)
Number of persons in household	-17.953 (-10.74)	-18.905 (-12.33)	-17.945 (-13.96)
Female head of household	5.380 (0.58)	0.799 (0.13)	2.393 (0.35)
Indigenous household	-22.711 (-2.53)	-6.323 (-0.78)	-36.001 (-4.03)
Years of education of head of household	10.365 (5.59)	8.271 (8.35)	7.666 (7.16)
Age of head of household	2.946 (9.94)	0.880 (3.81)	1.230 (6.52)
Rainfall	0.060 (0.35)	-0.098 (-1.30)	-0.072 (-0.97)
Altitude	-0.009 (-1.49)	-0.027 (-6.52)	-0.013 (-3.13)
Slope	-0.011 (-0.14)	-0.271 (-2.79)	-0.224 (-2.50)

Explanatory variable	2002	2011	2012
Urban dummy	45.687 (5.04)	42.985 (5.12)	47.081 (5.13)
Soil quality	2.497 (0.75)	5.479 (1.63)	0.216 (0.007)
Constant	2.244 (0.08)	181.786 (8.40)	148.065 (7.27)
Number of observations	1586	2679	2204
R2	0.2748	0.2102	0.2284

Note: Numbers in parenthesis are t-values based on robust standard errors

The estimated treatment dummy coefficients indicate that in 2002 agricultural households in cantons about to receive irrigation had significantly (at a 94% confidence level) higher *per capita* incomes than agricultural households in the remaining cantons, even when controlling for a number of pre-treatment characteristics. However, over time, this difference disappears, so that 10 years later, households in the treatment group no longer have higher incomes than households in the non-treatment group.

This is the opposite of what we would have expected. In 2002, we would have expected no significant treatment effect, as the irrigation projects were just starting to be implemented, whereas 10 years later we should have seen a positive treatment effect, if irrigation systems really served to increase incomes in the agricultural households of the cantons where they were constructed.

Table 5 shows the corresponding results for the Diversification Index. The regression results show that the Diversification Index tends to be systematically higher in households with a larger number of persons, a female head of household, and an older head of household. The coefficients on the Treatment dummy suggest that in 2002, agricultural households in cantons about to receive irrigation had a significantly (at a 99% confidence level) higher Diversification Index than agricultural households in the control group (all other things equal), but 10 years later this advantage had disappeared. This is again the opposite of what would be expected if irrigation programs really worked to increase income diversification in the agricultural households of the cantons where they were constructed.

Table 5
OLS regressions to test the treatment effect while controlling for pre-treatment characteristics. Dependent variable: Diversification Index. All agricultural households in survey

Explanatory variable	2002	2011	2012
Treatment dummy	0.045 (3.56)	-0.016 (-1.75)	0.015 (1.34)
Number of persons in household	0.011 (5.22)	0.020 (12.84)	0.021 (11.85)
Female head of household	0.034 (2.38)	0.050 (5.38)	0.035 (3.42)
Indigenous household	-0.026 (-1.94)	0.000 (0.05)	0.011 (0.97)
Years of education of head of household	0.001 (0.98)	-0.002 (-2.28)	-0.003 (-2.97)
Age of head of household	0.002 (4.82)	0.004 (14.42)	0.004 (12.38)
Rainfall	0.000 (1.30)	-0.0004 (-4.23)	-0.0004 (-3.27)
Altitude	0.000 (0.55)	0.000 (1.72)	-0.000 (-0.64)
Slope	-0.011 (-0.14)	0.000 (1.23)	0.001 (4.24)
Urban dummy	0.000 (1.52)	-0.002 (-0.15)	0.012 (1.05)
Soil quality	0.015 (2.38)	-0.002 (-0.38)	0.012 (2.13)
Constant	0.235 (5.86)	0.279 (10.36)	0.230 (6.82)
Number of observations	1586	2679	2204
R2	0.1963	0.1750	0.1802

Note: Numbers in parenthesis are t-values based on robust standard errors

While the results presented in Tables 4 and 5 suggest that PRONAR and PRONAREC irrigation systems have not produced significant impacts on agricultural households in the cantons where they were built, such linear models are not necessarily the best to test for effects. By applying Propensity Score Matching Methods (Rosenbaum and Rubin, 1983) we can take into account possibly important non-linear effects.

