TECHNICAL NOTE N° IDB-TN-03023

Effects of Land Administration: Evaluation of Ecuador's Rural Land Administration Program, SigTierras

Leonardo Corral
César Montiel
Maja Schling

Inter-American Development Bank
Environment, Rural Development and
Disaster Risk Management Division

November, 2024

Effects of Land Administration: Evaluation of Ecuador's Rural Land Administration Program, SigTierras

Leonardo Corral
César Montiel
Maja Schling

Inter-American Development Bank
Environment, Rural Development and Disaster Risk Management Division

November, 2024

Cataloging-in-Publication data provided by the

Inter-American Development Bank

Felipe Herrera Library

Corral, Leonardo.

Effects of land administration: evaluation of Ecuador's rural land administration program, SigTierras / Leonardo R. Corral, César E. Montiel-Olea, Maja Schling.

p. cm. — (IDB Technical Note; 3023)

Includes bibliographic references.

1. Land tenure-Ecuador. 2. Land use, Rural-Ecuador. 3. Agricultural wages-Ecuador. 4. Agriculture-Ecuador. I. Montiel, Cesar. II. Schling, Maja. III. Inter-American Development Bank. Environment, Rural Development and Risk Management Division. IV. Title. V. Series.

IDB-TN-3023

http://www.iadb.org

Effects of Land Administration: Evaluation of Ecuador's Rural Land Administration Program, SIGTIERRAS

Leonardo R. Corral[†], César E. Montiel-Olea[‡], Maja Schling[¤]

November 2024

Abstract

This paper evaluates the impact of a rural land administration program in Ecuador, SigTierras. Using a doubly robust estimation, which combines a difference-in-differences design with inverse propensity weighting, we estimate the causal effect of the program on beneficiary households with land tenure issues. We find that SigTierras had no effect on improving the perception of land tenure security, reducing land conflicts, or increasing the use of land inputs such as pesticides and fertilizers. SigTierras did significantly increase agricultural wages and annual household income of beneficiary landowners. These results suggest that land administration programs must incorporate specific mechanisms to ensure parcels can effectively be regularized and lower the burden and private cost of required legal formalization procedures. It is further crucial to understand the sociocultural context in which such policies are implemented. Where informal tenure provides sufficient tenure security, providing lower cost solutions, such as digital cadaster maps of the parcel, may be sufficient to incentivize landowners to complement farm production with off farm income generating activities.

JEL classifications: H43, O13, P32, Q15

Keywords: Land Tenure, Land Ownership, Agriculture, Ecuador

[†] leonardo_corral4@hotmail.com, Independent Researcher
[‡] cmolea@catalist.us, Data Scientist, Catalist
[¤] majas@iadb.org, Senior Economist, Inter-American Development Bank

Acknowledgements

We would like to thank Marisol Inurritegui and Mario González-Flores for their helpful inputs on this paper in its conceptual stage. We are grateful for the support from Antonio Bermeo Noboa and Andrea Terán Espinosa from the executing unit of the SigTierras Program for their invaluable insight during the preparation of the study.

1 Introduction

Land is a central economic asset and major source of income for rural households. Land tenure insecurity is considered an important barrier, since it hinders agricultural investment and productivity, particularly among smallholder farmers who lack the certainty that they will be able to garner the benefit streams that emerge from the use of their land in the medium- to long term (Ali, et. al., 2014; Ghebru & Holden, 2015; Higgins et al., 2018; Lawry et al., 2017; Quisumbing & Kumar, 2014). Conceptually, securing property rights is expected to improve agricultural productivity and income through four primary pathways. First, secure land tenure provides farmers with an incentive to make long-term land investments in their plots, and adopt more efficient production technologies (Besley, 1995; Deininger & Jin, 2006; Goldstein & Udry, 2008). Secondly, holding legal title may enable farmers to use their land as collateral, thereby facilitating access to credit that can be used to finance productive activities (Feder & Feeny, 1991). Third, regularized ownership enhances efficiency in the land market by reducing the cost and risk of land transfers, improving factor intensity and potentially enhancing productive efficiency through the reallocation of land to more capable farmers (Abdulai et al., 2011; Deininger, 2003). Fourth, holding a legal land title reduces the risk of land conflicts, enabling farmers to allocate their resources more efficiently toward productive activities instead of activities geared towards protective measures against possible theft or squatting (Besley & Ghatak, 2010; Malik & Schwab, 1991).

Despite these supposed benefits of tenure security, Latin America and the Caribbean continues to grapple with high levels of land tenure informality and insecurity to this day, particularly in rural areas. Land distribution in Latin America and the Caribbean remains the most unequal in the world, with the top 10% of landowners controlling 75% of land, and the bottom 50% owning only 2% of plots (Ward & Baldinelli, 2020). Although comprehensive data do not exist on this matter, some examples illustrate the situation. In 2022, in Peru, 65% of farmers did not have a property title, and only 20% had a property title registered in Public Registries (INEI, 2023). In Guatemala, it is estimated that, by 2015, 40% of rural plots were not yet titled (World Bank, 2015). In Bolivia, 30% of agricultural land still awaited to be regularized, titled, and registered by 2016 (IDB, 2016). Similarly, in Ecuador, property rights over agricultural land are characterized by a high degree of informality and uncertainty. In 2008, less than 40% of agricultural plots in Ecuador had a *título perfeccionado*, defined as a title that: (a) is formally registered in the Property Registry; (b) reflects current ownership status; and (c) is free of conflict. The remaining 60% of plots either had never had a registered title or had an invalid title because it had not been updated to reflect land transactions such as sale or inheritance. To date, many land administration systems in the region still face significant challenges, such as incomplete or inaccurate information on land and limited sharing of this information between cadastral and property registration institutions, as well as limited institutional capacity to perform the basic functions of a modern land administration system.

Motivated by the recognition that insecure lang tenure is an impediment to agricultural development, numerous developing countries and international development agencies have invested heavily in land administration and regularization in the last few decades. Between 1995 and 2006, the World Bank committed US$1.8 billion to land tenure programs (Bell, 2006). In Latin America, the Inter-American Development Bank (IDB) has to date allocated more than

US$500 million towards programs of this nature, with the express objective of improving land administration systems and conferring land titles as a means to bolster tenure security of smallholder farmers.

Nevertheless, the evidence about the effectiveness of such land administration and regularization programs remains inconclusive. While some studies have found positive impacts of tenure security on household investments as well as agricultural productivity and income (Bandeira & Sumpsi, 2009; Brasselle et al., 2002; Deininger & Chamorro, 2004; Deininger & Feder, 2009; Galiani & Schargrodsky, 2010; Gignoux et al., 2013; Goldstein & Udry, 2008; Higgins et al., 2018; Lawry et al., 2017; Ngango & Hong, 2021), others have found no relationship or highlight the importance of considering the geographic and socio-cultural context as a determinant of the effectiveness of land regularization (Boucher et al., 2005; Fort, 2008; Suchá et al., 2020; Zegarra et al., 2008). However, many studies rely on cross-sectional data and have not been able to estimate causal effects due to challenges presented by the underlying endogeneity that exists between tenure security and productive decisions.

In the absence of experimental evaluations, an additional methodological challenge arises when trying to identify such parcel owners that are in need of tenure security prior to the beginning of a land regularization campaign. This is because information on the legal status of the parcel is normally collected during the cadastral sweep, which takes place during the implementation phase. Moreover, empirical evaluations on land administration programs typically analyze the effect of providing tenure security on all the parcel owners participating in a program regardless of whether they actually experience tenure insecurity. Within this setting, causal evidence on land administration and regularization programs is typically based on estimations of the Intent-to-Treat Effect (ITT) or the Average Treatment Effect (ATE). This is misleading as the estimator of interest of a land administration program's impact is the Average Treatment Effect on the Treated (ATT), that is to say, the effect of a land administration program on those households that actually need the treatment to increase their tenure security and possibly enjoy the benefits of titling previously described.

Thus, in this paper we provide a sound methodological approach to assess the effects of a land administration program in Ecuador, SigTierras. It is important to mention that the prospective evaluation was designed to facilitate the obtention of an ATT estimand. This is because the impact evaluation was designed in a way that identified both the treatment and control group after a cadaster sweep was completed. Specifically, after the cadaster sweep, it was possible to identify households with perceived land tenure issues that might benefit from treatment. Control households were identified by first selecting control cantons and census tracts based on their similarity to treated cantons in terms of their land tenure and agricultural characteristics, and secondly selecting households that experienced similar tenure issues as treated households based on information obtained via a filter questionnaire.

From a policy perspective, the primary question that this paper seeks to answer is the following: What was the impact of SigTierras on households with land tenure issues in terms of different socio-economic and agricultural indicators? To answer this question, we apply a doubly robust methodology. First, we use propensity score matching (PSM) to identify such households from the control group that exhibited most similarities to the treatment group in terms of different household characteristics at baseline. This allows us to establish a reasonable counterfactual

for the subsequent analysis. We then apply a difference-and-difference (DD) model incorporating the inverse probability weights from the PSM in order to estimate the causal impact of SigTierras on the variables of interest, including perception of land tenures security, incidence of land conflicts, investments in land inputs, as well as household income.

We find no effect of SigTierras on perception of land tenure security, incidence of land conflicts, and investments in land inputs such as pesticides and fertilizers. We do, however, find that treated households increased their annual household income relative to control households. As we will explain further, we believe that the absence of results can be ascribed to three main reasons. First, during project design, SigTierras did not establish the necessary legal and administrative mechanisms to ensure that those parcels under informal legal status would regularize their tenure. Second, during execution, SigTierras focused on providing spatial certainty by creating and issuing georeferenced digital maps (via Geographic Information Systems) to parcel owners; however, this does not appear to have translated into higher tenure security for beneficiaries. Finally, as highlighted by Corral and Montiel Olea (2019) in their study on the conditions driving the take-up for SigTierras' legal component, the System for Legal Orientation (SIOL), we assert that in many rural households that were intervened through SigTierras, informal property rights substituted effectively for formal property rights, thus, lowering the value of land regularization.

The remainder of this paper is structured as follows. Section 2 provides background information for SigTierras, its components and the main results that were documented in the Project Completion Report (PCR). Section 3 presents a conceptual discussion about the mechanisms through which SigTierras is likely to affect different household outcomes. Section 4 presents the evaluation design, and describes how cantons and households were selected for the treatment and control groups. Section 5 describes the data-collection process, reports relevant descriptive statistics, and presents an overview of attrition between the baseline and endline survey. Section 6 describes our identification strategy and methodological approach. Section 7 presents the results of impact estimation on different outcomes and discusses them in the context of the program. Finally, Section 8 offers concluding remarks and policy recommendations of our analysis for future land administration projects.

