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Assessing the Effectiveness of Projects Supporting On-Farm Conservation of Native Crops: Evidence From the High Andes of South America

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Summary. — This paper presents an approach for assessing the effectiveness of projects aimed at creating incentives for smallholder farmers to continue maintaining crop diversity under evolution on their farms in relevant centers of genetic diversity—a process known as on-farm conservation. It is applied to five projects involving native crops in the High Andes of South America. Results show evidence that projects have been effective at supporting farmers to maintain crop diversity on-farm while generating positive livelihood outcomes. Implications and challenges of both the approach and the results for sustainable use and conservation of crop biodiversity are discussed.

Key words — crop genetic diversity, livelihoods, South America, Bolivia, Ecuador, Peru

1. INTRODUCTION

Smallholder farmers who continue to grow diverse landraces in their farms in centers of crop diversity, a process referred to as on-farm conservation (OFC), provide a service to society by sustaining crop evolution that generates the broad genetic variation necessary for crops to adapt to change (Bellon & van Etten, 2014; Brush, 2004). Continued access to a broad range of novel genetic variation is essential for maintaining the capacity of crops to respond to unpredictable weather patterns, pest and disease epidemics, and global market fluctuations (Gepts, 2006; McCouch, McNally, Wang, & Sackville-Hamilton, 2012). Crop genetic diversity is unequally distributed around the world and is concentrated in centers of diversity which often coincide with centers of crop domestication (Gepts, 2006), where many smallholder farmers continue to maintain it (Brush, 2004; Jarvis *et al*., 2008). These farmers and the infraspecific crop diversity they manage—i.e., the phenotypic and genetic variation present within a particular crop species—constitute socio-biological systems by which crop evolution takes place in distinct environments as a result of multiple selection pressures caused by human preferences and various biotic and abiotic factors (Bellon, 2009; Brush, 2004; Gepts, 2006; Vigouroux, Barnaud, Scarcelli, & Thuillet, 2011). These systems depend crucially on farmers' preferences, incentives, knowledge, management practices, institutions, and social organization (Bellon, Pham, & Jackson, 1997; Brush, 2004; Zimmerer, 2010). Farmers continue to maintain this diversity—known as *de facto* conservation—because it provides them with a range of benefits such as adaptation to agro-ecological heterogeneity (Ceccarelli, 1996; di Falco & Chavas, 2009; Worthington, Soleri, Aragon-Cuevas, & Gepts, 2012), ways to manage risk (Cavatassi, Lipper, & Narloch, 2011; di Falco & Chavas, 2009; di Falco & Perrings, 2005), options to obtain more diverse products for consumption and sale (Brush, 1992; Keleman, Hellin, & Flores, 2013; King, 2007), and the provision of marketing opportunities (Devaux *et al*., 2009; Keleman *et al*., 2013; King, 2007), not to mention for cultural value (Arslan & Taylor, 2009; Brush, 1992; Isakson, 2011; Perales, Benz, & Brush, 2005; Rana, Garforth, Sthapit, & Jarvis, 2007).

Economic development and cultural change, however, in many cases can reduce the value of maintaining crop diversity on-farm (Bellon, 2004; Isakson, 2011; Zimmerer, 2010). This is due to the availability of scientifically bred varieties and complementary external inputs which may foster specialization into a few varieties (Evenson & Gollin, 2003; Heal *et al*., 2004; Van de Wouw, Kik, van Hintum, van Treuren, & Visser, 2010), more efficient marketing channels that may lead to the disappearance of market niches (Tisdell & Seidl, 2004; van de Wouw *et al*., 2010), and dietary changes and availability of new products which reduce the demand for diverse local varieties (Andersen, 2012; Keller, Mndiga, & Maass, 2005). Managing crop diversity on farm can be quite labor-intensive, so increased migration and off-farm labor opportunities can decrease its feasibility (Isakson, 2011; Rana *et al*., 2007; Zimmerer, 1991). In addition, farmers may abandon traditional seed management practices such as seed saving, selection, and sharing—which are key to maintaining evolutionary processes on farm—in favor of purchasing commercial seed, thus hindering crop evolution in their farms (Vigouroux, Cedric *et al*., 2011). Even if traditional practices are maintained,

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the seed systems that underpin them tend to be mostly local (Bellon, Hodson, & Hellin, 2011; Kawa, McCarty, & Clement, 2013; Pautasso *et al*., 2013), which may restrict farmers' access to the wider crop diversity available in a region that could provide more competitive local varieties in the face of change (Bellon *et al*., 2011; Isakson, 2011). Thus, while maintaining crop diversity on-farm can entail important private costs to smallholder farmers in the face of economic development and cultural change, it also has an important public value by contributing to the maintenance of crop capacity to adapt to changing conditions, critical to the resilience of agricultural and food systems under unpredictable conditions (Folke, 2006). These farmers, who tend to be marginal, cannot be expected to maintain crop diversity for the long-term benefit of society at the expense of their short-term personal or family wellbeing. For these reasons, if society values resilient agricultural and food systems, there is a need for outside intervention to support farmers in maintaining this diversity. In the last 20 years, many projects to support OFC have been implemented worldwide. There has been very little systematic assessment, however, of the extent to which OFC projects have actually made a difference beyond what *de facto* conservation is already delivering (Bellon, Gotor, & Caracciolo, 2015; Bellon & van Etten, 2014). For example, a recent and extensive review (Jarvis, Hodgkin, Sthapit, Fadda, & Lopez-Noriega, 2011) identified 59 different types of interventions for supporting OFC worldwide, but there is little evidence that they actually made a difference. Projects supporting OFC can only contribute to agricultural and food systems resilience if they are effective, actually making a difference beyond what farmers can achieve on their own.

The objective of this paper is to present an approach for assessing the effectiveness of OFC projects based on the examination of a series of linked and sequential hypotheses that test for evidence of a project-driven process of change, which should occur if a project is successful. It then applies it to analyze five OFC projects in the High Andes of South America *ex-post* involving six native grain and tuber crops, as well as a broad diversity of plant species in one of the projects. The main crops involved are quinoa (*Chenopodium quinoa* Willd.), cañahua (*Chenopodium pallidicaule* (Allen)), potatoes (*Solanum tuberosum* Linn.), oca (*Oxalis tuberosa* Mol.), ulluco (*Ullucus tuberosus* Caldas), and maswa (*Tropaeolum tuberosum* R.&P.). The High Andes region is an important center of domestication and diversity for these crops (Castillo, 1995; Harlan, 1992). Smallholder farmers there continue to be important custodians of the phenotypic and genotypic diversity of these crops (Castillo, 1995; Zimmerer, 1996). Many OFC projects have been implemented in the region by a variety of institutions, from NGOs to universities and national research organizations, and are supported by different donors, from national governments to foundations and international agencies. The five projects analyzed here were implemented in Ecuador, Peru, and Bolivia and represent a range of implementing agencies, donors, partners, and combinations of native crops, providing a broad perspective on OFC efforts. Although an *ex-post* analysis is not ideal since it entails many limitations and challenges – which will be discussed here—it provides an opportunity to learn from a wealth of experiences that already have taken place and the complex realities in which they have occurred. This paper addresses a major gap in the body of knowledge on OFC: the lack of quantitative evidence that projects aimed at supporting it work beyond what famers do on their own. This is done by providing a conceptual approach and empirical evidence to test whether this type of project can be effective [1] in supporting farmers in maintaining crop diversity on-farm that is both relevant for society and able to generate positive livelihood outcomes.

This paper is organized as follows. Section 2 presents the conceptual approach used, discussing the aims of OFC projects, a generic theory of change for them -from which a set of hypotheses to be tested to assess their effectiveness are derived- and some of the challenges involved. Section 3 presents the projects that were analyzed, their objectives and the interventions they provided, as well as some background on the areas where they took place. Section 4 presents the methodological approach employed, with a description of the data collected on the projects, sample selection and the econometric approach used, including the description of the indicators and other variables used. Section 5 presents the results, including a characterization of the households studied, the native crop diversity they maintain, the assessment of the projects by their implementers, the application of options by participants and the econometric results. Section 6 presents the discussion and some concluding remarks.