The variables we use for matching are: Number of persons in household; Indigenous dummy; Rainfall; Slope; and Soil quality. These are all variables that may affect the likelihood of getting chosen for the program, and which may also affect the outcomes, but which themselves cannot be affected by the program. There are a number of options available when estimating the propensity score, and we chose between logit and probit models and different number of matching blocks in order to secure that the balancing condition is satisfied in all the Propensity Score Matching Models estimated (Becker and Ichino, 2002). Table 6 presents the average treatment effect, with their bootstrapped standard errors, for the four different matching methods of Becker and Ichino (2002). The Ordinary Least Square (OLS) results from Tables 4 and 5 are also included for comparison.

As we can see, the Propensity Score Matching estimators tend to confirm the OLS results. The only indicator that is systematically and significantly different between households in treatment cantons and control households is the Diversification Index in 2002 (pre-treatment or very early treatment). After that, all significant differences disappear. If we calculate the change in treatment effects over time (after treatment minus before treatment), we can calculate a difference-in-differences estimate of the impact of irrigation on our two vulnerability indicators.

Table 6
Average treatment effects for Vulnerability/Resilience Indicators, 2002, 2011 and 2012

Average treatment effect	Per capita household income [95% confidence interval]			Diversification Index [95% confidence interval]		
	2002	2011	2012	2002	2011	2012
OLS	17.56 [-0.25;35.38]	-0.75 [-13.45;11.95]	5.29 [-8.75;19.33]	0.045 [0.020;0.070]	-0.016 [-0.035;0.002]	0.015 [-0.007;0.034]
Nearest Neighbor Matching	17.97 [-14.26;50.21]	-53.53 [-95.54;-11.53]	-26.32 [-73.44;20.80]	0.043 [0.001;0.086]	-0.017 [-0.058;0.024]	0.018 [-0.032;0.068]
Radius Matching	8.63 [-12.56;29.82]	2.35 [-10.64;15.34]	11.08 [-4.38;26.55]	0.042 [0.019;0.066]	-0.021 [-0.039;-0.003]	0.024 [-0.002;0.050]
Kernel Matching	10.59 [-8.79;29.96]	1.36 [-13.52;13.91]	10.57 [-4.14;25.28]	0.043 [0.019;0.068]	-0.019 [-0.040;-0.001]	0.023 [-0.001;0.047]
Stratification Matching	12.07 [-9.06;33.20]	-2.63 [-14.56;9.30]	9.79 [-7.50;27.09]	0.042 [0.011;0.072]	-0.016 [-0.033;-0.002]	0.022 [0.001;0.043]

Source: Authors' elaboration

The results in Table 7 show that the difference-in-differences estimates are negative for both indicators in almost all cases, but in most cases the effect is not statistically different from zero. The exception is the difference-in-differences estimates of the impact on income diversification between 2002 and 2011, where we find that households in cantons with

PRONAR/PRONAREC projects improved their level of income diversification significantly less than matched households in cantons without PRONAR/PRONAREC projects. This result is very robust across all estimation.

Table 7
Difference-in-differences estimate of the Average Treatment Effect for our Vulnerability/Resilience Indicators, 2002-2011

	Dif-in-dif 2002-2011		Dif-in-dif 2002-2012	
	Per capita household income	Diversification Index	Per capita household income	Diversification Index
OLS	-18.31	-0.061	-12.27	-0.030
Nearest Neighbor Matching	-71.50	-0.060	-44.29	-0.025
Radius Matching	-6.28	-0.063	2.45	-0.018
Kernel Matching	-9.23	-0.062	-0.02	-0.020
Stratification Matching	-14.7	-0.058	-2.28	-0.020

Source: Authors' elaboration.