2 Description of the Program & Context

A factor that has contributed to the predominance of informality in Ecuador is the inefficiency of the Municipal Cadasters and Property Registries, the two key institutions responsible for granting and maintaining property rights (IDB, 2010). The Government of Ecuador (GoE) identified this situation of informal property rights and weak institutions as a significant constraint to rural development and, in 2002, the government launched the Rural Land Regularization and Administration Program (PRAT) with technical and financial support from the IDB. PRAT developed and implemented an effective methodology for the physical and legal regularization of property rights in the country, through comprehensive campaigns to establish cadasters, regularize land tenure, and register property. This "sweep" methodology was tested in eight of the country's 221 cantons[1], clearing rights to 103,144 rural properties, resolving the lack of

[1] Cantons are the second-level subdivisions of Ecuador below provinces and are equivalent to municipalities.

formal status for 34,568 titles, and issuing titles for 5,338 properties, in line with the operation's original targets. The methodology proved to be cost-effective and nimble, allowing for broad coverage among farmers in addition to being participatory, as it provided a central role for subnational governments and beneficiaries in the process of formalizing ownership.

Based on the positive results of the PRAT program, the GoE decided to scale the program to the national level. Therefore, in 2010 the GoE launched the National System for Rural Land Information and Management and Technology Infrastructure (the SigTierras program) with the support of the IDB. SigTierras was designed as a land administration program whose main objective was to enhance legal certainty with regard to property rights, to support the application of canton tax policies, and to provide information for land management and land use planning in rural areas. To achieve these objectives, the program included three primary components:

1. **Cadastral mapping:** For each agricultural parcel in the program area, SigTierras generated a geo-referenced digital map. Complementary information, such as physical characteristics, property rights, and land tenure status, was collected via survey applied by SigTierras personnel.

2. **Reorganization of and investment in Cadasters and Property Registries:** In order to improve the management of transactions and property rights and improve the efficiency of tax collection, SigTierras provided financial and technical support to participating municipalities in order to facilitate the adoption of a new computerized system of data management. The program also supported the Property Registries in their transition from being based on individual-level records (*folio personal*) to parcel-level records (*folio predial*) and from being privately to municipally managed. It was hoped that these investments would increase the efficiency of tax collection and reduce the transactions costs associated with all forms of land transactions**.**

3. **Regularization of land titles**: Owners of parcels that lacked a *título perfeccionado* were offered financial support and technical assistance to acquire or update their titles. In addition, individuals involved in land conflicts would be provided legal assistance to resolve conflicts that prevented the acquisition or updating of titles. This component was implemented through the establishment of the System for Legal Orientation (SIOL; *Sistema de Orientación Legal*).

2.1 Eligibility Criteria and Implementation

SigTierras was a program based on demand insofar as municipalities needed to complete a multistep application process and assume 20% of the total program cost in order to enroll. Once these pre-conditions were met, each municipality negotiated and signed an agreement (*convenio*) with SigTierras. Of a total of 171 cantons that showed interest in SigTierras, 47 were chosen to participate. The overriding selection criterion was budgetary constraints. Other factors affecting participation were delays in the application and negotiation process, and availability of 1:25,000-scale digital aerial photograph of the canton due to cloud coverage that prevented the timely completion of aerial photos. This last reason was an exogenous factor that was outside the control of the canton's authorities, however, having these aerial photos was a fundamental input to advance with the implementation of the program.

Once the *Convenio* was signed, the first step of program execution consisted in producing 1:5,000-scale orthophoto maps, and implementing the cadastral sweep (*barrido catastral*). To do so, a team of data collectors (*brigadistas*) visited each parcel in the participating cantons with the purpose of collecting data using a parcel record card (*ficha predial*). While one of the team members collected information about the parcel's tenure history, current tenure status, and other relevant characteristics such as parcel infrastructure and uses, the other team member collected information about the dimensions and boundaries of the parcel based on the orthophoto at 1:5,000 scale. All the information from the cadastral sweep was validated by the owner or occupant and in case of her/his absence, collected information was validated with neighbors. All the information from the cadastral sweep was uploaded to a central location for each region and went through a quality control process. Once the parcel level data had passed the relevant "checks", a map for each parcel was created with the following information: 1) date of issuance; 2) parcel information, including location, type of occupier, name and dimensions; and 3) names of bordering neighbors on all sides.

Once the cadastral sweep and mapping was finalized for a given area, program personnel presented the results in Public Exposition of Results Meetings (PEM). The PEM took place at the community-level (usually inside a school or other public place known to everybody) and was preceded by several days of communication campaigns so each community resident was made aware and could plan ahead to be present at the event. The purpose of the PEM was two-fold: 1) socialize the results of the cadastral sweep, and 2) verify that the information collected during the cadastral sweep was accurate. This last step involved presenting the boundaries of the parcel as well as any existing land tenure issues to each parcel owner. There were three types of possible issues associated with a parcel: a) the parcel did not have a title; b) the title was not registered, or c) there was something unclear regarding the legal aspects of the file. Parcel tenants who agreed with the results from the PEM signed a document expressing that they were in agreement with the results and, afterwards, received an official map of the parcel which was free of charge.[2] The PEM allowed the identification of parcel owners or occupants who were in possession of land that required a title, or whose land title needed formalization. Owners of parcels who lacked a *título perfeccionado* were encouraged to seek legal advice through SIOL.

Given that the cadastral sweep along with the PEM did not follow a predefined timeline, the execution of the Program in the 47 cantons took a considerable amount of time. In some cantons it started as early as 2012 while in others it started as late as 2016. By the end of 2016, which was the year SigTierras finalized its execution, the 47 cantons participating in the program had completed the cadastral sweep. According to the PCR of SigTierras, the main results achieved at the end of the Program can be summarized as follows:

1. Cadastral mapping and National Land Information System:

- Orthophoto maps were developed for 206,908 square kilometers of land with a

[2] In the event that the parcel occupant was in disagreement with the results, he/she could file a complaint through a Claim Act (*Acta de Reclamo*). The firms that were in charge of the PEM had the mandate to review each of the possible complaints made during the PEM, and to follow up afterwards if an immediate resolution was not achieved.

1:5,000-scale, achieving 100% of its target.[3]

- 55 cantons were cadastered and assessed according to the Ministry of Agriculture (MAG) and the PRAT methodology, surpassing the goal of 50 cantons.[4]
- 59 cantons were integrated into the National Land Information System (SigTierras), which allowed the files of the cadaster and register offices to be electronically linked. The system used georeferenced information and allowed easy updates on property information.[5]

2. Regularization of land titles:

- A total of 163,580 parcels initiated the regularization process. The project had the goal of regularizing the legal ownership status of 170,000 properties (i.e. a *título perfeccionado*).
- The cadastral sweep revealed that a total of 417,652 parcels presented tenure irregularities.
- Through the project, 39,267 parcels regularized their legal ownership status: 35,277 were located in state land and the remaining 3,990 in private land. Given that the goal was to regularize 170,000 parcels, the program only achieved 23% of its initial target on this key indicator associated with enhanced tenure security, and effectively regularized less than 10% of parcels found to have tenure irregularities.

The implementation timeline of SigTierras is presented in Figure 1. It shows the activities that took place since the first year of approval, 2010, until its closing in 2018.

2.2 SIOL Component

The project's design contemplated providing legal and technical assistance on demand to the owners of private and communal land to formalize property rights that were legally informal. The project design, however, did not fully flesh out how this would be implemented. The MAG, in charge of executing the project, did not have the legal competency to carry out regularization processes. Thus, it devised an ad-hoc mechanism coined System for Legal Orientation (SIOL). SIOL was a system comprised of three different stimulus or mechanisms. The first was a team of lawyers that provided free legal advice for those that approached it during the PEM. The second was a call center that provided legal support based on demand via telephone calls.[6] And the third constituted a support team at SigTierras offices located in each municipality. SIOL also implemented an on-line database that collected information for all individuals that sought legal

[3] An additional 4,230 square kilometers of orthophoto maps were developed for the canton of Quito; however, this information was not included in the program's results as it was financed by the municipality of Quito. Taking into account the information from PRAT, SigTierras, and the canton of Quito, the country has a land coverage of 225,449 square kilometers with orthophoto maps, which corresponds to 88% of the national territory.

[4] The program not only supported the cadastral sweep of the 47 participating cantons from SigTierras, but also updated the cadastre of 6 cantons from PRAT and 2 more from MAG. According to the MAG, the canton Antonio Ante did not appropriate the cadaster and valuation because it had its own municipal cadaster system.

[5] In addition to the 54 cantons that appropriated the cadastre and valuation from SigTierras, 2 more cantons from PRAT, 2 from MAG, and the canton Antonio Ante, which did not have the National System for Land Administration (SINAT) installed, were also integrated.

[6] The call center provided assistance on the specific requirements and steps to regularize land tenure.

advice.[7]

Owners of four types of parcels were eligible for SIOL: (i) parcels with a title that was unregistered; (ii) parcels that were titled with an unknown registration status; (iii) untitled parcels; and (iv) parcels with no information. In spite of the efforts to increase the regularization of land with tenure issues, only owners of 61,159 parcels approached SIOL. In other words, less than 15% of owners whose parcels had been found to have tenure irregularities in cantons participating in SigTierras sought support from SIOL.

3 Theory of Change & Expected Outcomes

Since well-defined property rights are expected to mitigate expropriation risk, facilitate gains from trade, and support financial market transactions, it is theorized that tenure security promotes investment in and efficient use of physical and human capital (Besley & Ghatak, 2010). Thus, it is posited that strong and well-defined property rights, achieved through the granting of a title or regularization of a land title, can raise the productive efficiency, income, and welfare of agricultural households. Based on this framework, the evaluation design of the SigTierras program elaborated during the preparation phase of the project, proposed a list of outcomes that were to be measured at the end of the program (Boucher, 2010).[8] These outcomes include the following: total household income; farm yield; value of agricultural production; net agricultural income; and value of household wealth. In addition, the evaluation design identified other intermediate outcomes including per-hectare farm expenditures on inputs (such as fertilizers) and land preparation; participation in land transactions (rental and sales markets, inheritance, mortgage); participation in formal and informal credit markets; household rationing status in formal and informal credit markets; terms of formal and informal credit markets (interest rate, loan size, maturity, collateral requirements); household perceptions of land tenure security; frequency and intensity of land conflicts; household participation in government programs including *Bono de la Vivienda*, a housing subsidy scheme; and organic certification.

There is mounting research work related to the intermediate and final outcomes proposed by Boucher (2010) as well as to other outcomes that might be relevant in the context of the way that SigTierras was implemented (Gignoux et al., 2013). To begin with, given that the primary focus of SigTierras centered around land delimitation activities, resulting in georeferenced parcel maps with community assent, we expect that the program would serve to ameliorate land conflicts and thus, decrease the frequency of land conflicts.[9] Furthermore, insofar as households can spend less time reallocating resources to land-guarding practices, they could invest their time in more productive activities that would contribute to higher production and

[7] The data contain information from the cadastral sweep, the type of consultation made by each household, the number of times and dates when parcel owners contacted SIOL, the adjustments to the legal status of the parcel (if any), and the judicial determination of the competent authority on land tenure regularization.