2. THE CONCEPTUAL APPROACH

The socio-biological systems that maintain landraces in centers of crop diversity produce both private and public benefits, but in ways that can result in a "social dilemma," where incentives can be against crop diversity and its sustainable use, and in favor of economic activities that erode them. Interventions may be needed to maintain the public benefits derived from crop diversity once *de facto* conservation ceases to be viable if these benefits are deemed socially desirable (Bellon *et al*., 2015). Any project aimed at the on-farm conservation of crop diversity intends to influence three areas: (1) the crop diversity maintained by farming households in a community; (2) the private benefits that farmers and their households derive from the maintenance of that diversity, i.e., food security, nutrition, income, cultural identity, and (3) the public benefits that society derives from that diversity, i.e., the option values derived from crop evolution. OFC projects usually consist of interventions that provide farmers with options such as technologies, development of capacities, and skills or forms of organization that change the way they access, manage, use, perceive, consume and/or market crop diversity. Their purpose is to retain or create private incentives for farmers to continue to maintain on farm crop diversity, associated practices and knowledge under changing circumstances and thus maintaining crop evolution – a public benefit. In a successful project, farmers should apply these options which should lead them to maintain crop diversity and should translate into livelihood benefits for them and their households in terms of enhanced income, increased food consumption and improved security, productivity, stability, and/or reduced vulnerability, which in turn should translate into maintaining crop evolution. This simple chain of events presents a generic theory of change for OFC projects, i.e., a narrative that articulates a logical chain of events linking interventions to changes leading to desired results, and provides an approach for empirically assessing their success (the conceptual framework that underpins this narrative is presented in Bellon *et al*., 2015). It does so by identifying four different but related hypotheses to be tested: (1) Participation in project interventions leads farmers to apply options provided by the interventions; (2) the application of these options leads to farmers maintaining higher levels of crop diversity than would have been possible without interventions; (3) farmers with higher levels of crop diversity obtain additional benefits from this diversity; (4) the higher levels of crop diversity linked with the application of these options are associated with higher levels of genetic diversity, and thus potential for continued crop evolution, than would have occurred otherwise. The first three hypotheses deal with social sciences issues, and are the focus of this paper, while the fourth deals with issues pertaining to crop population genetics and biogeography (e.g., Bellon *et al*., 1997; Brown, 1999; van Zonneveld, Dawson, Thomas, Scheldeman, & van Etten, 2014) and is beyond the scope of this paper.

Testing the first three hypotheses statistically presents empirical challenges that are common, but also well-understood, in the evaluation of agricultural interventions (Barrett & Carter, 2010; Caliendo & Hujer, 2006; Guo & Fraser, 2010; Heckman & Vytlacil, 2005). These include the presence of endogeneity, selection bias, and confounding effects which could complicate the identification of the real causal impact of a project in an observational setting. The problem of endogeneity stems from the unclear causal relationship between the maintenance of crop diversity and the application of the options provided by interventions. Our theory of change postulates that farmers who apply options provided by a project grow higher levels of crop diversity than they would have done without it; however it is possible that those with higher crop diversity apply more options, i.e., reverse causality. Selection bias may be present due to the possibility that farmers who choose to participate in an OFC project are those who value crop diversity more (e.g., face more heterogeneous environments or need multiple crop traits) and have a higher capacity to participate (e.g., have more free time, are wealthier, have more social capital), so that participants are a biased sample of the farming population at large, and participants and non-participants are different; thus comparing them is not appropriate. Engaging with farmers who value crop diversity, however, is actually desirable for an OFC project as it diminishes the costs of its implementation, i.e., the marginal benefits that the project has to deliver are smaller if dealing with this subset – rather than the population at large (Smale & Bellon, 1999)- but clearly complicates the evaluation of its effectiveness. There are usually a series of environmental, socioeconomic and cultural variables that may influence project results—known as confounding factors—such as wealth, education, ethnicity, gender, assets, sources of income, environmental heterogeneity, social capital, and so forth, whose failure to take into account in the analysis of project effects may lead to erroneous attribution of these results. Many technical options exist to address these problems (Barrett & Carter, 2010; Caliendo & Hujer, 2006; Gelo & Koch, 2014; Gotor, Caracciolo, Blundo-Canto, & Al-Nusairi, 2013), and our empirical framework takes these aspects explicitly into account.

3. THE CONTEXT: PROJECTS AND STUDY SITES

(a) *Projects analyzed*

Through an extensive internet-based search and literature review, we identified 26 projects[2] which focused on OFC of native crops in the High Andes of Ecuador, Peru and Bolivia. From those, five were selected for in-depth analysis through an expert consultation with practitioners and donors, based on a set of criteria that included: a focus on OFC of native crops in the Andean region; funding by a variety of donors; sufficient documentation; project design that encompassed a variety of different situations in terms of interventions, countries, crops, social and biophysical environments, as well as feasibility to contact and interact with project implementers (Table 1). Projects implemented between 12 and 19 specific interventions each. Table 2 presents the specific interventions implemented by each project, which we grouped by the common issues they dealt with, into seven themes: (i) enhancing farmers' knowledge about the native crop diversity available beyond their households and communities, as well as facilitating access to seed and planting material of this diversity; (ii) providing knowledge, skills, practices, and technologies to improve water management, soil fertility, general agronomic management, and pest control, as well as improving harvesting, processing, and storage; (iii) compiling and disseminating recipes, training on food preparation techniques for target crops, as well as providing information on better nutrition; (iv) enhancing the capacity of farmers to market target crops by forming marketing associations and organizing marketing fairs; (v) supporting farmers to participate in agro-tourism activities, particularly using the crop diversity they manage as a factor to capture guests' interest; (vi) enhancing the capacity of farmers to organize themselves, and (vii) enhancing the capacity of farmers to learn from each other. The projects were specifically designed for supporting and promoting the conservation and use of native crop diversity by contributing to generating benefits from this diversity for farmers. These benefits were clearly linked to higher and more reliable levels of production, consumption, and/or marketing of these crops. Projects used participatory approaches that connected project implementers with farmers and communities. According to project implementers, most interventions involved knowledge, varieties, practices, technologies, and social organization that were not known, present, or practiced in the communities prior to project implementation, and thus their use can be attributed to the projects. In the case of specific crop varieties, some may have been used by or known to specific households but not systematically available to the community—which is what the projects fostered—while others were introduced from other communities or reintroduced from gene banks. Only two projects included interventions involving the dissemination of traditional practices and were not included in our analysis.

(b) *Study sites*

The implementation of these projects took place in rural communities in the High Andes. In the case of Ecuador, the area of implementation of project A is located in the department of Imbabura, between 2,300 and 2,800 meters above sea level (masl), with an average precipitation of 625 mm/year, mean temperature of 15 °C and with a rainy season taken place between December and May. Basic infrastructure is lacking, though some farmers own irrigation systems. Farms are small with production destined mainly for sale in the areas with milder climates, and for self-consumption in the colder parts. In the case of Peru, the area of implementation of project B is located in the department of Cusco between 3,600 and 3,950 masl, with an average of 670 mm/year, mean minimum and maximum temperatures of 2.3 °C and 18 °C, respectively and with a frost-free rainy season taken place between November and March. In these areas, farmers grow a variety of tuber crops for sale and self-consumption, and in some areas these tubers make a crucial contribution to diets. Although productive in the marginal Andean soils, these tubers are vulnerable to many insect pests. The area of implementation of project C is located also in the department of Cusco, between 3,800 and 4,100 masl, with an average precipitation of 759 mm/year, mean minimum and maximum temperatures of −2.4 °C and 16.2 °C and a similar frost-free rainy season. This is an area

Table 1. *Projects studied*

ID	Country	Project name	General objective	Target species	Implementing agency	Donor	Period
A	Ecuador	Promotion of Andean Crops for Rural Development in Ecuador[a]	To promote rural development through the complementary conservation and the sustainable use of plant genetic resources of underutilized native crops of the inter-Andean valleys of Ecuador, through the collaboration between rural communities of Cotacachi, researchers and national and international agencies	Multiple species	The Union of Peasant and Indigenous Organizations of Cotacachi (UNORCAC)	US Department of Agriculture	2002–05 2006–08
B	Peru	Biodiversity of Andean Tubers: Strengthening the On-farm Conservation and Food Security of Andean Tubers in the Fragile Ecosystems of the Southern Peruvian Highlands	To strengthen the dynamics of in-situ conservation of Andean tubers and improve food security and income of the high Andean communities of the Cusco Region	Oca Ulluco Maswa Potatoes	University of Cuzco/ Centro Regional de Investigación en Diversidad Andina (CRIBA)	McKnight Foundation	1995–99 2001–05
C	Peru	Native Potato: Improved production of native Potatoes in the Andean Highlands of Peru	To increase food security of native Quechua and Aymara communities in the southern high Andean region of Peru by improving the production and marketing of native potato varieties	Potatoes	Intermediate Technology Development Group (ITDG)	McKnight Foundation	2005–09
D	Bolivia	Enhancing the Contribution of Neglected and Underutilized Crops to Food Security and to Incomes of the Rural Poor	To contribute to raising the incomes and strengthening the food security of small farmers and rural communities around the world through securing and exploiting the full potential of the genetic diversity contained in neglected and underutilized species	Quinoa Cañahua	Bioversity Int. & Fundación PROINPA	International Fund for Agricultural Development	2001–03 2007–09
E	Bolivia	National Genetic Resources System for Food and Agriculture, Andean Grains	To ensure the conservation of High Andean Grain germplasm and increase its usability through a coordinated effort between the Active Germplasm Bank of the Subsystem, the Work Collections and other strategic alliances	Quinoa Cañahua	Fundación PROINPA	Gov't of Bolivia	2003–08

[a] UNORCAC is a peasant organization with a long history of work in the region and on issues of biodiversity, thus the specific project analyzed here built on previous interventions, so in that case the observed changes cannot be attributed solely to a particular project, but should be seen more as the impact of UNORCAC.

