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The Effects of Tenure Security on Women's Empowerment and Food Security: Evidence from a Land Regularization Program in Ecuador

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Abstract

This paper evaluates the impact of a rural land administration program in Ecuador on female empowerment and household food security. Using a double robust estimation that combines the difference-in-difference approach with inverse probability weighting, we explore whether receiving a georeferenced cadastral map of one's parcel provides women with increased bargaining power, empowering them to participate more actively in productive and consumption decision-making that leads to improved diversification of the production portfolio and the household's food security. Although we find no significant effects on aggregate levels of empowerment, results show that female beneficiaries became more empowered with regards to access to resources, particularly in terms of applying for and receiving credit. Program participation also significantly affected women's time use, as beneficiary women spent more hours working in non-agricultural activities, investing in their own businesses, and generating off-farm wages. Households who received jointly titled cadastral maps also increased their food security and shifted their production portfolios towards crops and livestock products of both higher market and nutritional value. These results suggest that increasing informal tenure security through cadastral mapping may spur female empowerment, which enables women to increase their bargaining power within the household in order to improve their own and the family's overall welfare.

JEL Codes: H43, J16, O12, O13, Q15, Q18

Key Words: female empowerment, food security, land property rights, Ecuador, Latin America

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1 Introduction

Limited security over land tenure is one of the most important constraints faced by women in agriculture (FAO, 2011; Quisumbing et al., 2014), and both theoretical and empirical work in economics have provided evidence that it impedes equal opportunities within the household and the community (Agarwal, 1997; Udry, 1996; Bose & Das, 2017). Conceptually, intra-household bargaining models suggest that secure female land tenure can lead to increased levels of female empowerment (McElroy & Horney, 1981; Manser & Brown, 1980). Because women tend to favor nutrition and general well-being of the family in their choices, female influence in production decisions for home consumption should lead to a more diversified crop production and better nutrition within the household (Hallman, 2003; Duflo & Udry, 2004). Evidence has consistently shown that a more active participation of women in the intra-household decision making process about agricultural production and the use of income enhances household welfare (Skoufias, 2005; Allendorf, 2007; Sraboni et al., 2014). In this context, enhanced tenure security through cadastral mapping and land regularization provides women with a formal recognition of their ownership rights, and protection against dispossession through abandonment, separation, or divorce, which further strengthens their bargaining power within the household (Namubiru-Mwaura, 2014).

Although the existing empirical literature supports the hypothesis that female tenure security improves women's empowerment, and thereby increases household welfare as measured by production diversification and food security, rigorous evidence is still limited, particularly for the Latin American context. This may in part be ascribed to the fact that the definition of tenure security is often imprecise and varies significantly across studies. Conceptually, tenure security depends on a composition of economic and legal rights that will vary depending on the local context. While holding legal title to a parcel is clearly related to tenure security, the binary differentiation between farmers who hold a title and those who do not 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, 2008a; Doss & Meinzen-Dick, 2020). Since women have historically not been granted land access and ownership in most societies, the provision of "lesser", informal rights to their land may be sufficient to provide security against eviction or land loss if these rights are accepted within local norms. Additionally, studies have identified that a significant gender gap exists with regards to knowledge about land rights, given that men as the traditional heads of household tend to be more actively involved in the land's formalization process. Receiving joint title for a plot may then not be sufficient to increase women's perceived tenure security if they are not aware of their rights and responsibilities related to land ownership (Quisumbing & Kumar,2014; Deininger et al., 2008b). Given these nuances, in order to estimate the impact of land regularization efforts on women's empowerment, it is therefore crucial to understand exactly how a land administration system proposes to improve tenure security for women and how this is accomplished at the local level.

Ecuador is only one of many Latin American countries that has been making strides towards more gender-inclusive land administration regimes in recent decades. While the country legally recognized the equality of men and women as early as the 1980s, it wasn't until 2010 that an effort was moved forward to implement a more equitable land tenure regime nationwide. In 2002, the government implemented the Program for the Administration and Regularization of Rural Lands (PRAT) with support from the Inter-American Development Bank (IDB) in order to design and test a cost-effective methodology for the physical and legal regularization of property rights.

Following this successful pilot experience, the National System for Rural Land Information and Management and Technology Infrastructure Program, or SigTierras Program for short, was launched in 2012 and represented the first phase of the so-called Massive Land Legalization Project, after an initial pilot project that served to prove the design concept to be implemented and designed the technologies applied to the SigTierras Program. It received financial and technical support from IDB and aimed to regularize 170,000 parcels nationwide by 2016 (IDB, 2011). Using a cadaster sweep methodology, the program proposed first creating cadastral maps of 50 participating cantons[1] by using ortho-photography and parcel-level surveys, then providing technical and financial assistance to landowners in order to regularize their parcels, and in parallel supporting local canton governments in the adoption of computerized data-management systems to improve the efficiency and management of property registries.

Even though the Program did not reach its regularization target and had only issued official titles for 23% of all beneficiaries by 2016, SigTierras did complete cadastral mapping for more than 200,000 square kilometers of land area (Corral & Montiel, 2022). Crucially, the cadaster mapping and surveys resulted in the creation of over 160,000 individual georeferenced parcel maps, which were presented to community members in carefully organized and publicized meetings in each beneficiary community. This ensured that results were socialized at the local level, thereby increasing local knowledge, recognition and acceptance of established parcel boundaries. Each parcel owner was issued a printed parcel map that included physical parcel boundaries, information about physical characteristics, property rights, and land tenure situation, as well as the names of all parcel owners. Furthermore, in order to ensure the inclusion of women in the regularization process, any parcels occupied by a couple living in marriage or common-law union was issued joint ownership, both in regularization documents as well as the cadastral map. The program further required that a third of all program beneficiaries be female (Deere, 2018a). Following the evidence established by existing literature, women would further have benefited from the public dissemination of mapping results, both in terms of gaining local recognition of their land rights, as well as being educated about their rights and responsibilities in this context.

The policy-relevant question that we pose is therefore whether increases in informal tenure security among women within local customary tenure systems achieved through cadastral mapping can improve their levels of empowerment and bargaining power within the household, and whether this results in higher levels of production diversification and food security that benefit household welfare. To answer this question, we propose a doubly robust empirical strategy that relies on extensive panel survey data collected before[2] and after the implementation of the SigTierras Program for a sample of beneficiary households and a carefully selected control group. We focus on the sample of approximately 1,450 farmer households where both the household head and his or her partner were present at both baseline and follow-up, and apply the Inverse Probability Weighting (IPW) approach for empowerment-related indicators which were only available at follow-up, as well as a Difference-in-Difference with IPW methodology for all other outcome indicators in order to estimate the causal impact of SigTierras on empowerment, production diversification and food security.

[1] According to the administrative divisions of Peru, cantons represent a second-tier division below provinces and are approximately equivalent to municipalities or districts.

[2] Specifically, the baseline survey was conducted once information on tenure security had been collected to ensure that surveyed households faced insecurity and thus could benefit from the program.

The remainder of the paper is organized as follows: Section 2 provides a conceptual framework for the analysis based on existing empirical evidence. Section 3 describes the design of the SigTierras program, and the mechanisms through which it is likely to have affected female empowerment. Section 4 presents the data used, and discusses how measures of female empowerment, food security, and production diversification are constructed. Section 5 presents the identification strategy of the evaluation and describes the empirical methodology. Results of the analysis are presented and analyzed in Section 6, while Section 7 contains concluding notes and implications for future research.

2 Conceptual Framework

Smallholder farmers in developing countries across the globe face numerous hurdles to increase their agricultural productivity and escape the cycle of poverty and food insecurity. One barrier that has consistently been identified as one of the most crucial is land tenure insecurity (Gignoux et al., 2013; Lawry et al., 2017). It is thought to impede agricultural investment and productivity, and to negatively affect household welfare and food security (Quisumbing & Kumar, 2014; Ali, et. al., 2014). In Latin America, lack of formal tenure security continues to be a widespread issue, particularly in rural areas. In Peru, 45% of farmers lacked title in 2012. In Bolivia, 48% of titling had yet to be completed amongst farmers in 2014. And 60% of Ecuadorian farmers did not have property titles by 2008 (IDB, 2019; Corral & Montiel, 2022).