[8] Note that we follow the program's impact evaluation design to report on all variables that were considered of interest to confirm the relevance of the program's Theory of Change.

[9] Torero et al. (2005) study the impact of the Special Rural Cadastre and Land Titling Program (PETT) in Peru on different relevant outcomes. Using household survey data and a quasi-experimental design (i.e. propensity score matching with difference-in-differences), they estimate the ATE of government property titling. Their results find evidence for a significant reduction in the risk of expropriation among household recipients.

income (Besley & Ghatak, 2010).

Enhanced tenure security through titling might also provide incentives for rural agricultural households to investments in the land. Titling provides parcel owners with greater confidence that their investments will be capitalized into the price they would receive in the land market, ultimately increasing the value of their properties (Galiani & Schargrodsky, 2016). For example, Deininger and Chamorro (2002) investigate investments and income effects of massive of land regularization program in Nicaragua. Using household survey data and an econometric analysis, they find that household recipients increased land-secure investments by between 8% and 9% percent. They also experienced an increase in the value of the plots. Similarly, Torero et al. (2005) found that the granting of a registered title improved land values by 30 percent in Peru.

Additionally, where credit markets exist, even for households that never intend to sell their land, the ability to trade property through title could be valuable. The possession of a title can be facilitate access to new sources of credit because owners can use their land as collateral. This collateralization effect underlies the expectation that lenders react positively by increasing the supply of credit in order to absorb the potential increase in demand caused by the tenure security effect. Notwithstanding the theoretical impacts, the empirical results largely fail to detect any actual impacts of titling on credit (Sanjak, 2012). Titling might also lower transaction costs in the land market (e.g. rental, sale, mortgage, inheritance, etc.) by clarifying rights and making them more easily transferable.

In the specific case of Ecuador, the acquisition and regularization of titles may offer additional benefits insofar as possession of a registered titled is an eligibility requirement for certain government programs, such as subsidized housing loans and organic certification. Table 1 reports the complete list of outcomes and information on whether they can be measured with the data collected.

4 Evaluation Design

The original research design laid out in the loan proposal's Monitoring and Evaluation Plan (MEP) intended to estimate the average impact of SigTierras on a number of outcome variables at the household and municipality level (Boucher, 2010; IDB, 2010). To do so, the MEP proposed an identification strategy that would select a treatment and control group, and thus permit causal attribution of observed changes in these variables to SigTierras. Given that randomization of the treatment and control groups, at the household or canton level, was infeasible due to the program's eligibility criteria and implementation aspects, the control group was to be selected from the cantons that had expressed interest in participating in the program, but were not selected to participate in SigTierras because of budgetary constraints, delays in application and negotiation processes, or because cloud cover prevented timely completion of aerial photos needed to start implementation.

The sampling framework for the evaluation must take into account the project's implementation arrangements, and that prior to the cadaster sweep it is impossible to know the tenure status of each parcel. This has direct bearing on the type of impact estimate that can be assessed. For instance, if we were to randomly sample from the universe of parcels included in the cadaster

sweep, we would likely survey households with parcels that exhibited tenure irregularities, but also households whose parcels exhibited no tenure issues and therefore are unlikely to change their productive behavior in response to treatment. This would lead to an average treatment effect (ATE) estimate. Given that our interest lies in estimating the impact of enhancing tenure security for those households with perceived land tenure issues (i.e. the average treatment effect on the treated – ATT), we pursue a strategy that includes only those households with perceived tenure issues in our sample. Specifically, once the cadaster sweep was completed, we were able to identify parcels with perceived land tenure issues that might benefit from treatment.

Nine treated cantons were selected for the impact evaluation, located in the three major regions of the country and representative of SigTierras' intervention area: Coast (1); Sierra (7); Amazonia (1). To identify cantons that were similar to the 9 treated cantons, we draw from a pool of 121 cantons that expressed interest in SigTierras and that met the criteria to be considered eligible. Propensity score matching (PSM) was employed using socio-economic variables from the 2001 and 2010 Population and Housing Census (growth rate and 2010 levels) in order to identify potential canton controls.[10] Propensity scores when then used to identify the four most comparable control cantons for each of the 9 treated cantons. SigTierras' project implementation team then corroborated matches and selected the control canton they considered most similar to each of the treated cantons on the basis of land tenure and agricultural characteristics. Table 2 shows the cantons in the treated and control group, and Figure 2 illustrates their geographic distribution.

Next, we proceeded to select treated census tracts and households within each of the 9 treated cantons.[11] Since our unit of analysis is the farmer household, we used SigTierras administrative data on the universe of cadastered parcels and merged it with census tract information at the household level. Households eligible for inclusion in the impact evaluation were those with at least one parcel with perceived land tenure issues. For the 9 treated cantons, using the location and number of eligible households, census tracts were identified proportional to size. Census tracts with less than 12 eligible households (i.e. with at least one parcel with land tenure issues) were discarded. As it can be gleaned in Figure 3, 110 census tracts were selected as treated units from a universe of 1,224. In each selected census tract, 12 eligible households were randomly selected to be interviewed and 12 additional ones were randomly selected as back up. The stated benefit of this approach is the possibility to estimated Sigtierras' ATT. A potential drawback of this approach is that a household, having participated in the massive cadastral sweep, might have changed its perception of its tenure status, which may result in changes of their agricultural practices before baseline data was collected. Given the timing of the cadastral sweep, data collection, and the agricultural planting season, which all occurred in brief

[10] Variables measuring demographic characteristics (such as population, percentage of women); human capital (such as percentage of people who cannot read); level of access to services (such as percentage of households with health insurance, access to water, access to electricity, and sewage services); participation in the labor market (such as number of employed people, total people working in agricultural activities); and characteristics of the dwelling were included in the PSM. Additional variables measuring size, population density and rural density were also considered. For all these variables, the PSM included respective growth rates between 2001 and 2010.

[11] Given that the program was implemented in rural areas, the first step consisted in excluding census tracts from urban areas. Hence, only census tracts with disperse population and which have on average 80 households were chosen (this is the definition of a peripheral census tract used by INEC).

succession of one another, we do not anticipate this to be a source of bias. However, even if it were, the bias would likely result in downward bias of estimated impact.

Finally, in order to identify control households in the control cantons, as a first step, control census tracts were identified using PSM. Census tracts from the 2001 Population and Household Census were linked with census tracts from the 2010 Census. The nearest neighbor method was employed to select control census tracts, representing the three nearest neighbors to to each of the 110 treated census tract. Thus, 2 alternative control census tracts were identified in case there were insufficient households available for interviewing in the first census tract selected through PSM. As reported in Figure 3, 110 census tracts were selected as control units from a universe of 754. In each control census tract, a “filter” was applied during data collection to identify control households with similar tenure issues as the treated households. Only households reporting to have at least one parcel in need of regularization were considered for inclusion the control group. Through this procedure, 2,712 households were selected as part of the impact evaluation design: 1,356 in treated cantons and 1,356 in control cantons.

5 Data Collection

Between August and November 2014, a baseline survey was carried out using an agricultural household questionnaire based on World Bank’s Living Standard Measurement Study - Integrated Survey on Agriculture (LSMS-ISA). The survey was administered in the 18 cantons that were selected to be part of the treatment and control group. The field team completed 1,360 surveys in the treatment group and 1,386 in the control group. Survey respondents were primarily household heads with knowledge about:

i) the land tenure status of the household’s parcel(s), and ii) the production activities of the household. The baseline questionnaire consisted of 12 modules (details about the survey are shown in Annex I) and collected information at the household and parcel level.

One section of the survey was devoted to questions about the self-reported legal status of each parcel (e.g. title registered, title unregistered, no title, or unknown tenure status) and its characteristics including land extension; the year in which it was acquired or obtained; the type of land in which the parcel is located (e.g. private or communal land); the parcel’s access to infrastructure and equipment (including access to electricity, roads, telephone network, and irrigation); and its use for agricultural and livestock production. Another module of the survey collected detailed information on the characteristics of the household and its members, including socio-economic characteristics; information on savings, credits, and loans; as well as household members’ access to and participation in social and agricultural programs. Each household was assigned a unique identifier, each parcel a unique cadastral code identifier.

Sigtierras finalized its implementation in 2016, and an endline survey was carried out in 2018 in order to allow more time for impacts to materialize. In general, evidence from land regularization and administration programs in Latin America and Africa suggest that visible impacts would be detectable only three or more years after the program was rolled out (Deininger & Chamorro, 2002; Katz & Chamorro, 2003; Goldstein et al., 2018). Thus, the endline survey was administered to the same sample of households four years after completion of the baseline survey. Additionally, the survey data from the baseline and endline were merged (using the

parcel's cadastral code) with administrative records from SIOL that identified those households that had requested the program's legal support.

Table 2 reports summary statistics and balance checks for household characteristics at baseline. We find significant differences between the treated and control groups along a few characteristics. Specifically, control group household heads are less likely to be female, they are on average younger, more educated, and more likely to work in agriculture. Treated households have fewer members working in agriculture and are more likely to receive monthly cash transfers from the government program *Bono de Desarrollo Humano*, a program aimed at supporting families experiencing poverty. While household size and the number of plots owned are similar, the control group on average owned more land, larger parcels, and more parcels without a tenure document.

In terms of attrition between the administration of baseline and endline survey, Table 3 shows that the probability of completing the endline survey for the control group was 91%, while treated households were 2.1 percentage points more likely to complete it (column 1). When we analyze the main causes of attrition, we find no differential likelihood that the household was not found (column 2), however, treated households were 4.3 percentage points less likely to have moved (column 3), and 2.6 percentage points more likely to refuse to respond (column 4). We consider that differential attrition is negligible and the reason for attrition variable enough to not represent a substantial estimation bias.

6 Econometric Approach

6.1 Identification Strategy

To test the causal impact of the SigTierras program, we apply a doubly robust estimator that combines DD with inverse propensity weighting using propensity scores. Given that our estimand of interest is the ATT, we compare changes in different outcomes associated with increase land tenure security in household that receive SigTierras (i.e. households that have land tenure issues) relative to the changes in households that do not. Our estimating equation can be written as:

$$y_{it} = \alpha + \beta\, Treated_i + \mu\, Post_t + \tau\, Treated_i * Post_t + \epsilon_{it} \quad (1)$$

where y_{it} is any outcome variable of interest for household *i* in period *t*; $Treated_i$ is a binary indicator that takes the value of one if the household received treatment by SigTierras and zero otherwise; $Post_t$ is a dummy variable taking the value one if the observation corresponds to the post-program period (2018) and zero otherwise, $Treated_i * Post_t$ is an interaction between $Treated_i$ and $Post_t$, and ϵ_{it} is an error term. We cluster standard errors at the census tract level. The coefficient β measures the average pre-treatment difference in the outcome variable between the treatment and control group, while μ measures the general time trend between pre- and post-treatment periods in the outcome variable. Finally, τ measures the average ATT of the program and is our coefficient of interest.