Table 2. *Specific interventions provided by each project*

	Ecuador	Peru		Bolivia	
Interventions grouped by themes	A	B	C	D	E
Providing new knowledge about the native crop diversity held beyond the household and community					
Collection of local varieties of native crops in collaboration with participating households				√	√
Identification and description of local varieties of native crops in collaboration with participating households				√	√
Organization of competitions showing the diversity of crops and varieties available				√	√
Implementation of an ethnobotanical garden displaying the local plant diversity	√				
Education on agrobiodiversity for children at community schools	√				
Providing access to additional diversity of target crops					
Implementation of fairs for seed exchange	√				
Reintroduction of native fruit trees, crops and crop varieties	√			√	√
Diversification of the "chacra" (small farm)	√				
Obtained seed from communal seed fund			√		
Returned seed to communal seed fund after harvest			√		
Evaluation of new and reintroduced native varieties of target crops				√	√
Providing new knowledge, skills and practices for the agronomic management of target crops					
Implementation of water harvesting	√				
Implementation of micro-irrigation system	√				
Implementation of sprinkler irrigation			√		
Application of soil biofertilizer (Azotolam)			√		
Application of organic liquid fertilizer (Biol)			√		
Application of alpaca compost			√		
Ridging			√		
Pre-germination of planting material		√	√		
General training on crop management		√		√	√
Providing new knowledge, skills, practices and technologies for managing important pests of target crops					
Collect adult weevils at night		√			
Collect weevils at larval stages with blankets		√			
Application of "tarwi" (lupin) ash to prevent weevil attack			√		
Collect weevils			√		
Use of chickens to control weevils		√			
Use of traps and deployment of biological control agents		√			
Education of children on pest control in rural schools		√			
Training of farmers on general pest control methods for quinoa and cañahua				√	√
Training of farmers on how to prevent weevil attacks				√	√
Providing new harvesting knowledge, practices and technologies for target crops					
Training on improved harvesting methods				√	√
Early harvest of potato tubers		√			
Providing new knowledge, skills, practices and technologies for storing and/or processing target crops					
Improvements on storage systems		√			
Processing of oca into Q'awi (local sub-product)		√			
Construction of ponds for oca processing to reduce bitter taste (khaya)		√			
General training on better harvesting practices					
Providing new knowledge, skills and practices for preparing and consuming target crops					
Training on new recipes and preparations for target crops	√				
Organizing fairs of traditional foods	√				
General training on nutrition and gastronomy				√	√
Providing new knowledge, skills, practices and organization on marketing target crops					
Organizing fairs for marketing native target crops	√				
Forming farmer associations to market quinoa		√		√	√
Forming farmer associations to market cañahua				√	√
Production of plant species for agro-industry	√				
Providing new knowledge, skills, practices and organization for participating in agro-tourism					
Establishment of a community museum				√	

(*continued on next page*)

Table 2 (*continued*)

Interventions grouped by themes	Ecuador A	Peru B	Peru C	Bolivia D	Bolivia E
Receiving tourist at home for the day	√			√	
Lodging tourists at home	√			√	
Training on producing handicrafts	√				
Production of handicrafts	√				
Training local farmers to provide advice to others on agricultural matters					
Training of selected farmers (locally known as Kamayoq) within community on different aspects of agriculture to provide advice and training to others			√		
Disseminating information to other farmers on agricultural matters					
Fostering the exchange of information farmer to farmer	√				
Listening to programs related to the management of target native crops		√			
Receiving advice from Kamayoq			√		
Providing new knowledge and skills to support farmer organization					
Support for strengthening farmer organization	√				
Helping organize farmer networks to produce native crops	√				
Organizing producer associations to foster the cultivation, marketing and use of native crops and/or for tourism				√	√
Providing new knowledge and skills on agro-forestry					
Dissemination of practices and inputs to develop agro-forestry in farmers' fields	√				
Total number of interventions per project	19	13	12	16	13

* Collection and characterization of varieties of target crops took place, but was not included by project implementers as one of the interventions where farmers participated in, so not counted in the number of interventions.

with difficult environmental conditions and farmers are subject to periodic droughts and cold spells and farmers rely on native potatoes that are well adapted to these conditions. In the case of Bolivia, the area of implementation of both projects D and E is the same, in the department of La Paz, near the shores of Lake Titicaca between 3,830 and 3,890 masl, with an average precipitation of 690 mm/year, mean minimum and maximum temperatures of 0.8 °C and 15.3 °C, and with a frost-free rainy season taken place between December and March. Floods and droughts are common in different times of the year, the former during the planting season and the latter during harvesting. Farms are small and usually composed of several scattered fields to manage risk, animal husbandry is an important activity as well.

4. THE METHODOLOGICAL APPROACH

(a) *Case studies and sample selection*

For the five selected projects described above, we conducted a detailed review of the available documentation and interviewed implementers about project execution, including information about objectives, activities and interventions carried out, indicators used, and their assessment of success. A household survey was carried out in communities where projects took place by teams of local youth who achieved a secondary education level at a minimum, and spoke Spanish and the local language, under the supervision of experienced researchers from the region between April and August of 2011. No project had *a priori* control groups and neither baseline nor end-line data were available, restricting the options to build a counterfactual. To address this constraint, a stratified random sample based on participation was drawn in each community. In all projects participation was open to all community members and participation was voluntary—those who were interested participated. All projects involved a core of regular participants; thus for our sample, one stratum was drawn randomly from this group, obtained from project records—defined here as *ex-ante* participants—and the other from a sample drawn randomly from a list of all households within the same community (thus sharing similar environmental and institutional conditions as the participants) who had not explicitly participated in the project, to serve as controls—defined here as non-participants. A total of 748 households were interviewed. The survey elicited information on project participation, application of the options provided by project interventions, and examples of how they were applied in the farmers' own words. An inventory of crops grown on each farm was obtained and for each crop the following information was collected: the number of farmer varieties that were sown, their seed sources, objectives of production, quantity produced in the previous growing season, quantities consumed and sold, as well as price received (if available). Standard socioeconomic information on family demographics, education, landholdings, sources of income, migration, participation in local organizations and government programs was also gathered. The variables used in the empirical analysis are described below and their definitions are presented in Table 3.

(b) *Empirical analysis*

To test the three proposed hypotheses, we estimated a system of three simultaneous equations—each corresponding to one of the first three hypotheses presented in the conceptual section—via a Generalized Method of Moments (GMM). The stochastic version of the model is formulated for the *i*-th household in the following way:

$$Household\,Benefits_i = \mathbf{x}_i'\boldsymbol{\omega} + \delta\,CropDiversity_i + e_i \quad (1)$$

$$CropDiversity_i = \mathbf{x}_i'\boldsymbol{\lambda} + \beta\,Application_i + u_i \quad (2)$$