Tenure insecurity is particularly pronounced among female farmers, whose contribution to agricultural production is vital. Women account for almost half of the agricultural labor force in developing countries; and around 43% in Latin America, as well as 51% of the region's food production (IICA, IDB & Microsoft, 2020). Nevertheless, they still own significantly less and lower value land than their male counterparts, as women continue to be considered unequal to men in many societal and cultural contexts (Deere & Doss, 2006; Deere et al., 2013). Nationally representative household surveys in Latin America[3] have revealed that women only own between 14 and 32% of agricultural land (Deere et al., 2012). This gender gap in land access has important implications for household welfare: conceptually, intra-household bargaining models suggest that secure female land tenure can lead to increased levels of female empowerment (McElroy & Horney, 1981; Manser & Brown, 1980). Because women tend to favor nutrition and general well-being of the family in their choices, female influence in the household's production decisions for home consumption is presumed to lead to a more diversified crop production and better nutrition outcomes for the family (Hallman, 2003; Duflo & Udry, 2004).

Indeed, evidence has consistently shown that a more active participation of women in the intra-household decision-making process about agricultural production and the use of income enhances household welfare. A recent systematic literature review conducted by Aziz and colleagues (2022) reveals a reliably positive link between empowering women and improved food and nutrition security. For instance, a study by Rahman and Islam (2014) on the effects of a National Food and Nutrition Policy implemented in Bangladesh indicates that empowering women resulted in the production of various vegetables and fruits at homesteads that reduced malnutrition. Also in the case of Bangladesh, Sraboni et al. (2014) apply an instrumental variable framework and estimate a positive relationship between women's empowerment and household

[3] The countries sampled included: Honduras (2004), Nicaragua (2005), Paraguay (2000), Haiti (2001) and Mexico (2002).

food security, as measured in terms of calorie availability and household dietary diversity. Meanwhile, De Pinto et al. (2020) explore the association between empowerment and diversification of agricultural production and find that certain aspects of women's empowerment, such as a woman's participation in production decisions, result in increased crop diversification and a transition towards vegetables and fruits.

Given the existing causal relationship between women's empowerment and improved household welfare, governments and policy makers around the world have increased their efforts to address gender inclusion in land tenure regimes. While land administration legislation in Latin American countries historically assigned land rights and title to the male head of household, thereby effectively excluding women from formal access to land, legislative reforms in countries such as Colombia, Costa Rica, the Dominican Republic, Guatemala, and Nicaragua initiated efforts to redistribute land rights more equally and inclusively as early as the 1990s (Corral & Montiel, 2019). This was usually accomplished by changing statutory law so that tenancy would be assigned jointly to the household head and their partner, as well as including female heads of household in titling efforts (Doss & Meinzen-Dick, 2020; Deere, 2018a). As a result, women were increasingly included in titling documents: In Peru, 57% of all titled rural properties between 2002 and 2006 (approximately half a million) were granted jointly (Glavin et al., 2013). In Bolivia, more than 86% of the 1.1 million rural titles issues between 2011 and 2014 were joint (Deere, 2018b).

Empirical studies, though still limited, suggest that this effort has indeed contributed to increasing female tenure security and, by extension, their empowerment and bargaining power within the household. Meinzen-Dick and colleagues (2019) carried out a systematic review of the existing studies on women's land rights, and report positive yet sparse evidence of the impact of more secure female land tenure on measures of empowerment, participation in household decision making, as well as personal and household welfare: For instance, studies included in their review detect positive effects of women having formal tenure on their participation in household decision making (Santos et al., 2014; Wiig, 2013; Mishra & Sam, 2016), and that their more active involvement in household decisions on consumption and production in turn result in improved nutrition and health outcomes of the family (Ghebru & Holden, 2013; Allendorf, 2007; Kumar & Quisumbing, 2015). Furthermore, studies suggest that increased female tenure security reduces incidences of domestic conflict and violence between the woman and her partner (Grabe, 2010; Grabe et al., 2015; Panda & Agarwal, 2005). On the productive side, the positive effects of strengthening women's tenure security range from enhanced resilience to shocks by facilitating credit for consumption smoothing (Asfaw & Maggio, 2018), increased adoption of natural resource management practices that can be considered long-term land investments (Deininger et al., 2008a; Quisumbing & Kumar, 2014; Dillon & Voena, 2017), improved access to credit in some contexts (Persha et al., 2017; Santos et al; 2014), to increased participation of women in community and producer groups (Grabe, 2015).

Nevertheless, the cited evidence consistently highlights the fact that rigorous evidence on the impacts of female tenure security remains limited and mixed, particularly with regards to measures of empowerment and productive outcomes (Meinzen-Dick et al., 2019). Importantly, most studies on the subject matter have been conducted in Africa, so that the impacts found there may not have external validity for countries in other regions of the world, including Latin America (Meinzen-Dick et al., 2019). Recent literature reviews have pointed to the fact that a reason for mixed results may also be found in the imprecise definition of tenure security (Meinzen-Dick et al., 2019; Giovarelli et al., 2016; Doss et al., 2014). Conceptually, tenure security depends on a composition of economic and legal rights that will vary depending on the local context. While

holding full ownership of land in the form of a legal title is clearly related to tenure security, the binary differentiation between farmers who hold a title and those who do not may obscure the underlying nuances and dynamics of the land regime, which effectively determine whether a farmer feels secure in their tenure (Deininger et al, 2008a; Doss & Meinzen-Dick, 2020).

This is particularly relevant in contexts where tension exists between traditional norms and national statutory law: While it is an essential condition that women be granted equal and nationally recognized rights to land ownership, the enforceability of and adherence to these rights within pre-existing customary tenure systems will depend on the recognition and acceptance of the local community (Doss et al., 2014; Knight, 2010). For women in particular, it may be true that only legal title would confer land rights with regards to transferability, but the provision of "lesser" rights to their land may be sufficient to provide security against eviction or land loss if these rights are accepted within local norms. For instance, one evaluation of a land certification program in Ethiopia finds a positive and significant impact on longer-term land investments, including terracing and bunding, among both male and female-headed households (Deininger et al., 2008a). An important element of this program was that registration certificates were issued to households based on a low-cost, decentralized mechanism which operated at the community level and actively involved neighbors and community members in a public boundary demarcation process, which appears to have increased local awareness and acceptance of the assignment of land rights, thereby increasing tenure security. Even in the long term, the increased social awareness and acceptance of women's land rights conferred higher levels of perceived tenure security to female-headed households, which resulted in increased likelihood of renting out parcels, as well as investing in water and soil conservation on their plots (Alvarado et al., 2022). A randomized control trial of a program in Tanzania that formalized customary tenure rights to villagers found that women benefited from this approach, as they saw their access to land and perceived tenure security increase as a result of the intervention (Persha & Patterson-Stein, 2021).

Additionally, the exercisability of strengthened land rights, both within a statutory and a customary rights context, will depend crucially on the extent to which women have knowledge of their tenure rights. Limited impacts on levels of land investment and perceived tenure security may thus be due in part to women's relative lack of awareness about their rights, meaning whether they understand the rights' implications and how to benefit from them effectively. Several studies have identified a significant gender gap with regards to knowledge about land rights, as men as the typical heads of the household, tend to be more actively involved in local formalization processes and are more likely to attend dissemination activities that provide education about the process and content of formalization. Thus, receiving joint title for a plot may not automatically increase perceived tenure security if the woman was not educated about her rights and responsibilities. For instance, Quisumbing & Kumar (2014) identify a crucial disparity in men's and women's knowledge about land rights in the context of a land certification program in Ethiopia. Although no differences were found in terms of the land that was successfully registered for male- and female-headed households in the project area, the authors find that gender gaps in knowledge about tenure security, land transferability and gender rights significantly affected productive impacts as measured by the adoption of soil conservation practices, to the detriment of female-headed households. In the same vein, Deininger et al. (2008b) find that knowledge about Uganda's new legal provisions for land tenure considerably increased the household's likelihood to implement tree planting and soil conservation activities, where female-headed households once again were found to have lower awareness of the law's implications, on average.

In summary, more research is needed on the impacts of land right formalization efforts on female smallholder farmers and their families, particularly in the Latin American region. In order to appropriately estimate impacts of such interventions, one should carefully consider the design of the program, and how it may affect existing customary land regimes and women's awareness of their land rights. The following section therefore describes the object of this evaluation, the National Rural Land Information and Management System Program (Sigtierras Program) in Ecuador, in an effort to establish a clear theory of change within the context of existing empiric evidence.