Note: Numbers in bold are significant at the 95% confidence level. The remaining numbers are not significantly different from zero

Insignificant estimation results would not be surprising given that we cannot identify actual beneficiary households, but only households in cantons that have benefitted from at least one PRONAR or PRONAREC project. While more than 10 thousand families have benefited from PRONAR and PRONAREC projects, these constitute only a fraction (about 10%) of the total number of agricultural households in the involved cantons. Thus, even if the direct beneficiary households had experienced amazing progress, this would be diluted by averaging the results together with their more numerous neighbors whom did not experience such progress. Thus, it would indeed be difficult to get significant positive effects with these data limitations.

However, the fact that the signs of the estimated difference-in-differences treatment effects are almost all negative, and in some cases even significantly negative, suggests that the dilution explication is not the only explanation. It is likely that one or more of the pitfalls suggested in the analysis of the Theory of Change may indeed have been important in the implementation of the projects.

We explore this possibility in detail in the following two sub-sections through a more detailed analysis of each of the steps in the Theory of Change. First we analyze some of the intermediate indicators, although here we also face severe data limitation constraints, and then we analyze the results of qualitative information gathered through expert interviews and focus groups with key informants from beneficiary communities.

4.2. Results of the quantitative analysis of intermediate indicators

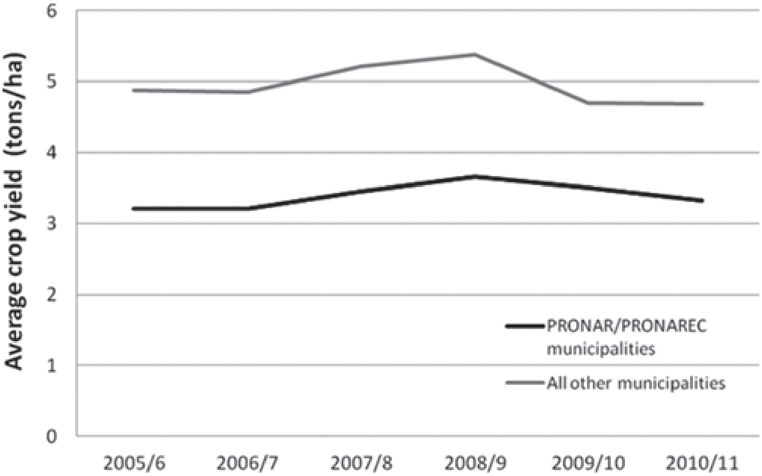
One of the first intermediate impact indicators from the Theory of Change is crop yields. Unfortunately, this information is not available in the household surveys. The most detailed information we could obtain on crop yields in Bolivia consisted of a municipality level data base provided by the National Statistical Institute (INE) on 32 different crops for every growing season from 2005/6 to 2010/11. This is not a very long time series, and it is not as geographically disaggregated as the canton level information used in the previous section, but it is still worth checking how crop yields have developed in municipalities with PRONAR/PRONAREC irrigation projects and municipalities without.

Figure 3 shows that crop yields are considerably lower in PRONAR/PRONAREC municipalities than in all other municipalities in Bolivia, so there is plenty of room for improvement. The improvements observed between the 2005/2006 and the 2010/2011 growing season are very small, and although the gap seems to have closed a little bit, the change is not statistically significant.

Of course, these are very course data, and it may not be fair to judge the effectiveness of small community interventions by average yields at the municipal level. To get more accurate results we would have to measure yields over several years at comparable agricultural plots with and without irrigation systems.

The second intermediate indicator in the Theory of Change is the extension of cultivated land, since irrigation may permit the cultivation of marginal lands that might not otherwise be cultivated. Again, there was no benefit to detect for PRONAR/PRONAREC municipalities, as the area of cultivated land expanded less in these municipalities (5%) than in other municipalities (8%) between 2005 and 2011.