Table 3. *Description of the variables used in the regression model*

Variable names	Variable definitions
Dependent variables	
Application of options, all projects	Number of options provided by interventions applied by a household
Crop diversity	
Project A	Predicted value of the first factor extracted from a factor analysis of the number of cultivated crops, the average number of varieties for cultivated crops, and number of lots under rotation over the total number of lots grown the previous year
Project B	Predicted value of the first factor extracted from a factor analysis of the number of potatoes, oca, ulluco, and maswa varieties grown by the household the previous year
Project C	Predicted value of the first factor extracted from a factor analysis of the number of varieties of sweet and bitter potatoes grown by the household the previous year
Projects D & E	Predicted value of the first factor extracted from a factor analysis of the number of cañahua and quinoa varieties grown by the household the previous year
Benefits	
Project A	Predicted value of the first factor extracted from a factor analysis of the number of a series of ratings on the level of satisfaction experience by the household with respect to different variables such as housing, access to education, economic activities, social life and contacts, as well as nutrition and food security
Project B	Total amount of potatoes, oca, olluco, and maswa produced for self-consumption and sale the previous year
Project C	Total amount of sweet and bitter potatoes produced for self-consumption and sale the previous year
Projects D & E	Total amount of quinoa and cañahua produced for self-consumption and sale the previous year
Common covariates	
Ex-ante participation	Dummy referring to whether a household was drawn from the sample of *ex-ante* participants (=1) or from non-participants (=0)
Number of plots	Number of plots in the farm, indicator of environmental variability
Spanish	Spanish is the language spoken most frequently in the household = 1, 0 = Quechua or Aymara
Sex household head	Sex of the household head, 1 = male, 0 = female
Age head of household	Age of the head of the household (years)
Education head of household	Number of years of schooling completed
Migration	Number of family members that live in the house less than 9 months
Labor availability	Sum of the number of months in a year family members live in the household
Landholdings	Total farm area (ha)
Wealth	Number of different domesticated animal species owned by household—indicator of wealth since ownership of animals is an important form of wealth in the Andes, and by using the number of species we take into account a diversified asset base
Organizations	Number of organizations known to the head of the household—indicator of social capital
Sources of non-agricultural income	Number of sources of income besides own agriculture, indicator of participation in non-agricultural economy
Location 1	Dummy referring to a particular location where the household lives. Each location is common within a study, but refers to different locations across studies. In all projects, except A, locations refer to villages. In project A, a location refers to a Parish encompassing different villages.
Location 2	Idem
Location 3	Idem
Location 4	Idem
Soil quality	Fraction of the total landholdings classified by the farmer as of very good and good quality
Pest control	Average number of target crops to which the farmer applied pest and disease control practices
Hilling	Average number of target crops for which the farmer did hilling
Inorganic fertilizer	Average number of target crops to which the famer applied inorganic fertilizer
Organic fertilizer	Average number of target crops to which the famer applied animal manure

$$Application_i = \mathbf{x}_i'\boldsymbol{\theta} + \gamma Participation_i + v_i. \quad (3)$$

where $\mathbf{x}_i$ is a vector of confounding factors and exogenous variables that could influence the three outcomes of interest: *Household Benefits*, *Crop Diversity*, and *Application of options provided by interventions*, as well as the *Participation* of the household *i*, such as socio-economic characteristics of the sample, the environment, and the location of households; $\boldsymbol{\omega}$, $\boldsymbol{\lambda}$, and $\boldsymbol{\theta}$ are the parameter vectors of the equations' system, measuring the effects of the exogenous variables on our outcomes of interest, while e_i, u_i, and v_i are the error components. The model allows us to test the three hypotheses simultaneously, involving a chain of hierarchical/causal relationships, thorough the estimates of parameters γ, β, and δ.

The model measures, through the estimation of the parameter γ, whether the household was drawn from the sample of *ex-ante* participants (Participation = 1) or from the one of non-participants (Participation = 0) and the consequent effects on the application of options provided by interventions (Eqn. (1)). Parameter β provides a quantitative estimate of the impact of project interventions on crop diversity (Eqn. (2)), while parameter δ accounts for the additional benefits obtained by a household from this diversity (Eqn. (3)). Being aware of the potential endogeneity problems in estimating these relationships, estimates were obtained using the multiple equation GMM estimator [3] (Hayashi, 2000). This approach controls for reverse causality and other possible sources of endogeneity (Heckman & Vytlacil, 2005), conditionally on the variables chosen as instruments. The choice of the instruments should be guided by the soundness of the assumptions behind the model as well as by empirical evidence (Nichols, 2007). We used *ex-ante* participation as an instrument assuming that *ex-ante* participation can influence "crop diversity" only through the application of options; moreover, the application of options may influence additional benefits obtained by a household only through the use of crop diversity. These assumptions simply reflect the design and types of project interventions that target different aspects of production, consumption, and/or marketing of native crops to generate household-level benefits. These are reasonable assumptions once we control for selection bias. Selection bias was assessed and controlled by using inverse probability weighting (IPW), where the conditional probability of participated (or propensity score) is estimated from the following participation model:

$$p(\mathbf{x}_i) = pr[W_i = 1|\mathbf{x}_i, \mathbf{b}] \quad (4)$$

with $\mathbf{b}$ is the parameters vector of the participation model, and $W_i = 1$ if the *i*-th household participates in the program or $W_i = 0$ if it does not participate; $p(\mathbf{x}_i)$ can be written as $\mathbf{F}[H(\mathbf{x}_i)]$. The most frequently used functional forms for $\mathbf{F}$ are the normal or logistic probability distribution functions (Guo & Fraser, 2010). We estimated the propensity scores $p(\mathbf{x}_i)$ using a logit model with the dependent variable coded as 1 for participant households and 0 for non-participants.

By using this technique, households were weighted by the inverse probability of project participation, which removed the imbalances of pre-intervention characteristics between participant and non-participant households, then used within a regression framework to provide unbiased estimates [4] (Gelo & Koch, 2014; Guo & Fraser, 2010; Linden & Adams, 2010). It is important to stress that the implementation of the propensity scores within the above-specified empirical framework is strictly functional for controlling selection bias that could affect parameter estimates. Evidence of the effectiveness of projects depends on the statistical significance of the parameter estimates of the simultaneous equations model. Obviously this technique only corrects for biases in observable characteristics and not in unobservable ones. Diagnostic tests were carried out to assess the validity of the instruments (Durbin–Wu–Hausman test for endogeneity and the Weak Instrument test) (Cameron & Trivedi, 2005). All the statistical analyses were performed using STATA software (Version 12.1, http://www.stata.com).

(c) *Outcome indicators*

The outcomes of interest in our three hypotheses were made operational through the following variables. The indicator of the application of options was the number of options applied by a household. A similar indicator has been used elsewhere in the context of a complex project involving the provision of numerous options to participants (Pamuk, Bulte, & Adekunle, 2014). The indicator of crop diversity was the result of a factor analysis performed on the number of farmer varieties of all target crops planted by a household. This indicator aimed at capturing the structure of how the number of varieties was distributed among target crops per household. [5] In four of the projects, the indicator for the benefits to a household was the quantity of produced target crops consumed and marketed. This indicator is relevant because, as presented above, interventions were aimed at increasing the amount of target crops produced (through agronomic practices), consumed (through better harvesting and processing as well as food preparation and cooking), and marketed (through organizing better marketing approaches). In one project, however, the indicator was a life satisfaction index derived from a series of ratings on the level of satisfaction experienced by the household with respect to different variables such as housing, access to education, economic activities, social life and contacts, as well as nutrition and food security. The data from the two projects in Bolivia were merged to increase the sample size and statistical power given that both projects were implemented by the same institution in the same general geographic area and involved almost the same interventions.

(d) *Confounding factors*

The confounding factors include variables that could influence the household interest in crop diversity, as well as their interest and capacity to participate in projects. These factors include number of plots and soil quality as indicators of agro-ecological heterogeneity that is expected to promote diversity by creating numerous production niches (Brush, Taylor, & Bellon, 1992), as well as total landholdings that should influence the capacity of households to allocate land to different crops (Benin, Smale, Pender, Gebremedhin, & Ehui, 2007). Labor availability and migration may constrain the farmers' ability to maintain diversity (Isakson, 2011; Zimmerer, 1996), but also to manage risk (Barrett, Reardon, & Webb, 2001) and participate in projects (Gelo & Koch, 2014). Wealth and sources of non-farm income can enable farmers to replace diversity by providing alternative sources of risk management, such as the purchase of inputs to homogenize the environment (e.g., fertilizers) or of consumer products that substitute self-produced ones (that are no longer produced), but can also enable the maintenance of diversity by allowing the production of lower yielding appreciated varieties (Benin *et al.*, 2007; Brush *et al.*, 1992; Isakson, 2011; Smale, 2006). Social capital (e.g., participation in social networks) can provide access to seed and planting material, enabling diversification (Badstue *et al.*, 2007), as well as increasing the likelihood of participation in projects (Gelo & Koch, 2014). Personal characteristics of the household head, such as: language as an indicator of ethnicity and cultural identity; age as an indicator of experience and knowledge about native varieties; sex which can influence social status within the community and access to opportunities, as well as formal education as an indicator of skills to participate in markets and access new information, have been shown to influence crop diversity (Benin *et al.*, 2007; Brush *et al.*, 1992; Isakson, 2011; Perales *et al.*, 2005; Smale, 2006) and likelihood of project participation (Abebaw, Fentie, & Kassa, 2010; Wanjala & Muradian, 2013; Zbinden & Lee, 2005). The specific locations (e.g., villages) where households are located provide the infrastructure and institutional contexts in which decisions to grow diversity or participate in projects take place, and thus should be included as fixed factors (de Janvry & Sadoulet, 2001). Particularly in the estimation of Eqn. (3) for those projects where the dependent variable was the quantities of target crops produced that were consumed and sold (see below), we included variables such as use of organic and inorganic fertilizer use, pest control, and hilling to control for agronomic management factors that could affect total production.