3 Land Administration in Ecuador and SigTierras' Theory of Change

Ecuador has been making slow but steady advances towards gender-inclusive land administration since the 1980s. In 1981, Ecuador became only one of eight countries in Latin America that ratified the Convention on the Elimination of All Forms of Discrimination Against Women (CEDAW) (Deere, 2018a). In 1982, the country began legally recognizing property rights of persons in common-law partnerships ("uniones de hecho"), which increased land right access for women in particular (ibid). Despite these legal advances, land administration efforts remained focus on male land tenure until the early 2000s: Both the first and second Land Reform Laws of 1964 and 1973 respectively, strongly favored men, as land title was to be issued to the head of household, who was generally identified as the man of the family. Only in 2008 did the updated Constitution explicitly recognize the woman's rights to land tenure, and land administration efforts began being targeted towards and inclusive of women. The Organic Law on Rural Lands and Ancestral Territories (known as the Land Law), which was passed in 2016, finally cemented social, generational and gender equality in land access and tenure (ibid).

It is in this context that the Government of Ecuador launched the so-called Massive Land Legalization Project in 2012. The National System for Rural Land Information and Management and Technology Infrastructure, known as the SigTierras Program, represented the first phase of this effort and received financial support from the Inter-American Development Bank in the order of US$90 million.[4] In terms of overall program design, the SigTierras Program was based on the Rural Land Regularization and Administration Program (PRAT) launched in 2002 as a pilot project. This project tested and effectively implemented a so-called "sweep" methodology, which used comprehensive canton-level cadaster sweeps to regularize land tenure and register properties (Corral & Montiel, 2022). After PRAT's successful regularization of properties in eight cantons, SigTierras then aimed to expand this approach nationwide. With the objective of increasing productive efficiency and income of rural households as well as improving the overall performance of the rural economy, Sigtierras aimed to apply the sweep methodology to 50 cantons and consisted of three primary components[5]: (i) cadastral mapping, (ii) reorganization of and investment in cadasters and property registries, and (iii) regularization of land titles. For the first component, the program would use ortho-photography based cadaster sweeps to create geo-referenced digital maps of all parcels within a selected canton. With regards to the second component, SigTierras provided technical assistance to support the selected 50 cantons in the adoption of computerized data-management systems in order to improve the efficiency and management of property registries, property transactions and tax collection. Lastly, component 3 aimed to provide legal assistance to parcel owners whose titles had been identified to be

[4] While the loan itself was approved in 2010, program activities did not initiative until 2012.
[5] The following description is based on the SigTierras loan proposal document (IDB, 2010).

incomplete or who were encountering unresolved land conflicts. This included the establishment of a formal System for Legal Orientation (SIOL).[6]

For the purposes of this study, it is important to highlight how the SigTierras Program went about obtaining parcel information through the cadaster sweep methodology: To accomplish this, a 1:5,000-scale orthophoto map was first created for each participating canton, and survey teams then visited each parcel to obtain additional information from the parcel owner or occupant, including physical characteristics, property rights, and land tenure situation. Collected survey and geospatial information was linked and reviewed once uploaded to a regional database for quality control purposes before a georeferenced parcel map was created for each parcel within the canton. This map included the georeferenced boundaries of the parcel, as well as the date of issuance, the parcel information collected during the survey, as well as the names of all bordering neighbors.

These maps were not simply uploaded to a central administrative system, but rather publicly socialized at the community level. Specifically, once all cadaster sweep and mapping activities were finalized, a Public Exposition of Results Meeting (PEM) was held in each community. In order to ensure that these PEM counted with high participation rates, the event was announced in advanced via communication campaigns and held in locations central to community life, such as a school or other public place (Corral & Montiel, 2022). The PEM then aimed to present the results of parcel mapping to all community members, to verify the accuracy of the results as well as generate community awareness of established parcel boundaries. Once an individual parcel owner or occupant agreed to the results presented for their parcel(s), they were given the official map of their parcel with the included survey information. Those parcels whose tenure status remained informal due to lack of documentation or conflict were encouraged to seek legal advice through the SIOL system and were offered support for the final steps of titling.

In terms of explicitly ensuring that women were included in the titling process, the cadaster sweep, and subsequent activities of regularization recognized joint ownership if the occupants of a parcel were either married or lived in a common-law union, with both of their names being present on all relevant documentation pertaining to the parcel (Deere, 2018a). The PEM further aimed to ensure the participation of all community members, which offered an opportunity for women to learn about the conditions of their parcel and tenure. Lastly, legal assistance was available to women through SIOL to provide support in understanding and taking advantage of their property rights. The program also stipulated that a third of all program beneficiaries be women, to ensure the explicit targeting and inclusion of female landholders (ibid).

By the close of the program in 2016, 55 cantons had completed a cadaster according to the Ministry of Agriculture (MAG), and 59 cantons were integrated into the National Land Information System. The first stage of regularization efforts, meaning the cadaster sweep, required significant time, so that the time in which each canton began the cadaster sweep ranged from 2012 until 2016. Even though a total of 163,580 parcels had initiated the regularization process by the end of the project, which was close to its target of 170,000, only 39,267 parcels had regularized their legal ownership status, representing only 23% of the initial program goal (Corral & Montiel, 2022). Even though the Program fell short of its objective to formalize land tenure by a large margin, the successful initiation of the regularization process implied that more than 160,000 digital parcel

[6] It should be noted that the provision of these services depended on beneficiaries expressing interest in receiving support from the SIOL, and that take-up of these services was generally low (less than 15%) during program execution (Corral & Montiel, 2019).

maps were issued to parcel owners with community assent. It is worth mentioning that these parcel maps were sufficient documentation for owners to access other government programs, such as the public housing subsidy scheme “Bono de la Vivienda”, as well as accessing credit through savings and credit cooperatives (Deere, 2018a).

For the purpose of the theory of change of our evaluation, the specifics of SigTierras’ program design are relevant for three reasons: first, the socialization of cadaster results in PEM events ensured that the community was made aware of newly established parcel maps in order to guarantee that parcel boundaries and ownership status would receive the acceptance and recognition at the local level. As mentioned in the previous section, customary land regimes may supersede national statutory rights at the local level in certain contexts, and an informal recognition of individual parcel rights may therefore be more relevant for tenure security than the completion of the legal regularization process. This is particularly important in the context of joint ownership by spouses or common-law partners, whose joint status as parcel owners would also have been publicized during these meetings. It is therefore possible that female tenure security may have been enhanced by the issuance of parcel maps despite the fact that a large share of beneficiaries did not receive a formal title during the life of the program.[7]

Secondly, the organization of PEM served to enhance both awareness and knowledge of ownership status and land rights to community members. Given that these events were widely publicized, it is expected that female household members would have participated in these meetings, thereby increasing their knowledge of their rights and responsibilities. The literature highlighted in the previous section emphasized the importance of this knowledge amid female landowners in order for them to adapt their decision-making behavior as pertaining to their land tenure. Receiving an official parcel map that included tenure details such as ownership status and the names of both partners in the case of joint ownership would therefore likely increase the probability of women feeling empowered in their tenure status, particularly if this was done in front of the community. Lastly, the fact that the issuance of a parcel map enabled parcel owners to access additional resources through public programs and credit cooperatives further enhances the likelihood that even the informal strengthening of tenure may have a positive effect on female empowerment. As previously mentioned, the ability to generate individual income is strongly related to a woman’s possibility to enhance her bargaining power within the household and influence productive and consumption decisions in a way that may benefit overall household welfare.

In summary, we hypothesize, based on existing empirical evidence and the design elements of the SigTierras Program, the female program beneficiaries who received a georeferenced parcel map jointly with their partner would have increased their level of empowerment, in a way that leads to increased participation in household decision-making, thereby creating benefits at both the individual and household level, as measured by increased levels of agricultural production diversification and food security.

[7] It is worth highlighting, however, that the aspect of reduced legal land conflict would not be influenced by this mechanism, and may therefore represent a potential limitation to increases in bargaining power.