Figure 3: Average crop yields in municipalities with and without PRONAR/PRONAREC irrigation projects, 2005/6-2010/11



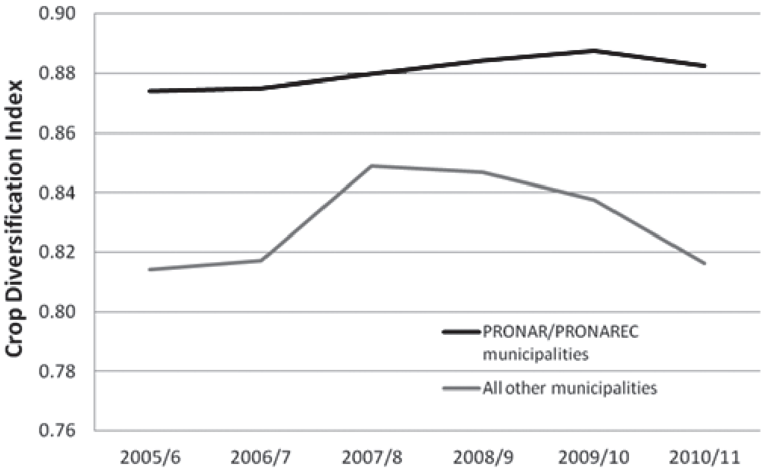
Source: Authors' elaboration based on municipality level data provided by INE

The third intermediate indicator was related to the number of cropping cycles. According to the Viceminister of Water and Irrigation, irrigation systems may permit the inclusion of some additional short-cycle crops, because irrigation will extend the growing season. This we do not have data on. However, the crop data provided by INE allows us to calculate a Crop Diversification Index that shows how diversified PRONAR/PRONAREC municipalities are compared to all other municipalities. Figure 4 suggests that PRONAR/PRONAREC municipalities cultivate a large number of different crops and that they have become even more diversified over time. The increases in quinoa and soy bean production for exports are responsible for this increase in diversification in PRONAR/PRONAREC municipalities. For non-PRONAR/PRONAREC municipalities the hump-shape is explained by a temporary boom in sunflower seed production. In any case, the observed changes are clearly well within the natural year-to-year variation, and thus not statistically significant.

The fourth impact pathway suggests that irrigation may permit a change towards more expensive high value crops, since the risk of loss due to drought would be significantly reduced. This effect is difficult to detect in the available data. The only crop that has increased significantly in extension in PRONAR/PRONAREC municipalities is quinoa, and this is clearly due to the opening up of international markets for quinoa and the tremendous increase in prices that this has caused. Previously, quinoa was a crop grown mainly by the poorest of

Bolivian farmers for auto consumption and local markets, so this does not work as an example of switching to a high value crop. It was the crop that switched, not the farmers.

Figure 4: Crop Diversification Index for all municipalities with and without PRONAR/PRONAREC irrigation projects, 2005/6-2010/11



Source: Authors' elaboration based on municipality level data provided by INE

In general, the situation of farmers depends a lot on the price at which they can sell their crops. Prices for the major crops at local markets[6] have all increased substantially in real terms between 2002 and 2012. Corn increased by 57%, quinoa by 88% and potatoes by 44%. This should benefit the households that produce more than they consume of these products, and this is one of the most important reasons for the increase in household incomes among agricultural households, since the increase in production quantity has been very limited (an increase of less than 10% between 2005 and 2010). The increase in prices is due to demand increasing faster than supply, and this has been possible due to the inclusion of export crops, such as quinoa and soy beans, in the production mix. However, this is not something that was encouraged by PRONAR and PRONAREC. Indeed, according to the Viceminister of Water and Irrigation, PRONAREC specifically excludes exporters, instead targeting farmers who produce for auto consumption or local markets, since exporters are assumed to have sufficient funds to invest in their own irrigation systems if they so desire.

6 We calculate median prices based on consumption information from the INE household surveys.

Another possible reason why irrigation systems together with higher incomes from higher output prices might not result in substantially higher agricultural production, may be that households lack the third crucial production factor – namely labor. The supply of labor could have been reduced for a number of reasons: i) young people might chose to study instead of work at the farm, ii) the men might chose to work in mining or construction, taking advantage of the unusually high prices of minerals and the construction boom over the last several years, or iii) the younger generation may have chosen to migrate in pursuit of alternative options. These issues can be analyzed in more detail once the 2012 household census becomes available for analysis.