Table 4. *Key socioeconomic characteristics of studied farmers and households*

	Ecuador	Peru		Bolivia	
Indicator by household	A	B	C	D	E
Total landholding (ha)	0.7	2.3	2.4	1.8	0.6
Language commonly spoken (ratio)					
Spanish	0.36	0.24	0.31	0.43	0.48
Quechua	0.64	0.76	0.69	0	0
Aymara	0	0	0	0.57	0.52
Female-headed households (ratio)	0.32	0.05	0.11	0.20	0.14
Age of head (years)	47.6	43.2	45	63.1	55.7
Education of head (years)	2.9	3	3.1	2.8	3
Family size (number)	5.2	4.4	4.2	4.1	4.6
Household with migrants (ratio)	0	0.07	0.12	0.17	0.16
Mean number of sources of income outside own agriculture	2.5	0.8	0.8	0.8	0.7

Table 5. *Indicators of crop diversity in the six studied projects (numbers in bold indicate target crops for the relevant project)*

	Ecuador	Peru		Bolivia	
Indicator[a]	A[b]	B	C	D	E
Total number of crops reported	137[c]	11	2	13	13
Mean number of crops/hh	**36**	2.2	1	3.7	3.4
Mean number of varieties/crop/hh	**1.2**	7.3	11.9	15.9	11.9
Quinoa (*Chenopodium quinoa*)					
Farmers planting (ratio)	**0.23**			**0.77**	**0.88**
Mean number of varieties/hh				**1.8**	**2.4**
Cañahua (*Chenopodium pallidicaule*)					
Farmers planting (ratio)				**0.52**	**0.04**
Mean number of varieties/hh				**1.7**	**2.3**
Oca (*Oxalis tuberosa*)					
Farmers planting (%)	**0.06**	**0.40**		0.17	0.17
Mean number of varieties/hh		**1.9**		3.2	2.4
Ulluco (*Ullucus tuberosus*)					
Farmers planting (%)	**0.07**	**0.58**		0.03	0.03
Mean number of varieties/hh		**2.1**		2.3	2
Maswa (*Tropaeolum tuberosum*)					
Farmers planting (%)	**0.03**	**0.19**		0.01	0.03
Mean number of varieties/hh		**1.5**		2	2.5
Potatoes (*Solanum tuberosum*)					
Farmers planting (%)	**0.53**	**0.95**	**0.98**	0.99	0.98
Mean number of varieties/hh		**3.5**	**11.9**	11.1	7.2

[a] Means were calculated for only for those who grow the crop.
[b] Data on infra-specific diversity for specific crops not presented due to difficulties in calculating them by specific crop.
[c] These data refer not only to crops, but also include, in addition to different cultivated species, fruit trees, herbs from home gardens and agroforestry species, as well as some species collected from the wild.

5. RESULTS

(a) *Household characteristics and native crop diversity*

Households in project sites have very small landholdings, are typically composed of speakers of indigenous languages- either Quechua or Aymara- and are headed mostly by middle-aged men with low levels of formal education, low levels of migration and few sources of income outside their own agriculture. When there are other sources of income, they are frequently non-farm labor, and very few households receive remittances (Table 4). The data show relatively poor marginal households maintaining important amounts of native crop diversity in a center of origin and diversity for these crops. These households maintain an important diversity of crop species and farmer varieties (Table 5). They tend to grow many more species than those targeted by the projects studied.

(b) *Project assessment by implementers and application of options by participants*

Interviews with project implementers indicated that they considered their projects a success; however they also recognized that no systematic efforts were made to assess project impacts. An analysis of project documents and discussions with implementers showed that there were no clear impact indicators, projects lacked systematic baselines, explicit theories of change for their interventions, and – with the exception of one project – there was no explicit framework to establish comparisons to assess whether these projects in fact made a difference or not in their areas of intervention. Implementers were also asked whether there were alternative suppliers for similar interventions as they implemented in their target communities. They indicated that to their knowledge there were none.[6]

Table 6. *Participation in project interventions and adoption of options provided by them*

	Ecuador	Peru		Bolivia	
Project	A	B	C	D	E
Total no. of households in sample	176	120	129	162	161
No. of non-participant households[a]	80	76	89	106	136
No. of *ex-ante* participant households[a]	96	44	40	56	25
No. of interventions/project	19	13	12	16	13
No. of participant households who applied at least one option[b]	114	95	90	76	52
Mean number of options provided by interventions applied per participant household	3.6	4.9	3.1	4.0	3.8

[a] As explained in the empirical section, these numbers were based on the study design selecting a random sample from households who participated in projects according to project records and a sample drawn randomly from a list of all households within the community.

[b] These numbers are higher than the number of *ex-ante* participants due to spill-over effects.

Table 7. *Logit regression of ex-ante participation for the five studied projects*

	Ecuador	Peru		Bolivia
Ex-ante participation	A	B	C	D&E
Number of plots	0.102	0.020	0.093	−0.028
Spanish	0.006	0.097	−0.781	0.161
Sex household head	0.139	0.221	−1.123	−0.423
Age head of household	0.009	0.014	0.026	0.036***
Education head of household	0.093	−0.017	0.079	0.188***
Migration		1.117	0.392	−0.148
Labor availability	−0.001	0.020	0.010	0.001
Landholdings	0.075	−0.022	−0.056	0.000
Wealth	0.290**	−0.049	0.205	0.100
Organizations	0.398*	0.824**	−0.057	0.266
Sources of income	0.336*	0.010	0.291	−0.501**
Location 1	−0.376	0.652	1.527**	0.162
Location 2	−0.346	0.828	1.894***	−0.753*
Location 3	−0.776	0.066	1.902***	−1.082**
Location 4	−0.924	−0.623		
Soil quality		−0.130	−0.658	0.484
Constant	−3.114***	−3.072**	−4.606***	−4.145***

Significance at the .10, .05, .01 level indicated by *, **, ***, respectively.

Results from the household survey show that the number of farmers who applied options provided by project interventions was much higher than expected from *a priori* information used to draw the sample of participants from project records (*ex-ante* participants) (Table 6). This is evidence of spill-over effects and that in fact project interventions were addressing real demands. On average, participants put into practice between 20% and 40% of the total options provided by a project. Farmers not only indicated whether they applied the options, but most of them also offered specific examples of how they did so. This is important because it offers qualitative evidence that respondents were not just providing a cursory yes or no answer to our questions, but were able to articulate how the application of options led to specific behavioral changes.

(c) *Econometric results*

Table 7 shows the results of logit regressions for the five projects with *ex-ante* participation as the dependent variable against a set of exogenous variables that could influence the household interest and capacity to participate in projects. The logit models have two purposes: (1) to calculate the propensity score used in the estimation of the system of three simultaneous equations; (2) to examine the variables behind the "selection bias" and the overall magnitude of the bias. Results show that as expected there was evidence of selection bias. Weighting the data with the inverse probability of project participation however, corrected for it on observable household characteristics, as shown by the results of Hotelling's T-squared means test on exogenous variables weighted by the inverse probability of project participation *versus* not weighted variables. Results of the Durbin–Wu–Hausman test for endogeneity and the Weak Instruments test support the validity of the instruments used (Tables 9 and 10 with the results are presented in the Appendix).

Regression results from the estimation of the system of three simultaneous equations (Table 8) show that the coefficients that relate to the three hypotheses proposed to assess the success of a project provide evidence that: (1) farmer *ex-ante* participation in project interventions was associated with the application of a higher number of options in all projects; (2) in all projects, the application by households of a higher number of options was associated with increased crop diversity; (3) in four projects, households obtained additional benefits from the crop diversity they grew in terms of higher quantities of the target crops consumed and sold from their production, (in the case of the projects in Bolivia and one in Peru) and a higher perception of life satisfaction among farmers in the project in Ecuador. As indicated above, these results already take into account and correct for other confounding variables[7].