The key identifying assumption in difference-in-difference designs is that that there are no

systematic differences across treatment and control groups in terms of unobservable variables that affect the change in the outcome variable. This is the assumption of "parallel trends", which states that in the absence of the program the average change in the outcome variable of treated households would have been the same as the average change experienced by the control households. When this assumption fails, the DD estimation can produce biased estimates because it confounds changes unrelated to the treatment with the effect of the intervention. In section 5 we saw that, although the control households were selected to be as similar as possible to the treated communities, treated and control households presented different demographic and socioeconomic characteristics for several of the variables considered (Table 2). While the parallel trend assumption does not require observable characteristics in treatment and control groups to be balanced at baseline, these differences may be correlated with trends in the outcomes of interest, hence casting doubt on the validity of the DD strategy.

One popular method to reduce the potential bias in this context is to match treatment and control units on pre-treatment outcomes and then applying DD on the matched sample (Ryan et al., 2015). While matching on outcomes corrects the non-parallel trend issue between groups, DD controls for any remaining outcome level differences (Lindner & McConnell, 2019). Moreover, we combine our regression model with inverse propensity weighting using estimated propensity scores to obtain a doubly robust estimation of ATT. The advantage of this doubly robust estimator is that it requires us to specify a model for the outcomes and another for treatment status as a function of the covariates. Moreover, with the doubly robust estimation only one of the two models need be correctly specified to obtain an unbiased effect estimator (Funk et al., 2011; Imbens & Rubin, 2015; Robins et al., 1995).

First, we estimate a PSM model to obtain predicted probabilities of membership in the treatment group. Then, we weight our outcomes for treated and control households from equation (1) by the inverse of the probability of treatment. To estimate the propensity score we use a logistic regression using treatment assignment as the dependent variable and a set of household characteristics as covariates. Recall that the propensity score is defined as the probability of an individual receiving the treatment conditional on a set of observed pre-treatment covariates. Below, we present how we specify the propensity score given a great number of covariates. We will use the weights from the estimated propensity scores to obtain an unbiased estimator of the average treatment effect on the treated as follows:

$$\hat{\tau} = \frac{1}{n}\sum_{i=1}^{n} Z_i Y_i - \frac{1}{n}\sum_{i=1}^{n} \frac{\hat{e}(x_i)(1 - Z_i)Y_i}{1 - \hat{e}(x_i)} \qquad (2)$$

where n denotes the number of individual observations (households); Z the treatment assignment for each observation (where $Z = 1$ if household is treated, and $Z = 0$ otherwise); $e(x_i)$ is the estimated propensity score;[12] and Y_i the outcome variable of interest.

From Austin and Stuart (2015), we know that to estimate an ATE our inverse probability weights would be given by $w_{i,ATE} = \frac{Z_i}{\hat{e}} + \frac{1-Z_i}{1-\hat{e}}$. However, for the ATT the weights are given by $w_{i,ATT} =$

[12] The propensity score for household i with observable characteristics x_i, is defined as the conditional probability of receiving SigTierras given the household baseline covariates as: $e(x_i) = Pr(Z_i = 1|X_i = x_i)$.

$Z_i + \frac{\hat{e}(1-Z_i)}{1-\hat{e}}$. More specifically, we have that:

$$w_{i,ATT} = \begin{cases} 1 & if\ Z_i = 1 \\ \frac{\hat{e}(1-Z_i)}{1-\hat{e}} & if\ Z_i=0 \end{cases} \quad (3)$$

It is evident that the weights $w_{i,ATT}$ are obtained by multiplying the weights $w_{i,ATE}$ by $\hat{e}$. In general, the weights are equivalent to survey weights insofar as they increase the representativeness of their respective target populations. Thus, with $w_{i,ATT}$ the treatment group is specified as the target population. The weight leaves the sampled treatment group unaltered but attempts to turn the control group into a more representative sample of the treatment group (Morgan & Todd, 2008).

Under the assumption that changes in the outcome variables would have been the same in the treatment and control group in absence of the program and conditional on covariate vector X_i, this methodology would yield an unbiased estimate of the average treatment effect, $\hat{\tau}$. However, this estimator is very sensitive to estimated propensity scores that are either close to zero or close to one as these would assign very high weight to the corresponding observations. To minimize this issue, we follow Imbens et al. (2009) and restrict the sample to the set of households for which the propensity score belongs to the interval $[\hat{\alpha}, 1-\hat{\alpha}]$, where $\hat{\alpha}$ is chosen based on the distribution of the propensity scores, with the objective of minimizing the variance of the estimated average treatment effect.[13]

6.2 Estimation

To estimate the propensity score, we need to choose a set of household characteristics at baseline as our explanatory variables. Our goal is to balance measured covariates between households who were treated and those that were not, thus making it likelier that any remaining difference is due to the Program. Finding the most suitable specification for estimating the propensity score is not trivial. In general, covariate selection is guided by tradeoffs between variables' effects on bias (distance of estimated treatment effect from true effect) and efficiency (precision of estimated treatment effect) (Garrido et al., 2014). In other words, as we increase the model's "flexibility" by adding more covariates into the propensity score estimation, we improve its predictive power (reduce bias) at the cost of reducing the area of the "common support", that is, the area of overlap of the distribution of propensity scores between treatment and control households. As the area of common support narrows, so does inference about impact effects for treated households for whom there are no longer valid comparison units.

The key is to reduce bias by including as many variables as possible related to both treatment status and the outcome while limiting the cost of sacrificing efficiency in the treatment estimates. Based on our survey questionnaire of close to 300 questions, we decided to create a list of 102

[13] Specifically, $\hat{\alpha} = \frac{1}{2} - \sqrt{\frac{1}{4} + \frac{1}{\hat{\gamma}}}$ and $\hat{\gamma}$ is the solution of the following equation:

$$\gamma \sum_i \mathbb{1}_{(\hat{e}(x_i)(1-\hat{e}(x_i)))^{-1} < \gamma} = \sum_i \frac{1}{\hat{e}(x_i)(1-\hat{e}(x_i))} \mathbb{1}_{(\hat{e}(x_i)(1-\hat{e}(x_i)))^{-1} < \gamma}$$

covariates that we believe could affect both the treatment status and most of the outcomes of interest. However, we still need to decide which confounders to include in our propensity score model. Moreover, this process should not only include linear terms but also other higher order terms such as polynomials to optimize the fit of the model.

Thus, we follow the methodology proposed by Imbens and Rubin (2015) to select the covariates to use in the propensity score model. A description of this can be found in Appendix A. Following this methodology, our final propensity score model includes a total of 33 covariates. Figures 4 and 5 show the performance of our model. Figure 4 highlights the substantial overlap between the propensity score distribution of treated and control units. Figure 5 shows that matching dramatically improves the overlap between the distribution of units across groups. Once we trim the sample to such households for which the propensity score lies in the interval $[\hat{\alpha}, 1-\hat{\alpha}]$, we are left with 5,127 observations (2,544 control units and 2,583 treated units). Table 4 reports the resulting balance tests adjusted by inverse propensity weighting for the trimmed sample. Even though the reduction in the number of observations is small, there is a notable improvement in terms of balance relative to the unadjusted sample (Table 2), as there are no statistically significant differences across groups for the variables considered.

7 Results

7.1 Regression Results

First, we test whether the program provided tenure security to households that received SigTierras. We measure perception of tenure security by the number of parcels that the household states they own, are titled, and are not titled. According to our theory of change, we would expect to see an increase in the number of parcels owned and titled, and a decrease in the number of untitled parcels as a result of SigTierras. As can be seen in Table 5, we find no evidence that treated households increased the number of owned or titled parcels (columns 1 and 2), nor that the number of parcels without title decreased (column 3), relative to control households. Next, we assess the impact of SigTierras on tenure security in terms of the frequency of land conflicts. As can be seen in Table 5, we do observe the expected effect on the occurrence of land conflicts in the last year (column 4) and last five years (column 5), respectively, in treated households relative to control households. Nevertheless, neither coefficient is statistically different from zero.

We then test the program's effect on productive investments. According to our hypothesis, we would expect that the program has a positive effect on investments in production inputs including seeds, pesticides, fertilizers, and hired labor. As we can observe in Table 6, we find no evidence that treated households increase their probability of investing in farm inputs due to the program. Treated households generally have a higher probability of purchasing seeds and pesticides relative to control households (columns 1 and 2), albeit these tendencies are not statistically significant. Contrarily, treated households are less likely to have purchased fertilizer and paid for labor relative to the control group (columns 3 and 4), with the latter being a statistically significant effect. In other words, results show that SigTierras reduced the likelihood of hiring labor by 9 percentage points amount treated farmers.

Finally, we test whether Sigtierras had a significant impact on household income. Table 7 reports the program's effect on the main sources of household income: agricultural wages, crop production, livestock production, self-employment, and transfers (columns 2-6). It also reports the effect on total household income, as the sum of all these sources (column 1). As we can see, we find strong and statistically significant evidence of an increase in total household income and agricultural wages. The program increases total household income by 755 USD, which represents an approximate 52% increase relative to the control group. Similarly, the program increases agricultural wage income by 732 USD, an almost 30% increase relative to the control group. No statistically significant effects are found for income derived from crop or livestock production, self-employment income and transfers.

7.2 Discussion of Results

Overall, the results we observe do not confirm our hypothesis that regularizing land tenure in SigTierras would lead to increased perception of tenure security and reduced incidence of land conflicts, which would lead to increases in productive investments in the land and thereby contribute to increase household income. Considering the design of SigTierras, these results are somewhat surprising; however, we assert that the lack of impact may be due to a crucial shortcoming of the program's design that became evident during its implementation and effectively resulted in only a small share of beneficiaries having their land regularized. As a matter of fact, SigTierras had aimed to regularize 170,000 properties by the end of the Program in 2016; however, only 39,267 (or 23% of the expected goal) had finalized the regularization process by that time. Even though 163,580 properties had initiated the regularization process by project end, which is equivalent to 96% of the original goal, of these only 117,827 property records had been submitted for the adjudication processes necessary for legal regularization. For the more than 417,000 parcels that the cadaster had revealed to have imperfect tenure, only 61,159 beneficiary property owners (or 14%) had sought legal orientation through SIOL towards properly registering their property.