4.3. Results of the qualitative analysis

As a complementary method of analyzing potential pitfalls, we carried out a qualitative analysis based on field visits to six beneficiary communities and interviews with current PRONAREC staff and former PRONAR staff. With very generous support and help from staff from PRONAREC and the Departmental Irrigation Services (SEDERI) in La Paz, Oruro, Cochabamba and Santa Cruz, we managed to carry out a series of focus groups with key informants from the six beneficiary communities spread across the highlands (Vilacollo and Rey Inca), valleys (Pirhuas, El Paso) and lowlands (Saipina and San Juan del Potrero)[7]. Communities were not chosen completely at random, but rather selected for us by PRONAREC staff according to accessibility with a very limited field work budget while trying to respond to a request for the inclusion of as wide a variety of experiences as possible (old, new, large, small, successful, conflictive, etc.). We do not claim that this small group of 6 communities is representative of all PRONAR/PRONAREC beneficiary communities, but they have presented a variety of interesting experiences and provided examples of concrete experiences of some of the hypothesized pitfalls.

We have transcribed and analyzed all the interviews according to the Theory of Change depicted in Figure 1, registering comments in evidence of a realized positive change and comments in evidence of an obstacle to the expected effect.

About the physical irrigation structures and water availability

7 Transcripts of all interviews are available in a separate field work report.

In all of the six communities visited, the PRONAR and PRONAREC programs did not build completely new irrigation infrastructure, but rather improved on existing, sometimes century old, systems of irrigation canals called *acequia*. Thus, the programs did not necessarily imply a dramatic change from no irrigation to irrigation, but rather an incremental improvement over the previous system.

According to beneficiaries in the communities visited, the improved canals (made of concrete) significantly reduce water loss, thus allowing more frequent and more effective irrigation, as well as more people irrigating at the same time. Above all, however, the improved canals reduce the time farmers have to spend on cleaning and maintaining the irrigation canals. The old dug-out canals got easily damaged during extreme weather events and community members had to spend substantial amounts of time fixing damaged canals.

Although the PRONAREC Project Profile (IDB, 2008a) indicated that the program would intervene with 100 micro irrigation systems and 10 irrigation programs on 8,000 hectares of agricultural land currently without access to irrigation systems, the reality is that most PRONAREC interventions constitute improvements over already existing *acequia* irrigation systems. Indeed, the only eligible beneficiaries of PRONAREC are irrigation associations (IDB, 2008b), suggesting that all beneficiaries already have some kind of irrigation system in place.

Investing in improvements of existing irrigation systems is a reasonable strategy, because, as explained in the PRONAREC Loan Proposal, there are more than 5,000 irrigation systems in Bolivia, covering a total area of 226,000 hectares, but the performance of many of these systems is inadequate because of (i) the scarcity of water from intermittent sources; (ii) the absence of regulatory works, stemming from the lack of a watershed approach in which water use rights are granted based on verification of the water balance; (iii) the unreliability of the irrigation infrastructure, leading to low storage and conveyance efficiency; (iv) inadequate water management coordination, particularly with regard to distribution; and (v) the fact that the best irrigation technologies available are not used on steep plots due to the lack of needed comprehensive technical assistance (IDB, 2008b).

Thus, while there is a clear need for improving existing systems, the choice to support only families who are already members of an irrigation association means passing by the potentially more vulnerable families that currently rely exclusively on rain for watering their crops. These latter families, which for historical, geographical and social reasons have not benefitted from neither the 1952 Agricultural Revolution, which redistributed land and water rights from the big land owners to the agricultural workers, nor from subsequent irrigation initiatives, might justifiably feel that ignoring them in favor of the already better off families who already have access to irrigation would be unfair.

Thus, there is at least a potential for conflict in the design of PRONAREC, and a potential for amplifying already existing inequalities in water access. People in our focus groups have mentioned this problem, but a much more thorough study would be needed to reliably assess the distributional impacts of the national irrigation programs.