It is worth mentioning that except for landholdings, all confounding variables were statistically significant in at least one

Table 8. *Results of the system of simultaneous equations weighted by the inverse probability of project participation*

	Projects			
	Ecuador	Peru		Bolivia
	A	B	C	D&E
Application of options				
Ex-ante participation	2.603****	1.371***	1.272****	1.922****
Number of plots	0.450***	0.218	0.358****	0.177
Spanish	−0.575*	1.312*	−0.274	0.064
Sex household head	0.426	−2.304**	−0.132	0.032
Age head of household	−0.016	0.025	−0.022	−0.007
Education head of household	0.088	0.201	−0.139	0.067
Migration		−0.524	−0.121	−0.093*
Labor availability	−0.008	0.021	0.005	0.000
Landholdings	0.117	−0.157	0.001	0.000
Wealth	0.339***	0.068	0.085	0.126
Organizations	0.060	−0.177	0.359**	0.406**
Sources of income	0.160	0.026	0.237	0.037
Location 1	0.168	−2.863****	−0.314	−0.309
Location 2	0.796	−1.348	0.082	−0.120
Location 3	−0.231	−2.470***	0.805	−0.771*
Location 4	−0.203	−1.747**		
Soil quality		1.298*	0.895*	−0.285
Constant	0.248	0.832	1.044	0.248
Native crop diversity				
Application of options	0.231****	0.259**	0.358***	0.053****
Number of plots	−0.069	−0.046	−0.044	0.002
Spanish	−0.320***	−0.522*	0.333**	−0.036*
Sex household head	0.187	0.421	−0.135	−0.002
Age head of household	0.002	0.004	0.003	−0.001
Education head of household	0.000	−0.073	−0.018	−0.004
Migration		0.066	0.035	−0.010**
Labor availability	0.002	−0.005	0.003	0.001
Landholdings	0.026	0.073	−0.003	0.000
Wealth	0.127***	0.129*	−0.045	0.001
Organizations	0.087	−0.121	−0.226***	0.043***
Sources of income	−0.019	−0.021	−0.167**	0.003
Location 1	−0.412***	0.709	−0.177	−0.162****
Location 2	−0.466**	−0.199	−0.508****	−0.127****
Location 3	−0.485**	0.479	−0.330	−0.064
Location 4	−0.269	0.264		
Soil quality		−0.705**	−0.324*	0.037
Constant	−1.110****	−0.975*	−0.175	−0.009
Household benefits				
Native crop diversity	0.574****	5.701**	−3.773	0.092**
Number of plots	0.097**	0.079	0.999	0.010***
Spanish	0.182	2.267*	1.127	0.010
Sex household head	−0.199	−0.894	−5.264**	−0.021**
Age head of household	−0.014***	−0.043	0.053	0.001
Education head of household	−0.034	0.058	1.642*	−0.004*
Migration		−0.431	−1.724*	−0.001
Labor availability	−0.003	0.067*	0.073	0.001*
Landholdings	−0.002	−0.094	0.282	0.000
Wealth	0.048	−1.172**	−0.855	0.000
Organizations	−0.183**	0.956	3.617**	0.005
Sources of income	−0.053	−0.810*	−2.992**	0.012**
Location 1	0.152	−1.527	2.347	−0.049***
Location 2	−0.251	5.098**	−10.089**	−0.020
Location 3	0.584**	−0.394	−5.788**	−0.044***
Location 4	0.639*	0.790		
Soil quality		3.097*	−4.525	0.003
Pest control		2.180	−0.725	−0.007
Hilling		−1.353	4.755	0.015
Inorganic fertilizer		4.297*	5.472	0.021
Organic fertilizer		−2.566	4.176	−0.010
Constant	0.983**	4.772	1.107	−0.030

Significance at the .10, .05, .01, .001 level indicated by *, **, ***, ****, respectively for a two-tail *t*-test, except for the underlined variables that pertain to our key hypotheses where the level of significance is for a one-tail *t* test corresponding to the alternative hypotheses Ha: parameter of interest (β, δ, γ) > 0.

of the equations in the model, and some were in all three equations. In most cases, the sign of the significant variables was different depending on the equation and the specific project, suggesting the contextual way in which they influence the implementation of OFC projects. Variables that were significant across projects and equations include: an indicator of soil quality, indicating the importance of the natural resource base; language commonly spoken which should influence how households interact with the outside; the presence of migrants in the household which should have an impact on the available labor, an important factor for the management of crop diversity; an indicator of wealth, which could hinder or promote crop diversity and the ability to participate in projects; knowledge of local organizations, an indicator of social capital, which should influence both the ability to participate in projects and apply the options that depend on forms of organization, as well as the access to seed through seed networks; and the locations where projects were implemented, indicating location-level fixed effects.

6. DISCUSSION

Results show great complexity. There were six native crops and, in one project, up to 137 plant species involved, a myriad of varieties for each crop, and a total of 79 interventions implemented addressing a rather diverse set of issues from access to varieties to food preparation. In addition, there were problems of endogeneity and selection bias due the fact that the projects built on the farmers' interests and motivations to maintain crop diversity as well as on the participatory nature of the projects, which, while part of their strength, further complicated their analysis. Our approach however, with a simple but tractable narrative of project-driven change, provided a testable framework for the analysis of this complexity, with measurable indicators and the postulation of clear causal relationships. Testing all three hypotheses simultaneously—with specific hierarchical relationships among them—provided robust evidence of the success of a project, confirming the stringent relationships we postulated *a priori* among the outcomes for their acceptance. Other lines of evidence supporting our results are that interventions would not have been available to farmers without the projects. Levels of application of options provided by interventions were very high, consistent with an effect due to the projects, and farmers provided clear examples of how they applied the options.

All projects implemented an array of different types of interventions tailored to the specific social and agro-ecological conditions of project sites that addressed different aspects of the production, consumption, and marketing of targeted native crop species, providing diverse and relevant options to smallholders in quite marginal conditions. The value of a basket of interventions is to provide diverse choices, some of which may be more meaningful to some farmers than others, depending on their specific contexts and circumstances. This has important implications for scaling-up, as by definition OFC relies on maintaining and addressing diversity. Therefore, scaling up cannot be done by homogenization, i.e., trying to apply the same interventions and associated options over large areas or groups of farmers, but rather by a process of systematic contextualization in which diverse options drawn from different types of interventions are assembled and targeted to fit different contexts, letting users choose which ones fit best under their own circumstances. This also means self-selection, farmer motivation, and capacity to choose are important drivers of the process.

Our empirical approach has limitations since all projects were studied after their completion and neither baseline information nor *a priori* controls exist, limiting the counterfactual that could be used. This is not an uncommon problem for studies that attempt to demonstrate the value of conservation projects (Lewis, Bell, Fay, Bothi, & Gatere, 2011). We are aware of these limitations and tried to address issues that arise from them, such as endogeneity, self-selection, and confounding variables through the use of appropriate statistical tools. The challenge of generating defensible evidence from imperfect data is common to development projects in rural areas (Winters, Maffioli, & Salazar, 2011) and can stem from a lack of interest, funding, or expertise on the part of project implementers in the design and collection of appropriate data necessary to generate evidence of project outcomes. Obviously, project implementers are interested in the success of their projects, but as this paper shows, their views and measures of what constitutes success can be implicit or poorly articulated, and differ from what scientists, donors, and policy makers may consider valid evidence in this respect. To the extent that public benefits are invoked to support projects and public funds are invested, there is a need to strengthen the generation of data and defensible evidence. It could be argued that to generate the rigorous evidence required to justify the implementation OFC projects, there may be a need to use randomized control trials (RCTs). RCTs are increasingly used and advocated for to test agricultural interventions (e.g., Duflo, Kremer, & Robinson, 2008, 2011; Farley, Lucas, Molyneaux, Penn, & Hogue, 2012), but there is also recognition of their limitations (Barahona, 2010; Barrett & Carter, 2010; Picciotto, 2012). To our knowledge RCTs have not been applied to OFC projects and given the complexity of the interventions, the contextual and heterogeneous nature of this type of project, the reliance of project implementation on the interest, motivation and capacity to choose of participants, factors that limit the relevance and feasibility of RCTs (Barrett & Carter, 2010), suggest that their application to this type of project would be challenging. In any case, we have shown that with our approach, it is possible to provide empirical evidence of project effectiveness also in non-randomized designed studies.

It is important to distinguish between the specific empirical results presented here that entail limitations (in terms of the selection of the cases, their local nature and data available) and the approach used that is widely applicable to an issue of global relevance, i.e., supporting OFC in centers of crop diversity. The approach is based on examining a series of linked and sequential hypotheses and aims at testing for evidence of a project-driven process of change that should occur if OFC is successful. The approach can be applied to different systems and circumstances, although the specifics will likely vary from one case to another. As shown here, successful projects can generate additional benefits through the maintenance of crop diversity on-farm that farmers can capture directly. This not only creates additional incentives for them to continue to engage in processes that generate novel genetic variation of value to society, but also contributes to making these processes acceptable to these farmers and to society by aligning their short-term private interests with society's long-term public interests. This study has shown that there is evidence that this can happen and that maintaining crop diversity can contribute to the generation of positive livelihood outcomes, although much research still needs to be done.

In conclusion, crop biodiversity and the farmers who maintain it in centers of diversity are not anachronistic remnants of the past but key contributors to society's capacity to adapt and respond to future, as well as the often unpredictable challenges associated with global change. They need to be supported and nurtured. OFC projects can play an important role in this process, but they need to be assessed systematically in order to determine their value.

NOTES

1. In the evaluation literature the difference in behavior resulting from interventions has been termed behavioral additionally (Gök & Edler, 2012), which is what we mean by effectiveness in this paper.

2. A list of the all the projects reviewed, including main donor involved and period of activity is available upon request.

3. Using moment conditions provides results asymptotically equivalent to those resulting by the full information instrumental variables efficient (FIVE) estimator (Bundy & Jorgenson, 1971).