We identify two primary factors that contributed to the limited effectiveness of the program in terms of finalizing the majority of regularization processes that were initiated through SigTierras and may therefore explain the lack of impact detected by this analysis:[14] First, SigTierras did not establish the necessary legal and administrative mechanisms to ensure that the parcels under informal legal status would regularize their tenancy. In contrast to the previous land regularization program, PRAT, from which it was scaled up, SigTierras' design did not include a mechanism dedicated to processing state land titling records with the direct support of the National Institute of Agrarian Development (INDA), which at the time was the agency responsible for the legalization of adjudication procedures. After its dissolution in 2010, this responsibility was transferred to the Undersecretariat of Lands (STRA) within MAG. In addition, the Property Registries, which until 2010 were operated by private companies regulated by the National Court of Justice, began to be administered by the Municipal Decentralized Autonomous Governments (GADM) in concurrence with the Central Government, through the National Directorate of Public Data Registry (DINARDAP). Neither STRA nor DINARDAP were part of

[14] This is congruent with what was also stated in the recommendation section from the Project Completion Report (PCR) of this Program.

the Project's implementation mechanism, which hindered the regularization processes on both State and private lands. Additional delays were caused by the enactment in May of 2016 of a new Organic Law on Rural Lands and Ancestral Territories (LOTRTA), which served to establish all land and territory in ancestral possession and ownership as legally belonging to indigenous peoples, which caused the suspension of any new adjudication applications for a year. Therefore, the Program's explicit objective to register and legalize a large number of properties in a short period of time was not realistic under national legislation and current institutions, particularly without having established a mechanism that defined agreements and protocols for the application of legalization procedures amongst the different responsible institutions involved.

The second contributing factor which contributed to a low incidence of successful regularization were the high transactional costs that beneficiary farmers faced. Sigtierras, unlike PRAT, did not allocate resources to subsidize notary costs for property registries and judicial procedures, which, depending on the necessary procedures, could amount to between US$116 and US$1,215 based on a study carried out in three participating cantons, and not accounting for additional transportation or opportunity costs to travel to public registrar offices. Procedures were not only costly in monetary terms, but also in terms of time. The formalization procedures that were required to perfect the legal tenure based on the cadastral survey typically take between two and seven years due to procedural complexity and limited capacity of local governments to process requests. Given that a majority of beneficiaries owned small and medium-sized properties, the transactional and time costs to regularize a parcel was disproportional to the estimated value of many such properties, both in terms of its potential sale value, or its productive potential. Anecdotally, several public policies to support small-scale rural producers in Ecuador have been implemented without conditioning their eligibility on the formalization of land tenure, which could have further decreased farmers' demand for regularization. For example, the *Bono de la Vivienda* program and similar subsidy schemes did not always require a prior verification of land tenure as a condition for participation, while several Savings and Credit Cooperatives in the rural sector were encouraged to develop lines of credit without requiring land as collateral. In summary, these conditions are likely to have contributed to the low demand for legal support through SigTierras' SIOL program, and suggest that landowners did not face the right incentives to opt for regularization of their tenure. Transactional costs they faced were too high, while the limitations of informal land tenure do not appear to imply substantial restrictions.

How is it possible, then, that household income increased among program beneficiaries while productive investments and incidence of land conflicts did not change? It is important to consider the nature of the prevailing land regime beyond the definition of legal tenure, since this may obscure the underlying nuances and dynamics of the land regime which determine perception of tenure security. Within a community, traditional customary tenure systems may easily outweigh national statutory law, so that social acceptance and recognition of one's ownership may be more relevant for perceived tenure security than legal formal title (Deininger et al, 2008; Doss & Meinzen-Dick, 2020). It is worth highlighting in this context, that a concurrent evaluation of SigTierras on women's empowerment and their household's food security found that women beneficiaries indeed enjoyed increased access to credit and enabled them to dedicate more time to off-work income generating activities, which contributed to significantly

higher off-farm wages and improved food security (Schling et al., 2023). Recall that for each parcel in the program's area, SigTierras generated digital cadastral maps with community assent to ensure land delimitation. We hypothesize that, for landowners, the provision of an official cadastral parcel map and the organization of community-level sensibilization meetings could serve as an alternative source of property documentation that may have enabled farmers to dedicate additional time to off-farm to generate additional income.

8 Conclusions

Despite a strong theory of change on the channels through which land tenure security should positively affect agricultural and welfare outcomes, the empirical work about the potential benefits from regularization programs remains inconclusive. In this paper, we used a doubly robust estimation to assess the impact of a land regularization and administration program in rural Ecuador, SigTierras.

SigTierras was a demand-based program that was implemented in rural Ecuador between 2010 and 2018 in 47 of the country's 221 cantons. Its objective was to enhance legal certainty with regard to property rights through the regularization of rural land for a target of 170,000 land parcels. Given that a cadastral sweep was performed during the implementation phase, the prospective evaluation identified the households in need of receiving the program. Thus, treated households were selected based on their tenure issues and their need for regularization, while control households were identified by first selecting control cantons and census tracts and then by using a filter that guaranteed their similarity to treated households. Due to the features of the household selection process, we developed a prospective evaluation that could allow us to estimate an Average Treatment Effect on the Treated, that it to say, what was the effect of SigTierras on those households that actually needed the treatment.

Our findings suggest that the program had no effects in terms of perception of tenure security, the reduction of land conflicts, and the increase in land investments. Strikingly, we find a positive and sizable effect of SigTierras on agricultural wages and total household income. Two possible explanations for the limited effectiveness of the program include that, one, during the design phase, SigTierras did not establish the proper legal and administrative mechanisms to ensure that parcels with land tenure issues could regularize their tenancy, since the necessary adjudication procedures fell to government institutions that were not part of the Program's implementation mechanism. In effect, less than 40,000 parcels (or 23% of the original target) had completed regularization by project end. Secondly, property owners in rural Ecuador do not face the appropriate incentive structure to encourage regularization, due to the substantial financial cost of the required legal procedures, as well as the excessive time frame of formalization. In practice, several public programs seem to not require proof of legal tenure to be considered eligible, thereby further disincentivizing farmers from obtaining legal tenure. Given these limitations, during implementation SigTierras focused on providing digital cadastral maps that were socialized in community level meetings to clearly delimit parcel boundaries among neighboring farms. While this may not have sufficiently increased tenure security to encourage productive investment in the farm, property owners appear to have reacted by dedicating additional time to off-farm work, which may have contributed to higher agricultural wages and household income.

The results then suggest that future land regularization efforts must be based on a thorough understanding of preexisting customary land tenure systems and the costs and benefits that landowners face when deciding whether to regularize their land title. The cost of formalization can be lowered significantly if such programs clearly define a mechanism to provide support farmers throughout the judiciary procedures, and if, prior to program start, agreements and protocols for the efficient application of legalization procedures are established among the entities with competency to carry out regularization.

9 References

Abdulai, A., Owusu, V., & Goetz, R. (2011). Land tenure differences and investment in land improvement measures: Theoretical and empirical analyses. *Journal of Development Economics*, 96(1), 66-78. doi: 10.1016/j.jdeveco.2010.08.002

Ali, D. A., Deininger, K., & Goldstein, M. (2014). Environmental and gender impacts of land tenure regularization in Africa: pilot evidence from Rwanda. *Journal of Development Economics*, 110, 262-275. doi: 10.1016/j.jdeveco.2013.12.009

Austin, P. C. & Stuart, E. A. (2015). Moving towards best practice when using inverse probability of treatment weighting (IPTW) using the propensity score to estimate causal treatment effects in observational studies. *Statistics in Medicine*, 34(28), 3661-3679. doi: 10.1002/sim.6607

Bandeira P., & Sumpsi J.M. (2009). Access to land, rural development and public action: The when and the how. *Development Policy Review*, 27(1), 33-49. doi: 10.1111/j.1467-7679.2009.00434.x

Bell, K. C. (2006). *World Bank support for land administration and management: responding to the challenges of the millennium development goals*. In: XXIII FIG Congress, Munich, Germany, 8–13 October 2006. Retrieved from https://www.fig.net/resources/monthly_articles/2006/november_2006/bell_november_2006l.pdf

Besley, T. (1995). Property rights and investment incentives: Theory and evidence from Ghana. *Journal of Political Economy*, 103(5), 903-937. doi: 10.1086/262008

Besley T., & Ghatak M. (2010). Property rights and economic development. *Handbook of Development Economics*, *5*(C), 4525-4595. doi: 10.1016/B978-0-444-52944-2.00006-9

Boucher, S. (2010). A proposed impact evaluation design for Ecuador's SigTierras program. Retrieved from https://idbg.sharepoint.com/:w:/r/teams/EZ-EC-LON/EC-L1071/_layouts/15/Doc.aspx?sourcedoc=%7BE306DBF9-CA85-4357-AF41-04905C68FE3E%7D&file=EC-L1071%20POD%20Link%20Requerido%20Esquema%20de%20Seguimiento%20y%20Evaluacion%20_%20INFCONS%20%5B35339830%5D.docx&action=default&mobileredirect=true

Boucher, S. R., Barham, B. L., & Carter, M. R. (2005). The impact of "market-friendly" reforms on credit and land markets in Honduras and Nicaragua. *World Development*, 33(1), 107-128. doi: 10.1016/j.worlddev.2004.09.004

Brasselle A.S., F. Gaspart, & Platteau, J.P. (2002). Land tenure security and investment incentives: Puzzling evidence from Burkina Faso. *Journal of Development Economics*, 67(2), 373-418. doi: 10.1016/S0304-3878(01)00190-0

Corral, L. R. & Olea, C. E. M. (2019). What drives take-up in land regularization: Ecuador's rural land regularization and administration program, Sigtierras. *Journal of Economics, Race, and Policy*, 3, 60-75. doi: 10.1007/s41996-019-00041-1

Deininger, K. (2003). *Land policies for growth and poverty reduction*. World Bank; Oxford University Press. Retrieved from https://hdl.handle.net/10986/15125

Deininger, K., Ali, D. A., Holden, S., & Zevenbergen, J. (2008). Rural land certification in Ethiopia: process, initial impact, and implications for other African countries. *World Development*, 36(10), 1786-1812. doi: 10.1016/j.worlddev.2007.09.012

Deininger, K., & Chamorro, J. S. (2004). Investment and equity effects of land regularisation: the case of Nicaragua. *Agricultural Economics*, 30(2), 101-116. doi: 10.1016/j.agecon.2002.09.004

Deininger, K., & Feder, G. (2009). Land Registration, Governance, and Development: Evidence and Implications for Policy. *The World Bank Research Observer*, 24(2), 233-266. doi:10.1093/wbro/lkp007

Deininger, K., & Jin, S. (2006). Tenure security and land-related investment: Evidence from Ethiopia. *European Economic Review*, 50(5), 1245-1277. doi: 10.1016/j.euroecorev.2005.02.001

Doss, C., & Meinzen-Dick, R. (2020). Land tenure security for women: A conceptual framework. *Land Use Policy*, 99, 105080. doi: 10.1016/j.landusepol.2020.105080