4 Data

4.1. Data Selection and Collection

In order to estimate the causal impact of land regularization on female empowerment and related indicators, this study takes advantage of the rigorous design of an impact evaluation that was implemented to assess the average impact of the SigTierras program on productive and socioeconomic outcomes. Following the description found in Corral & Montiel (2022), the evaluation design proposed an identification strategy that would select a treatment and comparable control group at the canton level. It should be noted that randomization at the canton or household level was not possible, given that participation in the program was based on the demand of municipality governments and consequently all households located within the borders of selected cantons would automatically participate in cadaster and title regularization activities.

The selection of participant cantons included several stages. First, cantons willing to participate in SigTierras had to complete an application process, agree to cover 20% of the program's cost and negotiate and sign an agreement with the SigTierras program if selected. Thus, in this part of the selection process, cantons self-selected into a list of potential beneficiaries that initially included 171 cantons. Cantons were then selected for participation from this based on a number of factors, including the budgetary limitations of SigTierras, the timely completion of the canton's application and negotiation process, and the availability of high-resolution digital aerial photographs, which was mainly impeded by continuous cloud cover in certain cases. Based on these factors, a total 47 cantons were selected to participate from the list of interested municipalities.

Of the 47 treated cantons, 9 cantons were selected for the impact evaluation's treatment group, with seven of the nine cantons being located in the highlands (*Sierra*) region of the country. To identify a valid counterfactual, the control group was then selected from 121 cantons that remained in the list of cantons which had completed the application process but had not been chosen to participate due to the factors named above. Using information on socioeconomic variables from the 2001 and 2010 National Census, a Propensity Score was constructed, and four control cantons were matched to each of the nine treated cantons (so each treated canton had 4 possible control cantons assigned). From these four control cantons per treated canton, the SigTierras' implementation team selected the one they thought was the most similar to each of the treatment cantons, resulting in a final selection of 9 control cantons.

Then, treated and control households were selected from treated and control cantons, respectively. Since the initial intention of the evaluation was to measure the impact of the program on households with perceived land tenure issues, the selection of treated households could not be completely random: Randomly selecting treated households from the treatment cantons would have ended up with a sample of household with land tenure issues and households with no land tenure issues. Thus, treated households were only chosen from the sample of households that, based on the cadaster sweep conducted for the program, reported having at least one parcel with land tenure issues. Cadastral information on location and number of eligible households was used to identify census tracts with 12 or more eligible households. In total, 110 census tracts were identified. In each tract 12 eligible households were randomly selected for the treatment group (and 12 eligible households as back-up), leading to a total of 1,356 selected treated households.

In order to select households from the nine cantons of the control group, information from the national censuses was once again used to estimate propensity scores for all available 754 census

tracts to select of three comparable control units per each treated census tract, based on the nearest-neighbor matching technique. In this case, one of the three matched census tracts would serve as the primary control unit, and the remaining two would serve as backup in case less than 12 households could be interviewed within the census tract. Again, only households reporting similar tenure issues as the treated households were selected for the control group. As a result, the selected control group contained 1,356 households, so that the evaluation sample of treatment and control consisted of a total of 2,712 households.

Our study uses data from the baseline and endline agricultural household surveys conducted among the sample of 2,712 households selected for the evaluation of the SigTierras program. The baseline survey was carried out in 2014 in the 18 selected cantons, while the follow-up survey was administered in 2018, two years after the closure of the program. The questionnaire applied to the selected agricultural households was based on the World Bank's Living Standard Measurement Study – Integrated Survey on Agriculture (LSMS – ISA), and gathered information regarding agricultural production and land characteristics, as well as information of the household and household member characteristics. More specifically, the survey consisted of the following modules: Sociodemographic characteristics, non-agricultural economic activity of household members, information on plots, agricultural production, migration and remittances, savings and loans, equipment, dwelling characteristics, household participation in social programs, and social and productive organizations. Two additional modules were introduced for the endline survey: A module on food security and a module on women's empowerment.

4.2. Sample Selection

Given the specific focus of our study, we will focus on a subsample of 1,450 observations of the total of 2,493 households present in both baseline and endline surveys. First, we limit our sample to the 2,438 households that responded the women's empowerment module, as this module includes the main variables of interest for our analysis. The women's empowerment module was always answered by a female member of the household that could be either the household head or their partner. Thus, excluding households that had not responded the women's empowerment module automatically excluded households where no female household head or partner was present. Second, we exclude 954 households where a significant change occurred in the dynamic between household head and their partner in the period between baseline and endline surveys. This includes cases where no partner or a different partner was present at either base- or endline, or where the head of household had changed between the two periods. This restriction is imposed in order to maintain the household composition constant during our study period, as any changes therein would likely affect the dynamic of intrahousehold bargaining and represent an endogenous factor influencing levels of women's empowerment. Finally, we exclude the 26 households (2% of cases) in our sample with a female household head, given that this has implications for the comparability of such households with the more common structure of a male household head and a female partner. It is likely that when a woman (single or with a partner) identifies herself as the household head, she is the main decision-maker in the household with the related implications for her levels of empowerment.

In the following, we present baseline summary statistics for the sociodemographic and productive characteristics of the households in our study sample. Mean values and standard deviations are reported for both control and treatment groups, along with the difference between the two and its statistical significance. When we refer to man and woman in these statistics, we always consider

the household head and their spouse. As we can see in Table 2a, there are no significant differences between the control and treatment groups in terms of their sociodemographic characteristics of the household. Households in our sample on average consist of 5 individuals, with an average of two children under the age of 17, and three members of working age (aged 17-65). However, we do observe important and significant differences in certain characteristics: The head of treated households is significantly more likely to be married, although it should be noted that the majority of couples in both control and treatment group are married, The female partner of the household head is slightly older in treated households, and has on average enjoyed one less year of education than her control counterpart. It is worth noting that men in both control and treatment group are on average older and more educated than their partner.

Table 1a also presents information on household wealth, as measured by the wealth index. This index is composed of four separate indices: A productive assets index, a non-productive asset index, a dwelling quality index, and an access to services index. These four indices were constructed as the weighted sum of their composing dummy variables[8], thus taking values between zero and one. The larger the value of the index, the more endowed the household is in terms of the relevant wealth category. The variables included in the creation of these indices were incorporated in the construction of the wealth index by using principal component analysis (PCA), a technique first introduced by Filmer and Pritchett (2001). The PCA creates a linear index based on the first principal component of the set variables, capturing the largest amount of information common to all variables (ibid). This index assigns adequate weights to individual characteristics included in the index, taking into account the contribution of different assets to overall wealth and the potential correlation between ownership of several assets (Moser & Felton, 2007).

As can be seen in the table, we do not observe any significant differences in terms of overall household wealth. However, when examining the four sub-indices, we observe that treated households are significantly wealthier in terms of their productive assets, as well as significantly less wealthy in terms of house quality. It is important to note that both control and treated households are, on average, very poor in terms of productive asset ownership. Lastly, we do not observe any significant differences in terms of the unproductive asset index and the access to services index.

Table 1a: Summary statistics, sociodemographic characteristics at baseline

Variable	Control	Treatment	Difference
Household characteristics			
Household size	4.87 (2.01)	4.99 (2.32)	0.122
Number of children aged 16 or less	1.97 (1.74)	1.91 (1.74)	-0.063
Number of members of working age (17-65 years)	2.55 (1.25)	2.65 (1.57)	0.107

[8] Assets such as irrigation pumps, harvesters, and tractors compose the productive asset index, while assets such as trucks, computers and refrigerators compose the unproductive index. The dwelling quality index is measured by the quality of the materials used in the household's main dwelling's roofs and floors. The access to services index was measured by the households' access to running water, sanitation, electricity, gas for cooking, showers, and phones.