In some cases there may also be design problems. In Saipina, for example, the beneficiaries complained that their irrigation canal only works when the river is high (during and after the rains), but not when the river is low, because the canal extracts water from the very border of the river next to the mountain, but during dry spells the river shrinks towards the middle of the river bed and do not feed the irrigation canal. Thus, exactly when water is most needed, the irrigation system is dry.

In general, whenever irrigation canals are fed directly by rivers, and not via an irrigation dam, water may be abundant when it is raining but very scarce or non-existing during a drought. Thus, the presence of irrigation systems is not necessarily a guarantee that water will be available when it is most needed. Projects which include dams for water storage are more effective at providing water during droughts, but are also much more expensive. Only two out of the 54 PRONAREC projects involve a dam.

While the easy maintenance of the improved canals is highly appreciated by beneficiaries, some irrigation systems have been left to deteriorate, as was easily observed during our field work. Carlos Montaño (a former PRONAR staff currently working at PROAGRO), was critical of the reduction in local contributions from 20% during PRONAR to 10% (or less) during PRONAREC, since the lower contribution generates less ownership and thus less motivation for maintaining the systems.

The size of the local contribution is a complicated dilemma. On the one hand, you would want the beneficiaries to be highly committed to the project, and the higher their contribution, the higher their stake in it. On the other hand, however, you don't want to exclude the poorest families, which might not be able to contribute even 10%. The average investment per family in PRONAR and PRONAREC exceeds US$ 3,000, so a 10% contribution is a substantial hurdle, even if it can be paid in labor rather than cash. PRONAREC has found that the insistence on the 10% contribution causes severe delays in the project implementation, as it is difficult to get all the beneficiaries to pay and/or work when needed. In some cases, the construction companies have had to pay beneficiaries to do the work they were supposed to contribute to the project in order to avoid lengthy and costly delays (Fernando Balcazar, personal communication). One possible solution is that the municipality steps in and pays the local contribution up front, and then the beneficiaries can pay off their contribution over time using their supposedly higher income resulting from improved irrigation.

About agricultural productivity and yields

Generally, beneficiaries report increasing yields and increased production due to the improved irrigation systems. But typically, they just produce "more of the same" using the same techniques as always.

One of the reasons for the lack of a "qualitative" change is inadequate training. While the training component improved from PRONAR to PRONAREC, including an Integral Technical Assistance component in the latter, there is the perception that the technical advisors associated with the PRONAREC programs did not have sufficient local knowledge to advise on improved agricultural methods, did not manage to communicate effectively with farmers (too technical language), and were not around long enough to be of assistance.

There also seems to be the impression among water cooperative members that water is not being used optimally and instead people use their historically allotted water rights, even if it means over-watering their crops. Beneficiaries complain of insufficient and inadequate training in the optimal use of irrigation, and also demand more modern technologies like drip irrigation or sprinklers.

The difference between PRONAR (*Programa Nacional de Riego*) and PRONAREC (*Programa Nacional de Riego con Enfoque de Cuencas*) was supposed to be the inclusion of a watershed approach. So far, this does not seem to have been implemented at all. There is still a strong focus on individual communities without coordination between communities within the same watershed, which sometimes leads to conflicts between up-river and down-river communities, and even sometimes splits communities giving only farmers on the left side improved irrigation canals while the ones on the right side are left without. Especially in the highlands, we also see that excessive irrigation up-river, causes salinization of land further down, thus damaging crop productivity. However, there is at least an intention to seriously include the watershed approach in PRONAREC 2, by setting aside up to 10% of the budget for investments in the watershed (for example a reforestation effort to protect the water source).

About output prices

A frequent complaint is that when each farmer brings more of the same to the local market, prices will drop, leaving farmers little better off. Beneficiaries report that in order to make a real leap into more high value activities, they would need complementary assistance, such as access to improved seed varieties, a milk processing plant, access to export markets, as well as the training necessary to embark on something new.

This would require training and follow-through for several years instead of months. The lack of trainers qualified to do this could constitute an important limiting factor for PRONAREC, so alliances with universities, municipalities and other institutions should be sought.