Feder, G., & Feeny, D. (1991). Land tenure and property rights: theory and implications for development policy? *World Bank Economic Review: Washington, DC*. doi: 10.1093/wber/5.1.135

Fort, R. (2007). The homogenization effect of land titling on investment incentives: evidence from Peru. *NJAS – Wageningen Journal of Life Science,* 5(4), 325-343. doi:10.1016/S1573-5214(08)80024-3

Funk, M. J., Westreich, D., Wiesen, C., Stürmer, T., Brookhart, M. A., & Davidian, M. (2011). Doubly robust estimation of causal effects. *American Journal of Epidemiology*, 173(7), 761-767. doi: 10.1093/aje/kwq439

Galiani, S. & Schargrodsky, E. (2010). Property rights for the poor: Effects of land titling. *Journal of Public Economics*, 94(9-10), 700-729. doi: 10.1016/j.jpubeco.2010.06.002

Galiani, S. & Schargrodsky, E. (2016). The deregularization of land titles. *Man and the Economy*, 3(2), 169-188. doi: 10.3386/w22482

Garrido, M. M., Kelley, A. S., Paris, J., Roza, K., Meier, D. E., Morrison, R. S., & Aldridge, M. D. (2014). Methods for constructing and assessing propensity scores. *Health Services Research*, 49(5), 1701-1720. doi: 10.1111/1475-6773.12182

Ghebru, H., & Holden, S. (2013). "Links between tenure security and food security: Evidence from Ethiopia". Centre for Land Tenure Studies Working Paper, No. 02/13, Norwegian University of Life Sciences (NMBU), Centre for Land Tenure Studies. Ås, Norway: NMBU. Retrieved from http://hdl.handle.net/10419/242709

Gignoux, J., Macours, K., & Wren-Lewis, L. (2013). Evaluating the impact of land administration programs on agricultural productivity and rural development. *Inter-American Development Bank (IDB): Washington, DC, USA*. doi: 10.18235/0009086

Goldstein, M., Houngbedji, K., Kondylis, F., O'Sullivan, M., & Selod, H. (2018). Formalization without certification? experimental evidence on property rights and investment. *Journal of Development Economics*, 132, 57-74. doi: 10.1016/j.jdeveco.2017.12.008

Goldstein M., & Udry C. (2008). The profits of power: Land rights and agricultural investment in Ghana. *Journal of Political Economy*, 116(6), 981-1022. doi: 10.1086/595561

Higgins, D., Balint, T., Liversage, H., & Winters, P. (2018). Investigating the impacts of increased rural land tenure security: A systematic review of the evidence. *Journal of Rural Studies,* 61, 34-62. doi:10.1016/j.jrurstud.2018.05.001

Inter-American Development Bank (IDB, 2010). Loan Proposal for the Project "National System for rural land information and management and technology infrastructure. Retrieved from http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=EZSHARE-1648856495-88

Inter-American Development Bank (IDB, 2016). Project Profile for the Project "*Programa De Saneamiento De Tierras II". Washington, DC*: IDB. Retrieved from https://www.iadb.org/document.cfm?id=EZSHARE-1611783581-2

Imbens, G., Crump, R., Hotz, V. J., & Mitnik, O. (2009). Dealing with limited overlap in estimation of average treatment effects. *Biometrika*, 96(1), 187-199. doi: 10.1093/biomet/asn055

Imbens, G. W. & Rubin, D. B. (2015). *Causal Inference for Statistics, Social, and Biomedical Sciences: An Introduction*. New York: Cambridge University Press. doi: 10.1017/CBO9781139025751

Instituto Nacional de Estadística e Informática (INEI, 2012). *IV Censo Nacional Agropecuario 2012*. Retrieved from http://censos.inei.gob.pe/cenagro/tabulados

Lawry, S., Samii, C., Hall, R., Leopold, A., Hornby, D., & Mtero, F. (2017). The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review. *Journal of Development Effectiveness*, 9(1), 61-81. doi: 10.1080/19439342.2016.1160947

Lindner, S. & McConnell, K. J. (2019). Difference-in-differences and matching on outcomes: a tale of two unobservables. *Health Services and Outcomes Research Methodology*, 19(2), 127-144. doi: 10.1007/s10742-018-0189-0

Malik, A., & Schwab, R. M. (1991). Optimal investments to establish property rights in land. *Journal of Urban Economics*, 29(3), 295-309. doi: 10.1016/0094-1190(91)90003-P

Morgan, S. L. & Todd, J. J. (2008). A diagnostic routine for the detection of consequential heterogeneity of causal effects. *Sociological Methodology*, 38(1), 231-282. doi: 10.1111/j.1467-9531.2008.00204.x

Ngango, J., & Hong, S. (2021). Impacts of land tenure security on yield and technical efficiency of maize farmers in Rwanda. *Land Use Policy*, *107*, 105488. doi: 10.1016/j.landusepol.2021.105488

Quisumbing, A., & Kumar, N. (2014). *Land rights knowledge and conservation in rural Ethiopia: Mind the gender gap.* IFPRI Discussion Paper 1386. Washington, DC: International Food Policy Research Institute. Available at: http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/128480

Robins, J. M., Rotnitzky, A., & Zhao, L. P. (1995). Analysis of semiparametric regression models for repeated outcomes in the presence of missing data. *Journal of the American Statistical Association*, 90(429), 106-121. doi: 10.2307/2291134

Ryan, A. M., Burgess Jr, J. F., & Dimick, J. B. (2015). Why we should not be indifferent to specification choices for difference-in-differences. *Health Services Research*, 50(4), 1211-1235. doi: 10.1111/1475-6773.12270

Sanjak, J. (2012). *Land Titling and Credit Access: Understanding the Reality*. Property Rights and Resource Governance Briefing Paper #15. USAID Issue Brief October 2012. Retrieved from *https://www.land-links.org/wp-content/uploads/2016/09/Land-Titling-and-Credit-Access-Understanding-the-Reality.pdf*.

Schling, M., Pazos, N., Corral, L. & Inurritegui, M. (2023). *The effects of tenure security on women's empowerment and food security: Evidence from a land regularization program in Ecuador*. IDB Working Paper Series (No. IDB-WP-01558). Inter-American Development Bank (IDB): Washington, DC. doi: 10.18235/0005355

Suchá, L., Schlossarek, M., Dušková, L., Malan, N., & Šarapatka, B. (2020). Land tenure security and its implications for investments to urban agriculture in Soweto, South Africa. *Land Use Policy*, 97, 104739. doi:10.1016/j.landusepol.2020.104739

Torero, M. & Field, E. (2005). *Impact of land titles over rural households.* Office of Evaluation and Oversight (OVE) Working Papers 0705. Inter-American Development Bank: Washington, DC. Retrieved from https://www.researchgate.net/publication/5106170_Impact_of_Land_Titles_over_Rural_Households

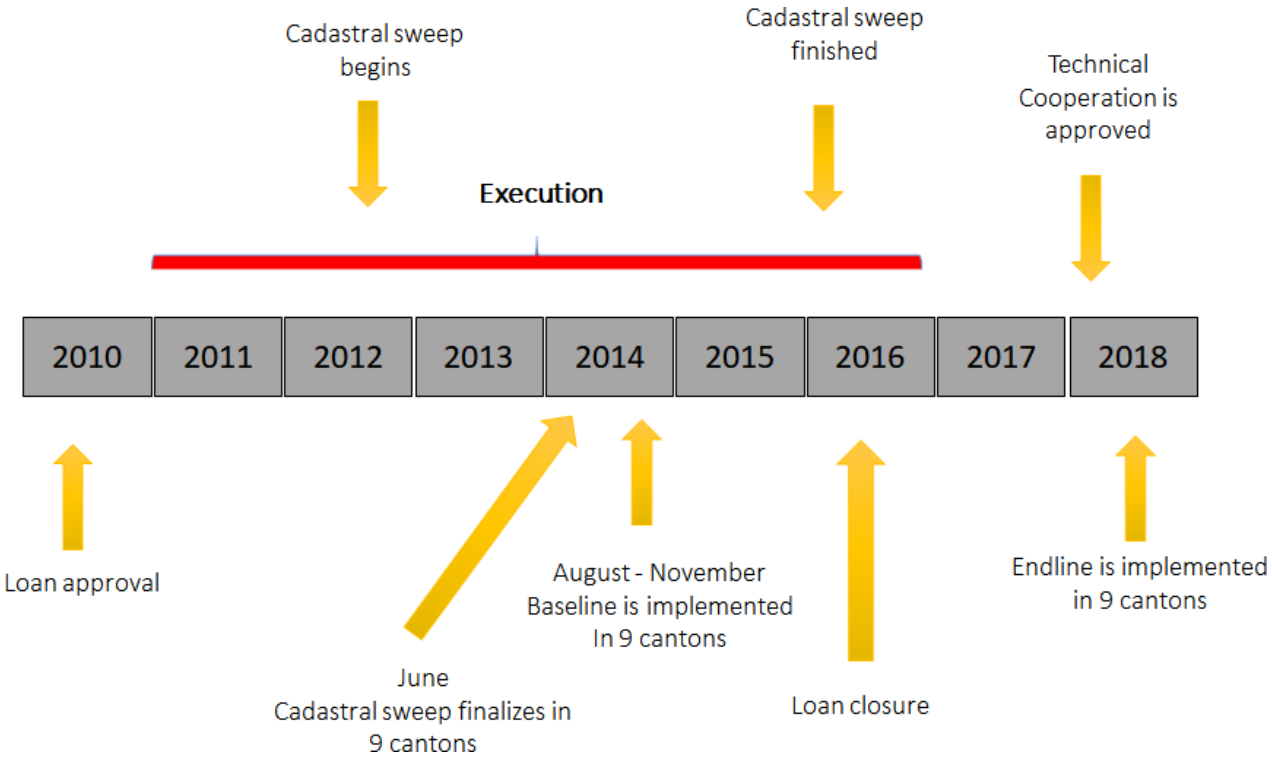
Ward, A., & Baldinelli, G. M. (2020). *Uneven ground: Land inequality at the heart of unequal societies*. International Land Coalition. Retrieved from https://www.landcoalition.org/en/uneven-ground/report-and-papers

World Bank. (2015). *Ending poverty and hunger by 2030: An agenda for the global food system*. Washington, D.C.: World Bank. Retrieved from http://hdl.handle.net/10986/21771

Zegarra, E., Escobal, J., & Aldana, U. (2008). Titling, credit constraints and rental markets in rural Peru: exploring channels and conditioned impacts. *IDB Technical Note, Inter-American Development Bank*. Retrieved from https://publications.iadb.org/publications/english/viewer/Titling-Credit-Constraints-and-Rental-Markets-in-Rural-Peru-Exploring-Channels-and-Conditioned-Impacts.pdf