Table 1a (*continued*)

Variable	Control	Treatment	Difference
Household members characteristics			
Household head is married	0.71	0.79	**0.083*** **
	(0.45)	(0.41)	
Household head speaks a native language	0.17	0.14	-0.021
	(0.37)	(0.35)	
Woman's age	43.48	46.24	**2.764*** **
	(14.87)	(15.19)	
Man's age	48.04	49.30	1.262
	(15.47)	(15.29)	
Woman's years of education	5.55	4.62	**-0.929*** **
	(3.37)	(3.25)	
Man's years of education	6.07	5.32	**-0.753*** **
	(3.34)	(3.19)	
Household wealth			
Productive asset index	0.00	0.01	**0.005*** **
	(0.02)	(0.03)	
Unproductive asset index	0.38	0.37	-0.001
	(0.23)	(0.23)	
House quality index	0.69	0.64	**-0.053*** **
	(0.35)	(0.38)	
Access to services index	0.52	0.52	-0.001
	(0.22)	(0.21)	
Wealth index	0.14	0.17	0.026
	(1.81)	(1.80)	
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

Table 1b presents the summary statistics for productive characteristics at baseline. We find no significant differences in the size of the land, or the number of plots owned. We also find no differences in the land fragmentation[9], access to irrigation or probability of experiencing a land conflict. However, we do find that treated households have owned the land for almost four years longer than those in the control group; and have a higher probability of having invested in at least one of their plots. We also find significant differences in agricultural expenditure, with treated households spending US$165 more annually. This difference seems to be explained by differences in the expenditure on crop inputs (pesticides, fertilizers and seeds), specifically on fertilizers and seeds. There are no significant differences in livestock expenditure or expenditure on hired labor.

[9] Land fragmentation is measured by the Simpson's diversity index, constructed as $LF = 1 - \sum_{i=1}^{N} a_i^2 / \left(\sum_{i=1}^{N} a_i\right)^2$, where a_i is the area of plot i and N the total number of plots (see Blarel et al. 1992; Tanet al., 2008; and others). The index ranges between zero and one and its value increases with the increasing distribution of land area over individual plots owned by household.

Table 1b: Summary statistics, productive characteristics at baseline

Variable	Control	Treatment	Difference
Land characteristics			
Total land area (in hectares)	4.30	3.99	-0.311
	(11.97)	(11.61)	
Number of plots owned	2.25	2.23	-0.019
	(1.47)	(1.62)	
Average age of household plots	13.41	16.93	**3.518*** **
	(11.00)	(12.67)	
Land fragmentation index	0.25	0.27	0.02
	(0.27)	(0.27)	
Household has access to irrigation	0.12	0.11	-0.006
	(0.29)	(0.29)	
Household reported a land conflict in the last year	0.12	0.10	-0.014
	(0.32)	(0.31)	
Household invested in at least one plot	0.04	0.11	**0.063*** **
	(0.21)	(0.31)	
Household has perennial trees	0.43	0.46	0.024
	(0.50)	(0.50)	
Household owns at least one titled plot	0.50	0.48	-0.015
	(0.50)	(0.50)	
Agricultural expenditures (in USD)			
Annual expenditure in all crop inputs	254.14	397.30	**143.16***
	(1,362.24)	(1,817.97)	
Annual expenditure in pesticides	111.73	126.91	15.18
	(1,128.16)	(798.59)	
Annual expenditure in fertilizer	97.40	163.86	**66.46***
	(435.98)	(960.04)	
Annual expenditure in seeds	45.02	106.53	**61.52*** **
	(343.16)	(432.40)	
Annual expenditure in livestock	455.41	477.21	21.80
	(835.39)	(1,001.98)	
Annual expenditure in hired labor	100.12	104.46	4.34
	(494.36)	(1,540.45)	
Total annual expenditure in inputs	709.55	874.51	**164.96***
	(1,659.39)	(2,101.30)	
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

In terms of annual household income, **Table 1c** shows that members of treated households have a significantly lower annual agricultural wage, measured as the wage received from agricultural work done outside of the household. We do not find any significant differences in wage from non-agricultural activities or self-employment. We also find no differences in income generated by crop

or livestock sales. In general, women and men from the control group report a significantly higher wage income[10] than their treated counterparts. Accounting for all of these differences is important, as they could potentially bias impact estimates.

Table 1c: Summary statistics, household income at baseline

Variable	Control	Treatment	Difference
Annual household income (in USD)			
Total annual agricultural wage	535.70	134.14	**-401.55*** **
	(2,719.49)	(1,174.28)	
Total annual non-agricultural wage	985.20	740.18	-245.02
	(5,377.28)	(4,985.04)	
Annual income from crops	767.36	1,271.52	504.16
	(3,994.60)	(12,204.08)	
Annual income from livestock	329.66	801.20	471.54
	(7,574.84)	(11,593.81)	
Annual income from self-employment	46.31	60.21	13.90
	(670.80)	(701.26)	
Annual total income	3,061.55	3,478.22	416.67
	(10,777.45)	(17,732.79)	
Household member wage income (in USD)			
Woman's annual wage income	284.84	72.40	**-212.44*** **
	(1,833.72)	(622.44)	
Man's annual wage income	1,151.98	458.69	**-693.29*** **
	(5,562.82)	(3,089.94)	
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

4.3. Female empowerment, time use and occupational decisions

To measure the impact of SigTierras on women's empowerment, we rely mainly on indicators constructed using the empowerment module. In our subsample, this module was responded by the household head's partner, which in all cases was a female member of the household. The module was designed for the construction of the Abbreviated Women's Empowerment in Agriculture Index (A-WEAI), a multidimensional measure of women's empowerment specifically designed for the agricultural context, first developed by Alkire et al (2013). The A-WEAI includes questions on agricultural use and agricultural production decision making, as well as other indicators that make it suitable for quantitatively measuring empowerment in the context of agricultural households. Because of its suitability, this indicator has become very popular in the economic literature, and Alkire et al (2013) has been cited In more than 160 times, making it the most cited empowerment index in agricultural settings (Priya et al, 2021).

The application of this module required interviewing the respondent in a space separate from other family members so that they felt they could speak freely, thereby avoiding bias in their

[10] This considers both agricultural and non-agricultural wages.

responses. The questions included in the A-WEAI refer to five dimensions of women's empowerment: (i) production, (ii) resources, (iii) income, (iv) leadership, and (v) time use. These five dimensions are aggregated to form the 5 Dimensions of Empowerment Index (5DE). Then, the A-WEAI is constructed by linearly combining this indicator and the Gender Parity Index (GPI), where the GPI accounts for 10% of the A-WEAI index. The GPI is calculated as the difference between the woman and the man's 5DE, and therefore enables us to compare empowerment scores between the male and female partner within the household.

Due to the overall length of the questionnaire in this study the male partner did not answer the A-WEAI module of the questionnaire, which would have been necessary to construct the GPI. Nevertheless, we are able to construct a 5DE for the woman, which allows us to assess the levels of empowerment that the woman enjoys within the household. Additionally, some questions found in other modules refer directly to the man's situation within the household, allowing us to construct a number of variables that complementarily capture male empowerment levels.

In order to implement the measurement of the 5DE, we construct the six indicators related to the five dimensions of women's empowerment. The additional indicator exists because the resources dimension is measured by two separate indicators: asset ownership and credit. The indicators capturing each dimension are constructed as binary variables, equal to one if a woman is considered disempowered in this dimension, and zero if she is not. A woman is considered empowered in the production dimension if she has at least some level of input in decisions regarding crop or livestock production. In the resources dimension, a woman is considered empowered in terms of the asset ownership indicator if she owns (or jointly owns) at least one major asset (agricultural land, large and medium livestock[11], fishponds, mechanized farm equipment, house, large household durables[12], cell phone, nonagricultural land, and means of transportation). In terms of the credit indicator, a woman is considered empowered if she can influence decisions about or has had access to credit. The income dimension is measured as having a say or some degree of control over the income generated by at least one of the aforementioned agricultural activities. A woman is considered empowered in the leadership dimension if she is an active member of at least one group (association, organization or cooperative). Lastly, the time use dimension takes into consideration that workload was a source of disempowerment. Thus, a woman is considered empowered if she dedicates less than 10.5 hours a day to work activities (including domestic work and work outside of the household).

In a final step, these individual indicators are used to construct an Inadequacy Count, weighting each dimension by 0.2 and adding them[13]. The Inadequacy Count is a variable taking values from zero to one, where zero represents being empowered in all dimensions and one represents being disempowered in all dimensions. Thus, the larger the Inadequacy Count, the more multidimensionally disempowered the woman is.