4. Propensity score may be used as weights in analogy to the reweighting procedures used in survey sampling where adjustments are made for observations based on the probabilities for inclusion in a sample. Different weighting schemes are possible. The most frequently used is the inverse probability of treatment weighting (IPW). IPW regression is part of a larger family of causal methods known as marginal structural model (Joffe, Ten Have, Feldman, & Kimmel, 2004). Although this approach represents an effective solution to sample selection, Kang and Schafer (2007) show that IPW regression can be sensitive to misspecification when the estimated scores are particularly small. Our estimates do not have this problem.

5. This index builds on the "crop-cultivar diversity" index (sum of all varieties of all crops present in a farm) proposed by Last *et al*. (2014), but by using factor analysis, our index takes into consideration the underlying structure of the distribution of cultivars across crops. In all cases, the index used here, the crop-cultivar diversity index, and the number of varieties of each crop per household are highly and positively correlated in a statistically significant way, except for our index and olluco in project B (results not shown).

6. Our literature review did not indicate that there were other OFC projects in the study areas. While there may have been other types of projects there, it is unlikely that they were aimed at OFC.

7. One reviewer questioned whether regression estimates should control for the presence of censored endogenous variables. Overall, our outcome variables do not present a high rate of censoring with the exception of number of applied options. In order to check the robustness of our estimates we also estimated the model by using 2SLS with censored endogenous variable estimator. Our results (available upon request) show that censoring does not affect the sign and the statistical significance of our key coefficients.

REFERENCES

Abebaw, D., Fentie, Y., & Kassa, B. (2010). The impact of a food security program on household food consumption in Northwestern Ethiopia: A matching estimator approach. *Food Policy, 35*(4), 286–293.

Andersen, P. (2012). Challenges for under-utilized crops illustrated by ricebean (*Vigna umbellata*) in India and Nepal. *International Journal of Agricultural Sustainability, 10*(2), 164–174.

Arslan, A., & Taylor, J. E. (2009). Farmers' subjective valuation of subsistence crops: The case of traditional maize in Mexico. *American Journal of Agricultural Economics, 91*(4), 956–972.

Badstue, L. B., Bellon, M. R., Berthaud, J., Ramirez, A., Flores, D., & Juárez, X. (2007). The dynamics of seed flow among small-scale maize farmers in the Central Valleys of Oaxaca, Mexico. *World Development, 35*(9), 1579–1593.

Barahona, C. (2010) Randomised control trials for the impact evaluation of development initiatives: A statistician's point of view. *ILAC Working Paper 13*. Rome, Italy: Institutional Learning and Change Initiative.

Barrett, C., & Carter, M. R. (2010). The power and pitfalls of experiments in development economics: Some non-random reflections. *Applied Economic Perspectives and Policy, 32*(4), 515–548.

Barrett, C. B., Reardon, T., & Webb, P. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Policy, 26*(4), 315–331.

Bellon, M. R. (2004). Conceptualizing interventions to support on-farm genetic resource conservation. *World Development, 32*(8), 159–172.

Bellon, M. R., Gotor, E., & Caracciolo, F. (2015). Conserving landraces, improving livelihoods: how to assess the success of on-farm conservation projects?. *International Journal of Agricultural Sustainability, 13*(2), 167–182.

Bellon, M. R., Hodson, D., & Hellin, J. (2011). Assessing the vulnerability of traditional maize seed systems in Mexico to climate change. *Proceedings of the National Academy of Sciences USA, 108*(33), 13432–13437.

Bellon, M. R. (2009). Do we need crop landraces for the future? Realizing the global option value of in situ conservation. In A. Kontoleon, U. Pascual, & M. Smale (Eds.), *Agrobiodiversity and economic development* (pp. 51–59). London and New York: Routledge.

Bellon, M. R., Pham, J. L., & Jackson, M. T. (1997). Genetic conservation: A role for rice farmers. In N. Maxted, B. V. Ford-Lloyd, & J. G. Hawkes (Eds.), *Plant conservation: The in situ approach* (pp. 263–289). London: Chapman and Hall.

Bellon, M. R., & van Etten, J. (2014). Climate change and on-farm conservation of crop landraces in centres of diversity. In M. Jackson, B. Ford-Lloyd, & M. Parry (Eds.), *Plant genetic resources and climate change* (pp. 137–150). Wallingford and Boston: CABI International.

Benin, S., Smale, M., Pender, J., Gebremedhin, B., & Ehui, S. (2007). The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. *Agricultural Economics, 31*(2–3), 197–208.

Brown, A. H. D. (1999). The genetic structure of crop landraces and the challenge to conserve them in situ on farms. In S. B. Brush (Ed.), *Genes in the field* (pp. 29–48). Rome, Ottawa, Boca Raton: IPGRI, IDRC, Lewis Publishing.

Brush, S. B. (1992). Ethoecology, biodiversity, and modernization in Andean potato agriculture. *Journal of Ethnobiology, 12*(2), 161–185.

Brush, S. B. (2004). *Farmers' bounty. Locating crop diversity in the contemporary world*. New Haven, CT: Yale University Press.

Brush, S. B., Taylor, J. E., & Bellon, M. R. (1992). Biological diversity and technology adoption in Andean potato agriculture. *Journal of Development Economics, 39*(3), 365–387.

Bundy, J. M., & Jorgenson, D. W. (1971). Efficient estimation of simultaneous equations by instrumental variables. *The Review of Economics and Statistics, 53*(3), 207–224.

Caliendo, M., & Hujer, R. (2006). The microeconometric estimation of treatment effects—An overview. *Allgemeines Statistisches Archiv, Advances in Statistical Analysis, 90*, 199–215.

Cameron, A. C., & Trivedi, P. K. (2005). *Microeconometrics: Methods and applications*. New York NY: Cambridge University Press.

Castillo, R. O. (1995). Plant genetic resources in the Andes: Impact, conservation, and management. *Crop Science, 35*(2), 355–360.

Cavatassi, R., Lipper, L., & Narloch, U. (2011). Modern variety adoption and risk management in drought prone areas: Insights from the sorghum farmers of eastern Ethiopia. *Agricultural Economics, 42*(3), 279–292.

Ceccarelli, S. (1996). Adaptation to low/high input cultivation. *Euphytica, 92*(1–2), 203–214.

de Janvry, A., & Sadoulet, E. (2001). Income strategies among rural households in Mexico: The role of off-farm activities. *World Development, 29*(3), 467–480.

Devaux, A., Hortona, D., Velasco, C., Thiele, G., Lopez, G., Berneta, T., *et al.* (2009). Collective action for market chain innovation in the Andes. *Food Policy, 34*(1), 31–38.

Di Falco, S., & Chavas, J. P. (2009). On crop biodiversity, risk exposure, and food security in the Highlands of Ethiopia. *American Journal of Agricultural Economics, 91*(3), 599–611.

Di Falco, S., & Perrings, C. (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecological Economics, 55*(4), 459–466.

Duflo, E. C., Kremer, M. R., & Robinson, J. M. (2008). How high are rates of return to fertilizer? Evidence from Kenya. *American Economic Review papers (Papers and Proceedings Issue), 98*(2), 482–488.

Duflo, E. C., Kremer, M. R., & Robinson, J. M. (2011). Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya. *American Economic Review Papers, 101*(6), 2350–2390.

Evenson, R., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *Science, 300*(5620), 758–762.

Farley, K., Lucas, S., Molyneaux, J., Penn, K., & Hogue, E. (2012). *Principles into practice: Impact evaluations of agriculture projects*. USA: Millennium Challenge Corporation.

Folke, C. (2006). Resilience: The emergence of a perspective for socio-ecological system analysis. *Global Environmental Change, 16*, 253–267.

Gelo, D., & Koch, S. F. (2014). The Impact of common property right forestry: Evidence from Ethiopian villages. *World Development, 64*, 395–406.

Gepts, P. (2006). Plant genetic resources conservation and utilization: The accomplishments and future of a societal insurance policy. *Crop Science, 46*(5), 2278–2292.

Gök, A., & Edler, J. (2012). The use of behavioural additionally evaluation in innovation policy making. *Research Evaluation, 21*(4), 306–318.

Gotor, E., Caracciolo, F., Blundo-Canto, G. M., & Al-Nusairi, M. (2013). Improving rural livelihoods through the conservation and use of underutilized species: Evidence from a community research project in Yemen. *International Journal of Agricultural Sustainability, 11*(4), 347–362.

Guo, S., & Fraser, M. W. (2010). *Propensity score analysis: Statistical methods and applications*. Thousand Oaks, CA: Sage.

Harlan, J. R. (1992). *Crops and man* (2nd ed.). Madison, WI: American Society of Agronomy and Crop Science Society of America.