While lower prices constitute a disadvantage for the producers, it is of course an advantage for consumers, so a reduction in prices cannot be interpreted solely in a negative way.

About savings, investment, and migration

Most small-holder households realize that subsistence agriculture is not the only option for the younger generation, and many prioritize the education of their children highly in order to secure that these will have more opportunities in the future. Many, therefore, send the children off to study in the city, and few return to their communities after completing their education. This means that a lot of the investments made in human capital does not stay in the community.

In the valleys and low-lands where landholdings are larger, there is a bigger chance that a son will return with a relevant education (*e.g.*, agronomy) to work on the family farm, but in general, ambitions are targeted at the cities.

In regions with very small agricultural holdings, such as the Bolivian Altiplano, the out-migration and consolidation of land is key to improve incomes and living standards for those who remain in the rural areas, so migration is certainly not a bad thing. It is simply a fact that could explain why local investments in agriculture might not be as high as expected, and why labor constraints might be very important in the farmers' decision making process.

About diversification of income sources

Due to generations of sub-divisions of land holding between numerous children, land sizes –especially in the highlands– have become so small that they can barely sustain a family. Thus, small-holder households, with or without improved irrigation systems, are forced to diversify into alternative activities, such as construction or transportation.

However, since the observed improvement in diversification has occurred during a period of prolonged economic boom, the necessity argument does not explain why households have become significantly more diversified. Most likely, it is because of increased alternative opportunities, not only in construction and transportation, but also in mining, education, commerce, local government work, and others. In any case, the field work did not yield any statements about the improved irrigation infrastructure having contributed to increased diversification, even though it is conceivable that the time freed up from irrigation canal maintenance could have been used to engage in other productive activities.

5. Discussion and recommendations

This study has presented a mixed quantitative-qualitative analysis of the contributions of the national irrigation programs PRONAR and PRONAREC to the reduction in the vulnerability of agricultural households in Bolivia. We proposed two main vulnerability/resilience indicators to measure changes in vulnerability, and developed an explicit Theory of Change indicating how the irrigation projects were expected to impact these two key dimensions of vulnerability. The Theory of Change also allowed us to identify potential pitfalls that might prevent the desired outcomes from materializing.

In the quantitative part of the analysis, we showed that agricultural households in Bolivia have significantly improved their resilience indicators during the period of analysis from 2002 to 2012. However, similar improvements are observed both for households located in cantons that benefited from national irrigation projects and for matched control households located in cantons that never benefited from any of the national irrigation programs. If anything, the households in PRONAR/PRONAREC cantons fared slightly worse than the matched control households, especially in terms of income diversification. The matching was carried out to secure that the treatment and control households were as similar as possible in terms of a number of pre-treatment characteristics, such as climate, soil quality, household composition, education levels, etc.

A difference-in-differences estimation comparing the changes in vulnerability over time for households in cantons with completed PRONAR or PRONAREC projects and similar households in cantons without such projects, indicate that the former group improved their income diversification less than the control group. This difference was statistically significant at the 95% confidence level for changes between 2002 and 2011, but not so for changes between 2002 and 2012. Income increases tended to be smaller for households in PRONAR/PRONAREC cantons than for control households, but the differences were not statistically significant.

Insignificant estimation results would not be surprising given that we cannot identify actual beneficiary households, but only households in cantons that have benefitted from at least one PRONAR or PRONAREC project. While more than 10 thousand families have benefited from PRONAR and PRONAREC projects, these constitute only a fraction (about 10%) of the total number of agricultural households in the involved cantons. Thus, even if the direct beneficiary households had experienced amazing progress, averaging the results together with their more numerous neighbors whom did not experience such progress would dilute this effect. Consequently, it would indeed be difficult to get significant positive effects with these data limitations.

However, the fact that the signs of the estimated difference-in-differences treatment effects are almost all negative, and in some cases even significantly negative, suggests that the dilution explication is not the only explanation. It is likely that one or more of the pitfalls suggested in the analysis of the Theory of Change may indeed have been important in the implementation of the projects.

While our qualitative analysis was much too limited to be representative of all the communities covered by PRONAR/PRONAREC, by visiting just six beneficiary communities, we saw several of the potential pit-falls expressed in reality.