It might be relevant to mention that households in our sample do not solely rely on agricultural production to generate income. In fact, as shown in **Table 1c**, non-agricultural wage income accounts for almost one third of total household income, on average, for both control and treatment group. This problem was already identified by Alkire et al (2013), who state that "women who are engaged in decision-making on non-agricultural activities may appear disempowered if

[11] This excludes small livestock such as chickens, ducks, turkeys, rabbits, and guinea pigs.
[12] This excludes small household durables such as radios, pots, or other kitchen utensils.
[13] In the case of the resources dimension, the access to credit indicator was weighted by 1/15 and the ownership of assets indicator was weighted by 2/15.

they are not involved in agricultural decisions" and that the "focus on agriculture may not capture other domains of empowerment that may be more relevant to specific desired outcomes". To complement the analysis and consider other changes in empowerment that might not be related to agricultural production, we include a set of additional – non-agricultural related – variables. These variables include the disaggregation of time use, specific questions about credit, savings, income generation, investment decisions, and household gender dynamics.

Lastly, we include a number of indicators meant to capture the household's overall empowerment dynamics: We include some of the disempowerment dimensions of resources (asset ownership) and leadership for the man, thanks to the availability of these variables in the module. Although limited to these two dimensions, we construct an inadequacy count gender gap to compare relative empowerment between man and woman within the household in terms of resources and leadership. To generate this variable, we first create an inadequacy count for the man and woman respectively that considers only these two dimensions as the sum of both binary indicators, and then take the normalized difference between the two inadequacy counts. The larger the number, the bigger the difference between the woman and man is, implying a higher level of empowerment for the woman. Additionally, we consider a binary variable that captures the occurrence of relationship conflicts between the couple, that takes the value of one if the woman reports to have experienced a conflict regarding a decision taken by her that involved animals or money, and that was not consulted with her partner; and zero otherwise.

Table 2 presents summary statistics for these variables pertaining to women's empowerment, at the moment of the endline survey, for treatment and control group. We include the Inadequacy Count, all indicators for the five dimensions of disempowerment, measures of time use for different activities, additional binary indicators that capture the woman's access to credit and savings, the woman's wage and occupational decisions, as well as overall couple's empowerment dynamics.

Table 2: Woman Empowerment Summary Statistics at Endline

Variable	Control	Treatment	Difference
Women empowerment			
Inadequacy Count (CI)	0.47	0.48	0.011
	(0.17)	(0.17)	
Disempowerment in production dimension	0.48	0.54	0.062
	(0.50)	(0.50)	
Disempowered in resources dimension: asset ownership	0.20	0.16	-0.037
	(0.40)	(0.37)	
Disempowered in resources dimension: credit	0.87	0.83	-0.044
	(0.33)	(0.38)	
Disempowerment in income dimension	0.18	0.19	0.011
	(0.39)	(0.40)	
Disempowerment in leadership dimension	0.97	0.97	0.000
	(0.16)	(0.16)	
Disempowerment in time dimension	0.29	0.31	0.021
	(0.46)	(0.46)	

Table 2 (*continued*)

Variable	Control	Treatment	Difference
Time use			
Hours a day used in other work activities	8.44 (3.30)	8.83 (3.07)	0.3850
Hours a day used for leisure	1.59 (1.85)	1.31 (1.69)	**-0.273*** **
Hours a day used in agricultural work	2.57 (2.66)	2.59 (2.81)	0.024
Hours a day used in domestic work	4.41 (2.84)	4.39 (2.65)	-0.021
Results on Women's Resources			
Woman applied for credit	0.09 (0.29)	0.12 (0.33)	0.033
Woman received credit	0.08 (0.28)	0.12 (0.32)	0.035
Woman has savings	0.08 (0.27)	0.05 (0.21)	**-0.034*** **
Woman generated income	0.46 (0.50)	0.48 (0.50)	0.028
Women's occupation and investment decisions			
Main occupation is non-agricultural	0.29 (0.45)	0.33 (0.47)	0.043
Woman earned wage income (USD)	0.13 (0.34)	0.12 (0.33)	-0.010
Invested in own business in the last year (USD)	0.08 (0.27)	0.13 (0.34)	**0.054*** **
Amount invested in own business (USD)	39.21 (509.93)	24.16 (145.94)	-15.056
Couple's empowerment dynamics			
Man is disempowered in resources dimension (assets)	0.02 (0.13)	0.04 (0.19)	0.020
Man is disempowered in leadership dimension	0.06 (0.24)	0.03 (0.18)	**0.029*** **
Gender gap inadequacy gap (2 dimensions)	0.20 (0.42)	0.14 (0.40)	**-0.062*** **
Couple experienced marital conflict in the last year	0.12 (0.32)	0.08 (0.27)	**-0.038** **
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

Table 2 reveals that the average inadequacy count is around 0.5, suggesting that on average women are disempowered in half of the dimensions of empowerment. This level of disempowerment is mostly explained by disempowerment in access to credit and in the leadership dimension. In fact, 85% of the women in our sample are disempowered in terms of credit, and 97% are disempowered in terms of leadership. Next, 51% of women seem to be disempowered in the production dimension, and 30% in the time use dimension. Only 19% are disempowered in income and only 18% in asset ownership. In terms of time use, on average women in our sample spend most of their time working in other non-agricultural activities, working for around 8 hours a day. On average, they only spend 3 hours a day doing agricultural work. A total of 4 hours is dedicated to domestic work, and only 1.46 hours to leisure.

In terms of credit, we see that only around 10% of our sample applied and received credit, which explains the high level of credit disempowerment. Similarly, only 7% of women have savings. However, 47% reported generating their own income. In terms of how this income was generated, 31% report having a non-agriculture related main activity and 13% reported earning wage income. In terms of entrepreneurship, 10% report having invested money in their own business.

When looking at the man, we see that 3% seem to be disempowered in the asset dimension, 5% are disempowered in the leadership dimension. This represents a large contrast when compared to the statistics of their female counterparts. In terms of the inadequacy count, we can see that women are disempowered compared to their male counterparts. At the same time, conflicts between the couple are rarely reported, with only 10% reporting a conflict during 2018.

Without controlling for initial differences and unobservable factors that may influence behavior, we observe some significant differences between treatment and control group: treated women spend less time on leisure, invested significantly more in their own business, and treated couples experience less marital conflict.

4.4. Food security and diversification of agricultural production

To measure the effects of SigTierras on the household's food security we construct a food security dummy variable, following the index elaborated by the Food and Agriculture Organization of the United Nations (FAO, 2011) based on the Latin American and Caribbean Food Security Scale (ELCSA). First, we construct a food insecurity index, which includes eight questions focused on both objective information and subjective assessments of the concerns faced by the household in terms of food acquisition. The values of the index can range from 0 to 8, where 8 is more food insecure and 0 is less food secure. Second, we use this index to construct a binary variable of food security, which takes the value of 1 if the household is food secure (when the food security index takes the value of 0); and 0 if the household experiences any level of food insecurity (values between 1 and 7). , which will function as our main indicator of food security. Additionally, we consider whether the woman makes decisions over the food consumed of the household and whether she pays for this food. Table 4 presents the summary statistics for these variables. As observed, only 22% of the households in our sample are considered to be food secure.

To measure the diversity of the household's agricultural production, we construct four different indices of crop diversity. The first two indices focus solely on the household's crop production and are based on Simpson's Crop Diversity Index (SI), as first proposed by Simpson (1949), which takes the sum of the squared production dedicated to each different crop, divided by the square of the total production. In other words, the SI can be described using the following equation:

$$SI = 1 - \sum_{i=1}^{N} a_i^2 \Big/ \left(\sum_{i=1}^{N} a_i \right)^2$$

We use two different specifications of this equation, which determine how it should be interpreted. The first specification measures diversity in terms of the production area dedicated to various croups (in hectares), where a_i is then the number of hectares cultivated with crop *i*. The second measures diversity in terms of the production value of different crops, for which a_i is the market value of crop *i* (in US$). In both cases, N represents the total number of crops sowed by the household in a given agricultural cycle (see; Hirschman, 1964). Both indices take values between zero and one, where a higher value implies a higher level of crop diversification. Technically, the SI takes the value of zero when only one crop is being produced, and one when infinite number of crops are being produced. The advantage of using the SI is that it not only considers the number of different crops available, but also the distribution – or *relative abundance* – of the crops.