Hayashi, F. (2000). *Econometrics*. Princeton, NJ: Princeton University Press.

Heal, G. B., Walker, B., Levin, S., Arrow, K., Dasgupta, P., Daily, G., *et al.* (2004). Genetic diversity and interdependent crop choices in agriculture. *Resources and Energy Economics, 26*(2), 175–184.

Heckman, J. J., & Vytlacil, E. J. (2005). Structural equations, treatment effects, and econometric policy evaluation. *Econometrica, 73*(3), 669–738.

Isakson, S. R. (2011). Market provisioning and the conservation of crop biodiversity: An analysis of peasant livelihoods and maize diversity in the Guatemalan highlands. *World Development, 39*(8), 1444–1459.

Jarvis, D. I., Brown, A. H. D., Cuong, P. H., Collado-Panduro, L., Latournerie-Moreno, L., Gyawali, S., *et al.* (2008). A global perspective of the richness and evenness of traditional crop variety diversity maintained by farming communities. *Proceedings of the National Academy of Science USA, 105*(14), 5326–5331.

Jarvis, D., Hodgkin, T., Sthapit, B. R., Fadda, C., & Lopez-Noriega, I. (2011). Identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system. *Critical Reviews in Plant Sciences, 30*(1–2), 125–176.

Joffe, M. M., Ten Have, T. R., Feldman, H. I., & Kimmel, S. E. (2004). Model selection, confounder control, and marginal structural models. *The American Statistician, 58*(4), 272–279.

Kang, J. D. Y., & Schafer, J. L. (2007). Demystifying double robustness: A comparison of alternative strategies for estimating a population mean from incomplete data. *Statistical Science, 22*(4), 523–539.

Kawa, N. C., McCarty, C., & Clement, C. R. (2013). Manioc varietal diversity, social networks, and distribution constraints in rural Amazonia. *Current Anthropology, 54*(6), 764–770.

Keleman, A., Hellin, J., & Flores, D. (2013). Diverse varieties and diverse markets: Scale-related maize "profitability crossover" in the Central Mexican Highlands. *Human Ecology, 41*(5), 683–705.

Keller, G. B., Mndiga, H., & Maass, B. L. (2005). Diversity and genetic erosion of traditional vegetables in Tanzania from the farmer's point of view. *Plant Genetic Resources: Characterization and Utilization, 3*(3), 400–413.

King, A. (2007). Trade and totomoxtle: Livelihood strategies in the Totonacan region of Veracruz, Mexico. *Agriculture and Human Values, 24*(1), 29–40.

Last, L., Arndorfer, M., Balazs, K., Dennis, P., Dyman, T., Fjellstad, W., *et al.* (2014). Indicators for the on-farm assessment of crop cultivar and livestock breed diversity: A survey-based participatory approach. *Biological Conservation, 23*(12), 3051–3071.

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., & Gatere, L. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences USA, 108*(34), 13957–13962.

Linden, A., & Adams, J. L. (2010). Using propensity score-based weighting in the evaluation of health management programme effectiveness. *Journal of Evaluation in Clinical Practice, 16*(1), 175–179.

McCouch, S. R., McNally, K. L., Wang, W., & Sackville-Hamilton, R. (2012). Genomics of gene banks: A case study in rice. *American Journal of Botany, 99*(2), 407–423.

Nichols, A. (2007). Causal inference with observational data. *Stata Journal, 7*(4), 507–541.

Pamuk, H., Bulte, E., & Adekunle, A. A. (2014). Do decentralized innovation systems promote agricultural technology adoption? Experimental evidence from Africa. *Food Policy, 44*, 227–236.

Pautasso, M., Aistara, G., Barnaud, A., Caillon, S., Coomes, O., Delêtre, M., *et al.* (2013). Seed exchange networks for agrobiodiversity conservation. A review. *Agronomy for Sustainable Development, 33*(1), 151–175.

Perales, H. R., Benz, B. F., & Brush, S. B. (2005). Maize diversity and ethnolinguistic diversity in Chiapas, Mexico. *Proceedings of the National Academy of Sciences USA, 102*(3), 949–954.

Picciotto, R. (2012). Experimentalism and development evaluation: Will the bubble burst?. *Evaluation, 18*(2), 213–229.

Rana, R. B., Garforth, C., Sthapit, B., & Jarvis, D. (2007). Influence of socio-economic and cultural factors in rice varietal diversity management on-farm in Nepal. *Agriculture and Human Values, 24*(4), 461–472.

Smale, M. (Ed.) (2006). *Valuing crop biodiversity; On-farm genetic resources and economic change*. Wallingford, UK: CABI Publishing.

Smale, M., & Bellon, M. R. (1999). A conceptual framework for valuing on-farm genetic resources. In D. Wood, & J. M. Lenné (Eds.), *Agrobiodiversity: Characterization, utilization and management* (pp. 387–408). Wallingford, UK: CABI Publishing.

Tisdell, C., & Seidl, I. (2004). Niches and economic competition: Implications for economic efficiency, growth and diversity. *Structural Change and Economic Dynamics, 15*(2), 119–135.

Van de Wouw, M., Kik, C., van Hintum, T., van Treuren, R., & Visser, B. (2010). Genetic erosion in crops: Concepts, research results and challenges. *Plant Genetic Resources: Characterization and Utilization, 8*(1), 1–15.

van Zonneveld, M., Dawson, I., Thomas, E., Scheldeman, X., & van Etten, J. (2014). Application of molecular markers in spatial analysis to optimize in situ conservation of plant genetic resources. In R. Tuberosa, A. Graner, & E. Frison (Eds.), *Genomics of plant genetic resources* (pp. 67–91). Dordrecht: Springer.

Vigouroux, Y., Barnaud, A., Scarcelli, N., & Thuillet, A. C. (2011). Biodiversity, evolution and adaptation of cultivated crops. *Comptes Rendus Biologies, 334*(5–6), 450–457.

Vigouroux, Y., Cedric, M., De Mita, S., Pham, J. L., Gerard, B., Kapran, I., *et al.* (2011). Selection for earlier flowering crop associated with climatic variations in the Sahel. *PLoS One, 6*(5), e19563. http://dx.doi.org/10.1371/journal.pone.0019563.

Wanjala, B. M., & Muradian, R. (2013). Can big push interventions take small-scale farmers out of poverty? Insights from the Sauri Millennium Village in Kenya. *World Development, 45*, 147–160.

Winters, P., Maffioli, A., & Salazar, L. (2011). Introduction to the special feature: Evaluating the impact of agricultural projects in developing countries. *Journal of Agricultural Economics, 62*(2), 392–402.

Worthington, M., Soleri, D., Aragon-Cuevas, F., & Gepts, P. (2012). Genetic composition and spatial distribution of farmer-managed *Phaseolus* bean plantings: an example from a village in Oaxaca, Mexico. *Crop Science, 52*(4), 1721–1735.

Zbinden, S., & Lee, D. R. (2005). Paying for environmental services: An analysis of participation in Costa Rica's PSA program. *World Development, 33*(2), 255–272.

Zimmerer, K. S. (1991). Labor shortages and crop diversity in the southern Peruvian sierra. *Geographical Review, 81*(4), 414–432.

Zimmerer, K. S. (1996). *Changing fortunes: Biodiversity and peasant livelihood in the Peruvian Andes*. Berkeley CA: University of California Press.

Zimmerer, K. S. (2010). Biological diversity in agriculture and global change. *Annual Review of Environment and Resources, 35*, 137–166.

APPENDIX

Table 9. *Results of a Hotelling's T-squared generalized means test for a series of exogenous variables*[a] *not weighted and weighted by the inverse probability of project participation (test for the correction of selection bias)*

	Ecuador	Peru		Bolivia
	A	B	C	D&E
No. of non-participants	80	76	89	242
No. of *ex-ante* participants	96	44	40	81
H0: Vectors of means are equal for the two groups	Prob > F(14,161)	Prob > F(16,103)	Prob > F(15,113)	Prob > F(15,307)
Not-weighted	0.0539	0.1242	0.0156	0.0000
Weighted	1.0000	1.0000	0.9736	0.9988

[a] Variables included: number of plots, Spanish, sex of household head, age of head of household, education of head of household, migration, labor availability, landholdings, wealth, organizations, sources of income, soil quality, and locations.

Table 10. *Tests for endogeneity and weak instruments*

	Ecuador	Peru		Bolivia
	A	B	C	D&E
Test for weak instruments[a]	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Durbin–Wu–Hausman test for endogeneity[b]	$p < 0.001$	$p = 0.04$	$p = 0.02$	$p = 0.13$

[a] Small p-values indicate instruments relevance, H0: $E(z|x) = 0$.
[b] Small p-values indicate inconsistency of OLS, H0: $E(u|x) = 0$.