For example, we realized that most PRONAREC projects consist of improvements to already existing *acequia* irrigation systems, and that beneficiaries are always already existing irrigation associations. This implies an improvement for farmers who already have access to irrigation, but not a big qualitative shift from no irrigation to irrigation, as the Theory of Change supposed. We also heard complaints from non-recipients that it was unfair that the ones who already had irrigation received improved irrigation, while the ones who didn't have anything were ignored.

The communities visited explained that they were very pleased with the cement-covered canals as they were much easier to maintain compared to the old dug-out *acequia* canals. Still, in two of the six communities visited, the new canals were in serious need of maintenance.

The own contribution of beneficiaries has dropped to 10% or less, because PRONAREC has trouble getting beneficiaries to make their contribution (usually in labor) when it is needed. In some cases, the construction companies have had to pay people to do the work they were supposed to do for their own benefit. The fact that it is so difficult to get people to contribute to improving their own irrigation infrastructure, suggests that beneficiaries do not value the projects very highly. It would be important to find out if the beneficiaries are correct in their low valuation, or if it is truly difficult for them to contribute even 10% in labor. The average investment per family is US$ 13,500, so even a 10% contribution could take several months to work off.

An often-heard complaint was also the adverse price effect associated with increased agricultural production. Since PRONAREC beneficiaries typically produce only for local markets, a significant increase in the production of a whole irrigation association may adversely affect their sales prices at the local market. People requested help to make a qualitative change in their production, not just a quantitative change, which they know will cause adverse price effects.

Based on the combined quantitative and qualitative analysis, our recommendations to PRONAREC as well as donors are the following:

- Since there is no point in increasing agricultural production if there is no demand for the additional output, **the program needs to contemplate the crucial importance of market access**. It can do that either by redirecting efforts towards communities that are already producing for exports, or it can help the current target group of local producers become exporters (or at least suppliers for the big cities in Bolivia). The latter would probably imply a switch to new types of crops, for which extensive technical assistance would be needed, implying the technical assistance component of the program would have to be strengthened. Beneficiaries have mentioned the need for this kind of long-term assistance to change to new crops that they are not familiar with.
- **The contribution of beneficiary households should be increased again to 20%**, as it was during PRONAR. This helps secure that beneficiaries care sufficiently about the investment, so that they will take good care of it and will create appropriate social

structures around it. It also helps filter out projects with low or unclear returns. However, to avoid that this payment excludes the poorest communities from benefiting from the program, municipalities could make the required payments upfront to get construction started, and then subsequently let beneficiaries pay their contributions over time once they are reaping the benefits of the improved irrigation infrastructure.

- This study was not designed and budgeted to carry out a proper evaluation of the impacts of irrigation programs in Bolivia, but it has provided enough indications to suggest that **a more thorough evaluation needs to be carried out in order to better understand the impacts and limitations of the programs**. Ideally, such an evaluation should compare the changes in conditions for beneficiary households with the changes in conditions for similar control households which have not benefitted from the program. The control households cannot be nearby households, as these may actually be harmed by the project (***e.g.,*** if the additional production from beneficiaries causes output prices to fall for everybody), thus demonstrating an exaggerated difference between treated and control households. A full impact evaluation study would require very good baseline data from before the intervention, for both treatment and control households on vulnerability/resilience indicators as well as intermediate indicators. Such data probably does not exist, so it may not be possible to carry out such an ideal impact evaluation any time soon. Alternative, less ambitious analyses may also be worthwhile, however. For example, a more comprehensive qualitative analysis could delve much deeper into the priorities of potential beneficiaries. When they are faced with the choice between a practically free improvement to their irrigation system and no improvement at all, they will obviously choose the improvement. However, it would be interesting to present them with a wider list of hypothetical choices including similarly valued alternative items, such as a used pick-up truck, a small urban property, a higher education grant, a non-agricultural job or a cash bonus of US$ 13.500, and ask them to rank that list, to see how, in their minds, improved irrigation compares to other options.

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