While the Simpson's diversification index focuses on crop diversity, it is also of interest to consider the household's livestock production, since the products derived from this system can arguably improve the household's food security. Therefore, we also construct the Agricultural Richness Score (ARS), following Chegere and Stage (2020). The ARS is the sum of the number of all crops and animal products produced by the household, so that it can take any value ranging from zero upward (Sibhatu & Qaim, 2018). In our sample, values range between 0 and 29. As shown in Table 4, the average household has an agricultural richness score of 6.

As a final measure of production diversification, we consider diversity in terms of how much the household's agricultural production is able to cover the necessary requirements of an adequate human diet. We construct the Agricultural Diversity Score (ADS), which is a count of agricultural products produced by the household just as the ARS, but grouped into categories according to their food group (Sibhatu & Qaim, 2018). Thus, the ADS counts the number of different food groups produced. To assign the products to food groups, we again follow Chegere and Stage (2020) and use the 12 food groups proposed by FAO: cereals; white tubers and roots; legumes, nuts and seeds; vegetables; meat; eggs; fish and other seafood; fruits; milk and milk products; oils and fats; sweets; and spices, condiments and beverages. If a product belongs to more than one food group (i.e. chicken and eggs), then two groups are assigned to the same product. Following this methodology implies that the ADS can take values between zero and twelve. However, the maximum value found in our sample is 9. **Table 3** indicates that the average household in our sample can cover only 3 of the 12 food groups with their production.

Table 3: Food security and production diversity

Variable	Mean	Std. Dev.
Food security		
Food security index	2.58	2.40
Household is food secure	0.22	0.42
Woman makes decisions over food	0.83	0.38
Woman pays for food	0.10	0.30
Production Diversity		
Simpson's Crop Diversity Index (Hectares)	0.26	0.27
Simpson's Crop Diversity Index (Crops as market value)	0.22	0.26
Agricultural Richness Score (ARS)	6.28	3.85
Agricultural Diversity Score (ADS)	3.08	1.56

5 Empirical Strategy

5.1. Inverse Probability Weighting (IPW)

As explained in Section 4, and following the description provided by Corral & Montiel (2022), the selection of cantons participating in the SigTierras program was not randomized. However, the strategy used to select households in the control and treatment group addresses most of the issues concerning self-selection into the program. First, because the group of control cantons was selected from within those cantons that self-selected into the program but, because of budget constraints, delays in negotiations or the presence of cloud coverage making it impossible to take aerial photographs, were not selected to participate. Second, because control cantons were selected using a PSM that ensured their comparability with the treated cantons. Third, because households within the control group cantons were also selected using a PSM methodology – with data from the 2001 and 2010 Census – thus, also achieving comparability between treated and control households.

Although the treatment and control group were carefully selected to achieve comparability and find the average treatment effect on the treated (ATT), it is worth noting that the data used for our analysis considers only a subsample of these households. Particularly, we focus on households where the woman identified as the household head's partner is the same in both baseline and endline. Applying this restriction could potentially lead to certain skewness in our sample. Additionally, our study is focused on indicators that are primarily available from the endline survey. This implies some limitations in terms of controlling for unobservable characteristics.

In order to overcome this problem, we use an Inverse Probability Weighting (IPW) approach (Rosenbaum, 1987; Hirano and Imbens, 2001). The IPW method is based on the PSM approach (Rosenbaum & Rubin, 1983) and relies on the use of propensity scores, which are estimated using observable characteristics. Thus, the viability of this method depends on the assumption of conditional independence, which states that the assignment to the program is independent of the outcomes, once controlled for the selected observable characteristics (ibid). However, contrary to other matching methods, IPW uses the inverse of the estimated propensity scores to generate regression weights, in order to adjust the distribution of the treatment and control observations. We believe this is preferable, as it does not restrict the sample to the area of common support, allows to construct a synthetic counterfactual and simplifies the analysis by allowing the estimation of ordinary standard errors in a regression framework (Todd et al, 2010; Cavatassi et al, 2011). The examples of the use of IPW as a method to address concerns of self-selection bias in the economics literature are abundant (Titus, 2007; Ye & Kaskutas, 2009; Schling & Winters, 2018; Schling & Pazos, 2021).

As with PSM, the first stage for using IPW is to estimate the propensity scores. Second, we estimate the inverse probability weights ω_i for observation *i* as follows:

$$\omega_i = \left(\frac{Treatment_i}{p(Treatment_i)} + \frac{1-Treatment_i}{1-p(Treatment_i)}\right), \qquad (1)$$

where $Treatment_i$ is a dummy variable taking the value of 1 for individual i in the treatment group and 0 for those in the control group, and $p(Treatment_i)$ is the estimated propensity score for individual i. As a result, a greater weight ω_i will be assigned to those in the treatment group with lower propensity scores, as well as for those in the control group with higher propensity scores. Therefore, applying these weights should adjust the distribution in a way that increases the

overlap between the two groups and reduces the bias among observable characteristics, which should also reduce the bias of unobservable characteristics as a result (Cavatassi et al, 2011).

In total, we incorporate 37 variables from the baseline survey to estimate propensity scores. These include variables related to household characteristics and income, the characteristics of individual household members as well as their wage income, household wealth, land characteristics, and agricultural expenditures. One of our main goals when selecting these variables was to control for information that could lead to different levels of empowerment. As there is no data on direct measurements of empowerment from the baseline, we rely on information defining the household and the woman's socioeconomic characteristics. Variables defining the wealth and productive practices of the household are also included, as they can affect a woman's empowerment, as well as the production diversification and the food security of the household. The complete list of variables and their summary statistics can be found in **Table 1**.

The distribution of the propensity scores, before and after applying the IPW, can be found in **Graph 1**. As shown, after applying the IPW, the overlap between the distributions of treatment and control groups increases significantly, with near perfect overlap between distributions of treatment and control group.

Graph 1: Distribution of propensity scores with and without IPW

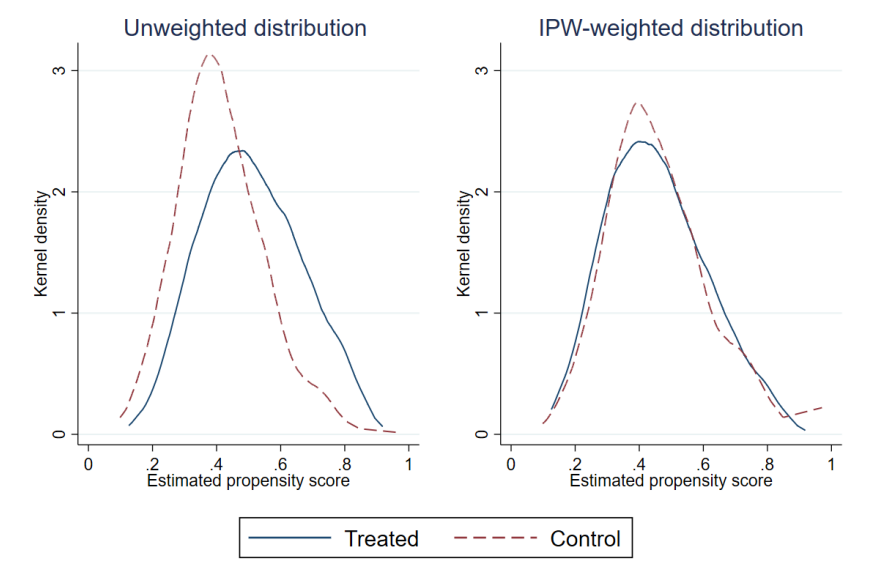

Table 4 presents the balance achieved between treatment and control group across the same list of variables presented in Table 1. **Table 4a** shows the balance for sociodemographic characteristics, **Table 4b** for productive characteristics, and **Table 4c** for variables pertaining to income and wages. As observed, we do not find any significant differences between treatment and control groups after applying inverse propensity weights, indicating that IPW was successful in achieving balance in observable characteristics at baseline.