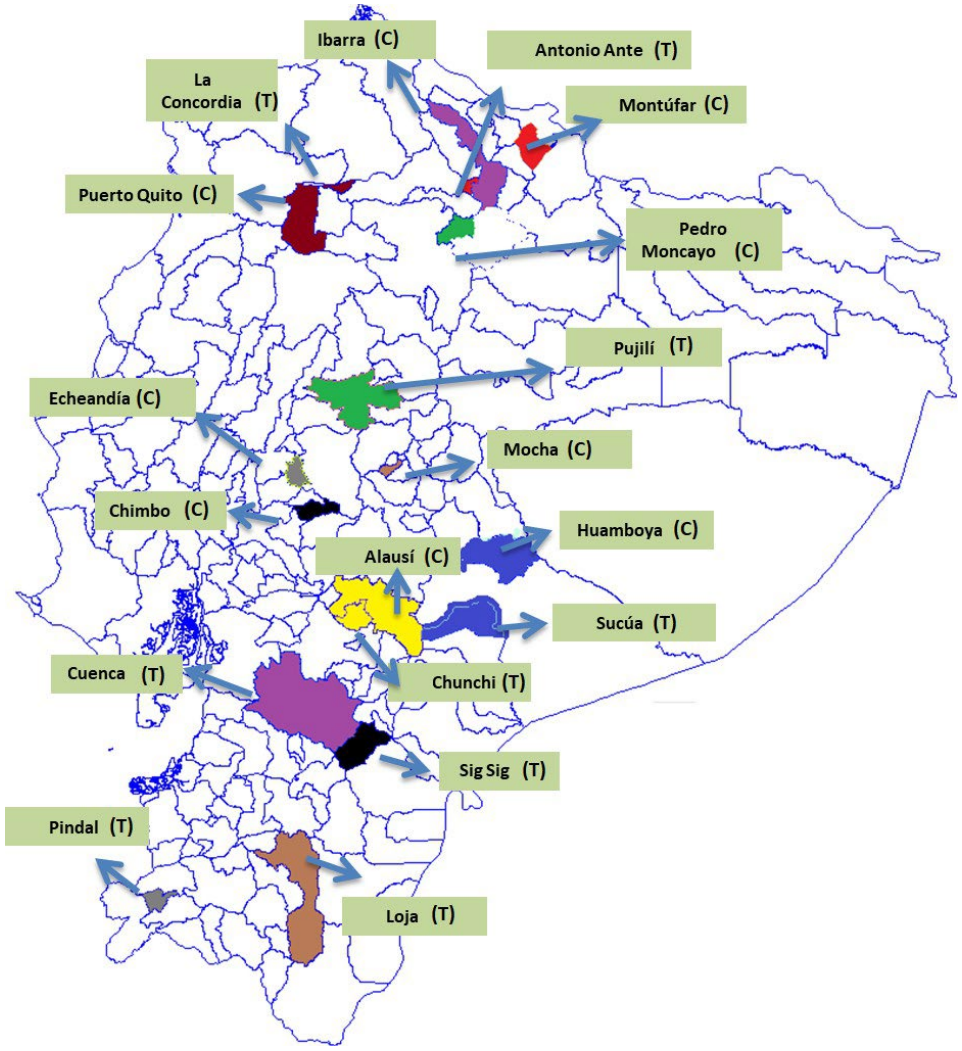
A Figures

Figure 1: Timeline of SigTierras



Notes: the Project Completion Report was prepared during 2018 but approved until 2019

Figure 2: Project map



Notes: the figure shows the treatment (T) and control (C) cantons selected for this study. Cantons with the same color were identified as "similar" through the propensity score matching exercise.

Figure 3: Distribution of treated and control households by canton and census tract

Intervention					Control				
Province	Canton	Census tract universe	Sample		Province	Canton	Census tract universe	Sample	
			Census tracts	Number of households				Census tracts	Number of households
Chimborazo	Sigsig	141	16	192	Chimborazo	Chimbo	42	16	192
Santo Domingo	La Concordia	29	11	132	Pichincha	Puerto Quito	52	11	132
Morona Santiago	Sucúa	34	10	132	Morona Santiago	Huamboya	33	10	132
Pichincha	Antonio Ante	29	9	132	Carchi	Montúfar	58	9	132
Azuay	Cuenca	683	20	240	Imbabura	Ibarra	127	20	240
Pichincha	Pedro Moncayo	68	11	132	Cotopaxi	Pujilí	245	11	132
Loja	Loja	176	11	132	Tungurahua	Mocha	27	11	132
Chimborazo	Chunchi	42	11	132	Chimborazo	Alausí	145	11	132
Loja	Pindal	22	11	132	Bolívar	Echeandía	25	11	132
Total		1.224	110	1,356	Total		754	110	1,356

B Tables

Table 1: Outcome Variables

	Outcome	Indicator	Can it be measured?
	Final Outcomes		
1	Total household income	Total income	Yes
2	Household expenditure	Total expenditure from a household	No data
3	Value of agricultural production	Value of production	Yes
4	Net agricultural income	None	No data
5	Value of household wealth	Not specified in the MEP	No data
	Intermediate Outcomes		
6	Farm yield	Not specified in the MEP	Yes
7	Farm expenditures per hectare	Expenditure per hectare in seeds, pesticide, fertilizer, labor	Yes
8	Land transactions	Rentals, sales, inheritance, mortgage	Few data
9	Access to credit (1)	Participation in formal and informal credit markets	Yes
10	Access to credit (2)	Household rationing status in formal and informal credit markets	No data
11	Land tenure security	Perception of different aspects of tenure security	Yes
12	Land conflicts	Frequency and intensity of land conflicts	Yes
13	Investment in fixed and farm assets	Farm investments, purchased seeds, pesticides, fertilizer and paid for labor	Yes
14	Participation in government programs	Participation in Bono de la Vivienda and Organic Certification	Partially

Notes: The list of outcomes follows the Monitoring and Evaluation Plan (MPE). The symbol (*) indicates that this outcome was included additionally based on the theory of change.

Table 2: Summary Statistics and Balance - Household level

	Control	Treated	(1) vs. (2)
	(1)	(2)	(3)
HH head is female	0.20	0.25	-0.06***
	(0.01)	(0.01)	(0.01)
HH head age (years)	50.69	53.19	-2.50***
	(0.32)	(0.33)	(0.46)
HH size	4.32	4.29	0.03
	(0.04)	(0.05)	(0.06)
HH head has primary	0.55	0.54	0.00
	(0.01)	(0.01)	(0.01)
HH head ethnic	0.14	0.13	0.02**
	(0.01)	(0.01)	(0.01)
N of dependents	3.41	3.42	0.00
	(0.04)	(0.04)	(0.06)
N adults in agriculture	1.73	1.59	0.15***
	(0.03)	(0.03)	(0.04)
Members in productive age	2.24	2.27	-0.03
	(0.03)	(0.03)	(0.04)
Receives *Bono*	0.58	0.62	-0.04***
	(0.01)	(0.01)	(0.01)
N plots owned	2.45	2.44	0.01
	(0.03)	(0.04)	(0.05)
N plots with irrigation	0.34	0.24	0.10***
	(0.02)	(0.01)	(0.02)
Total area (Ha)	8.73	26.53	-17.80
	(3.01)	(14.24)	(14.69)
Avg plot tenure (years)	14.64	18.41	-3.77***
	(0.25)	(0.28)	(0.37)
Owned equipment	0.72	0.76	-0.03***
	(0.01)	(0.01)	(0.01)
N animals	5.64	7.56	-1.92**
	(0.65)	(0.62)	(0.89)
N	2,573	2,627	5,200
Joint F-Stat	14.10		
P-value	0.000		

Notes: * $p < .10$,** $p < .05$, *** $p < .01$.

Table 3: Attrition Checks

	Endline Survey Result			
	Completed	Not found	Moved	Rejected
	(1)	(2)	(3)	(4)
Treated	0.021**	-0.001	-0.043***	0.026***
	(0.010)	(0.005)	(0.006)	(0.006)
Mean Control	0.910	0.016	0.045	0.016
Observations	2,707	2,707	2,707	2,707

Notes: * $p < .10$, ** $p < .05$, *** $p < .01$.

C Propensity Score Matching

Figure 4. Propensity Score

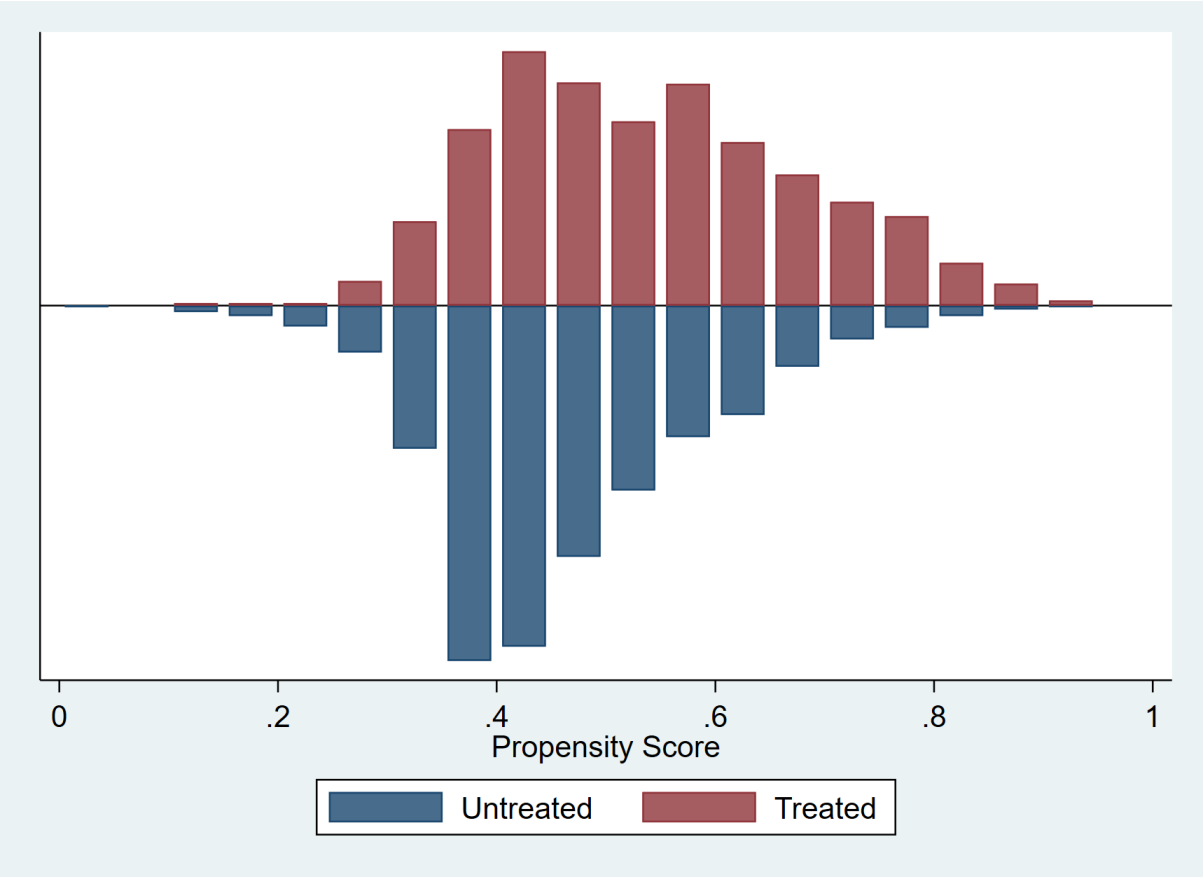


Figure 5. Distribution of treated and control units before and after matching

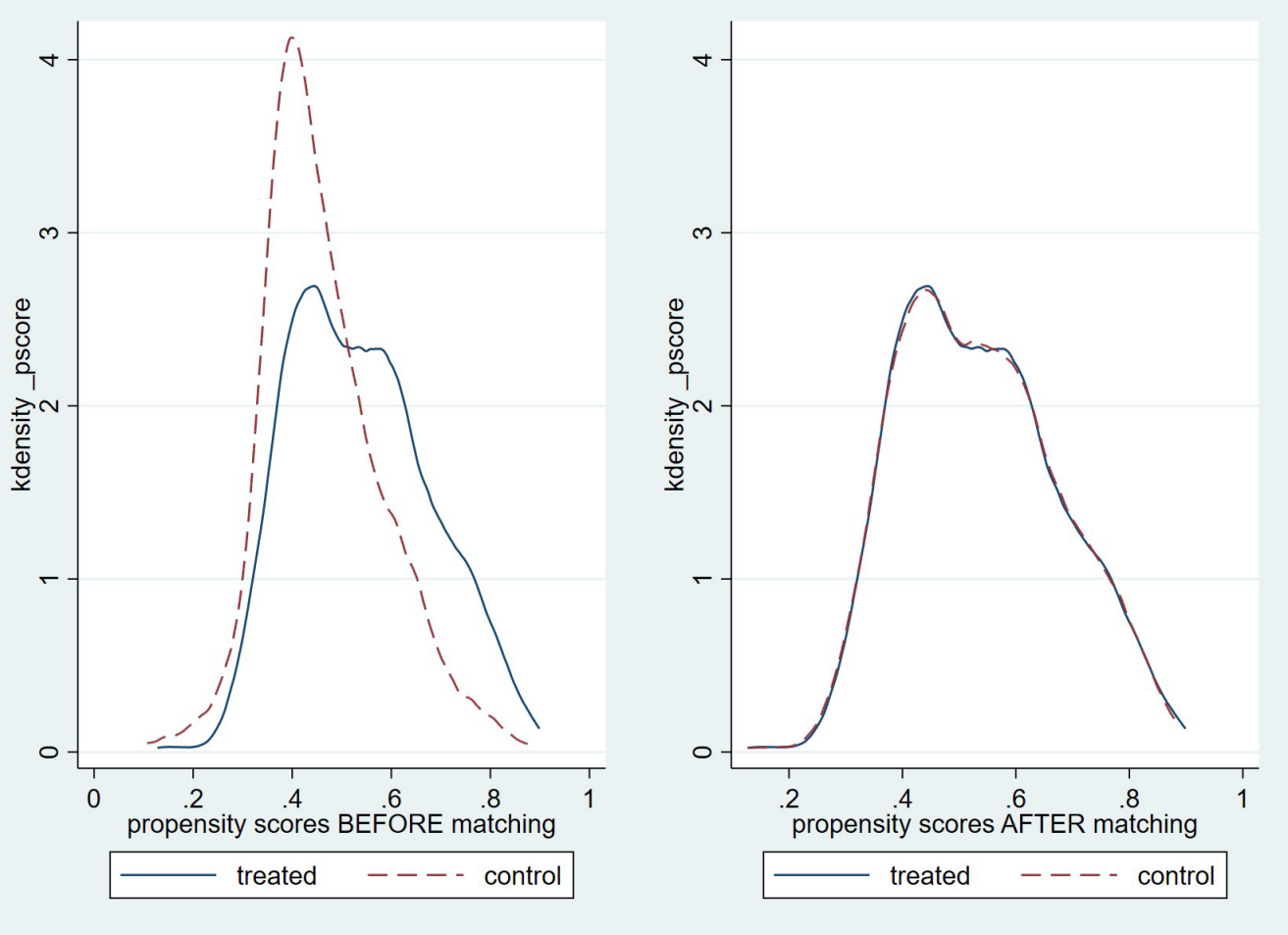


Table 4: Balance checks adjusted by PSM

	Control	Treated	(1) vs. (2)
	(1)	(2)	(3)
HH head is female	0.23	0.22	0.01
	(0.01)	(0.01)	(0.01)
HH head age (years)	52.01	51.83	0.18
	(0.33)	(0.35)	(0.48)
HH size	4.26	4.35	-0.09
	(0.05)	(0.05)	(0.07)
HH head has primary	0.56	0.54	0.02
	(0.01)	(0.01)	(0.01)
HH head ethnic	0.14	0.13	0.00
	(0.01)	(0.01)	(0.01)
N of dependents	3.37	3.46	-0.09
	(0.04)	(0.05)	(0.06)
N adults in agriculture	1.64	1.70	-0.06
	(0.03)	(0.03)	(0.04)
Members in productive age	2.25	2.26	-0.01
	(0.03)	(0.03)	(0.04)
Receives *Bono*	0.61	0.59	0.02
	(0.01)	(0.01)	(0.01)
N plots owned	2.44	2.42	0.02
	(0.04)	(0.03)	(0.05)
N plots with irrigation	0.28	0.27	0.01
	(0.02)	(0.01)	(0.02)
Total area (Ha)	22.30	7.62	14.68
	(11.79)	(2.31)	(12.02)
Avg plot tenure (years)	16.78	16.43	0.35
	(0.26)	(0.33)	(0.42)
Owned equipment	0.75	0.74	0.01
	(0.01)	(0.01)	(0.01)
N animals	5.07	5.22	-0.15
	(0.29)	(0.48)	(0.57)
N	2,544	2,583	5,127
Joint F-Stat			1.68
P-value			0.048

Notes: * $p < .10$,** $p < .05$, *** $p < .01$.

Table 5: Land Tenure Security and Land Conflicts

	Perception of number of plots			Intensity of conflicts in	
	Owned	With Title	Without Title	Last year	Last 5 years
	(1)	(2)	(3)	(4)	(5)
Treated	0.036	0.008	-0.051	-0.010	-0.022
	(0.079)	(0.084)	(0.071)	(0.008)	(0.013)
Post	0.421***	0.300***	-0.304***	0.017	0.010
	(0.035)	(0.035)	(0.040)	(0.015)	(0.016)
Treated*Post	-0.032	-0.201***	0.199***	-0.009	-0.003
	(0.060)	(0.039)	(0.044)	(0.016)	(0.019)
Mean Control Baseline	2.220	0.890	1.174	0.077	0.108
Observations	4,914	4,914	4,914	4,914	4,914

Notes: The standard errors in parenthesis account for potential correlation within census tracts. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 6: Investment in farm inputs

	Paid for input			
	Seeds	Pesticide	Fertilizer	Hired Labor
	(1)	(2)	(3)	(4)
Treated	0.152***	-0.094***	-0.012	0.004
	(0.041)	(0.033)	(0.031)	(0.032)
Post	-0.031**	-0.174***	-0.105***	0.147***
	(0.015)	(0.020)	(0.023)	(0.024)
Treated*Post	0.026	0.055	-0.016	-0.090***
	(0.029)	(0.034)	(0.035)	(0.025)
Mean Control Baseline	0.230	0.436	0.346	0.313
Observations	4,914	4,914	4,914	4,914

Notes: The dependent variables from these models are dummies. The standard errors in parenthesis account for potential correlation within census tracts. * $p < .10$, ** $p < .05$, *** $p < .01$.

Table 7: Household Income

	Total Income	Ag Wages	Crop	Livestock	SE	Transfers
	(1)	(2)	(3)	(4)	(5)	(6)
Treated	-116.110	-262.161***	14.931	91.652	-6.124	45.591
	(150.121)	(83.858)	(101.456)	(56.944)	(39.390)	(39.328)
Post	1840.383***	1962.116***	-19.975	-23.780	-18.598	-59.378
	(256.124)	(220.747)	(54.694)	(49.623)	(35.105)	(43.272)
Treated*Post	755.772**	732.486***	96.701	-50.855	15.078	-37.637
	(308.774)	(256.979)	(96.761)	(54.966)	(57.718)	(64.739)
Mean Control Baseline	1,556.850	563.684	472.862	49.182	44.865	426.257
Observations	4,050	4,050	4,050	4,050	4,050	4,050

Notes: The standard errors in parenthesis account for potential correlation within census tracts. * $p < .10$, ** $p < .05$, *** $p < .01$. All values are expressed in USD. Households with "Total income" above 95th percentile or below the 5th percentile at either baseline or endline are dropped. SE = Self Employment.

Appendix A. Methodology to select the covariates for the Propensity Score Matching model

We first identify a set of covariates to include linearly in the log odds radio of the propensity score. These variables are selected upon their theoretical association with the treatment status and not so much upon their statistical relationship with the treatment and outcome of interest. Based on section 4.1.3, we use variables such as the average number of years that a household has been settled in their parcels, whether a household receives the subsidy scheme of *Bono de Desarrollo Humano*, the number of members in the household in productive age, and the total area of the parcels that belong to the household. These are relevant characteristics from a household in as much as they were key questions on the ”filter” questionnaire (*Encuesta filtro*) that were applied during the selection of the control group.

Now that we have defined 6 variables for the baseline model, the next step is to choose a second set of variables. From the remaining 102 variables, we add one variable at a time to the logistic regression, each time checking whether we wish to add another covariate or not, and if so, which one. To do so, for each specification we calculate the likelihood ratio statistic for the test of the null hypothesis that the coefficient on the additional covariates is equal to zero. Thus, in this manner, in our first iteration we run 102 logistic models. For each model, we calculate the likelihood ratio statistic, taking as reference the baseline model with 6 variables. Thus, in this manner, we pick the variable that leads to the higher improvement in the likelihood function. In the second iteration, we run 101 logistic models. Again, we calculate the likelihood ratio statistic, but now our baseline model will have 8 variables. We keep doing this until the Maximum Likelihood Ratio Statistic obtained is lower than 1. In our final step, we choose a third set of variables, but in this case we use second order terms and all the possible interactions. We apply the same procedure to select which variables to include in the propensity score model. In this case, however, we stop adding covariates when the maximum Likelihood Ratio Statistics obtained is below the threshold of 2.71.