Table 4a: IPW-weighted sociodemographic characteristics at baseline

Variable	Control	Treatment	Difference
Household characteristics			
Household size	5.13	4.96	-0.171
	(2.28)	(2.21)	
Number of children (under age 16)	1.98	1.97	-0.007
	(1.72)	(1.72)	
Number of members in working age (16-64 years)	2.73	2.62	-0.112
	(1.43)	(1.48)	
Household members characteristics			
Household head is married	0.75	0.74	-0.009
	(0.43)	(0.44)	
Household head speaks a native language	0.15	0.16	0.006
	(0.36)	(0.37)	
Woman's age	44.27	44.61	0.339
	(15.14)	(14.67)	
Man's age	48.18	48.60	0.424
	(15.44)	(15.35)	
Woman's years of education	5.24	5.24	0.003
	(3.29)	(3.49)	
Man's years of education	5.80	5.82	0.025
	(3.21)	(3.44)	
Household wealth			
Productive asset index	0.01	0.01	-0.003
	(0.03)	(0.03)	
Unproductive asset index	0.39	0.38	-0.009
	(0.24)	(0.23)	
House quality index	0.68	0.68	-0.009
	(0.35)	(0.37)	
Access to services index	0.53	0.53	0.000
	(0.22)	(0.21)	
Wealth index	0.26	0.25	-0.013
	(1.87)	(1.83)	
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

Table 4b: IPW-weighted productive characteristics at baseline

Variable	Control	Treatment	Difference
Land characteristics			
Total area in hectares	4.59	4.53	-0.064
	(11.44)	(13.14)	
Number of plots owned	2.24	2.25	0.006
	(1.43)	(1.65)	
Land fragmentation index	0.27	0.26	-0.007
	(0.27)	(0.27)	
Household has access to irrigation	0.11	0.11	0.005
	(0.28)	(0.30)	
Household experienced at least one land conflict	0.11	0.11	0.004
	(0.31)	(0.32)	
Average age of household plots	15.72	15.15	-0.568
	(12.62)	(11.84)	
Household invested in at least one plot	0.09	0.07	-0.021
	(0.29)	(0.26)	
Household has perennial trees	0.47	0.46	-0.008
	(0.50)	(0.50)	
Household owns at least one titled plot	0.51	0.49	-0.019
	(0.50)	(0.50)	
Agricultural expenditures (in USD)			
Expenditure in crop inputs	367.50	317.86	-49.65
	(1,650.44)	(1,507.62)	
Expenditure in hired labor	100.97	101.11	0.14
	(491.89)	(1,479.74)	
Expenditure in pesticides	125.48	110.33	-15.15
	(966.56)	(718.96)	
Expenditure in fertilizer	119.10	130.23	11.13
	(478.56)	(782.14)	
Expenditure in seeds	122.92	77.29	-45.63
	(872.55)	(354.48)	
Expenditure in livestock	477.45	479.18	1.72
	(818.82)	(1,164.26)	
Expenditure in inputs	844.96	797.03	-47.93
	(1,887.96)	(1,934.13)	
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

Table 4c: IPW-weighted income variables at baseline

Variable	Control	Treatment	Difference
Household income (in USD)			
Household total agricultural wage	340.24 (2,116.82)	227.81 (1,854.85)	-112.43
Household total non-agricultural wage	815.74 (4,432.17)	994.35 (5,663.12)	178.62
Household income from crops	1,314.48 (6,469.32)	1,036.12 (10,692.19)	-278.36
Household income from livestock	5,700.44 (31,322.51)	996.06 (12,045.03)	-4,704.38
Household total income from self-employment	56.33 (688.43)	58.59 (722.90)	2.26
Household total income (USD)	8,646.98 (32,261.23)	3,743.07 (17,187.27)	-4903.91
Members wage income (in USD)			
Woman's yearly wage income	183.87 (1,405.75)	98.54 (732.47)	-85.33
Man's yearly wage income	828.53 (4,440.47)	866.10 (5,185.66)	37.57
Number of observations	767	683	

Note: Average value by group. Standard deviation in parenthesis. Difference unequal to zero if p-value significant at the 99 (***), 95 (**), or 90 (*) confidence level.

5.2. Difference in Difference with IPW

In this study we are interested in the effects that providing increased tenure security through the SigTierras program has on women's empowerment and food security. As previously mentioned, most of the variables related to empowerment derive from two additional questionnaire modules that were only included for the endline survey. Nevertheless, some of the impact indicators of interest have information available for both survey rounds, particularly variables related to non-agricultural wages and small business investment decisions, as well as production diversity.

This additional source of data enables us to combine IPW with a more robust Difference-in-Difference (DD) strategy, in order to control for additional sources of endogeneity bias that may have arisen from time-invariant unobservable differences between treatment and control group. This methodology relies on two assumptions. First, it supposes that the control group be a valid counterfactual for the treatment group in observable characteristics. Second, the DD methodology's validity is contingent on the so-called "parallel trends" assumption, which implies that any changes over time or within the two groups must follow the same pattern in the absence of treatment (Blundell & Dias, 2000). This condition might not be met if the pre-treatment characteristics associated with the outcome are not balanced between treatment and control groups. In this context, applying IPW allows to achieve balance across observable characteristics at baseline, thereby ensuring fulfillment of the first assumption. Given that no data is available on other pre-treatment periods, we are unable to formally test the parallel-trends assumption. However, it is worth noting that the application of IPW on baseline variables potentially associated

with the dynamics of the outcome variables at endline has been shown to facilitate the estimation of the ATT, in the case of a non-parallel outcome (Abadie, 2005).

The result of combining these two methodologies is a double robust estimator (Funk et al, 2011). The double robust estimator leads to an unbiased result if at least one of the two models is well specified (Funk et al., 2011; Imbens & Rubin, 2015; Robins et al., 1995). The estimation of the DD is weighted by the inverse propensity weights generated as proposed in equation (1). To estimate the DD model, we estimate the following equation:

$$y_{it} = \alpha + \beta * Treated_i + \gamma * Time_t + \delta * Treated_i * Time_t + \epsilon_{it}, \quad (2)$$

where y_{it} is the dependent variable for household i at time t, $Treated_i$ is a dummy variable that takes the value of 1 if the household i is treated, $Time_t$ is a dummy variable that takes the value of 1 for post-treatment period (endline survey) and 0 for the pre-treatment period (baseline survey), and ϵ_{it} is the error term. Therefore, coefficient β controls for initial differences between treatment and control group at baseline and coefficient γ accounts for a general time trend during the duration of the program. Coefficient δ then represents the differential trend over time between treatment and control group beyond the general time trend, thereby capturing the impact of the program on dependent variable y_{it}.

6 Results

6.1. Women's empowerment

We first present estimated impacts for the selected women's empowerment indicators, as shown in **Table 5**. As presented in column (1), we do not find any statistically significant effects on the total Inadequacy Count. When disaggregating disempowerment into its individual dimensions, as shown in columns (2)-(7), we find that SigTierras significantly reduced the probability of being disempowered in resources dimension with regards to access to credit by 6.3 percentage points (p.p.). We do not find any other significant effects on the probability of being disempowered for any the other dimensions.

Table 5: Results on Women's empowerment

	Inadequacy count	**Disempowered in Dimension**					
	Inadequacy Count (CI)	**D1 Production**	**D2: Resources (Asset ownership)**	**D2: Resources (Credit)**	**D3: Income**	**D4: Leadership**	**D5: Time**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated	0.006	0.047	-0.016	**-0.063*** **	0.005	-0.002	0.012
	(0.01)	(0.03)	(0.02)	(0.02)	(0.02)	(0.01)	(0.03)
Observations	1,382	1,382	1,382	1,382	1,382	1,382	1,379

Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).

Table 6 explores women's time use in more detail. No statistically significant differences are observed between treatment and control in terms of the number of hours dedicated to agriculture or domestic work. We do however find that women whose land was included in the cadastral mapping spend 11 minutes less on leisure than those whose land was not included in SigTierras'

mapping efforts. Additionally, women with treated parcels spend approximately 23 more minutes a day on work activities not related to agricultural work. These results could explain why we fail to find any significant effects in the time dimension of disempowerment, as these indicators focus particularly on changes in the availability of leisure time, and only a small change appears to occur between treatment and control group as a result of SigTierras activities. In other words, even if treated women in our sample are not less empowered in their time use than those in the control group, they do spend less hours a day on leisure and instead dedicate more hours to other work activities.

Table 6: Results on Women's Time Use

	Hours a day used in other work activities (1)	Hours a day used for leisure (2)	Hours a day used in agricultural work (3)	Hours a day used in domestic work (4)
Treated	**0.389****	**-0.187***	0.000	-0.029
	(0.20)	(0.10)	(0.16)	(0.16)
Observations	1,379	1,379	1,379	1,379
Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).				

Similarly, we explore the role of SigTierras cadastral mapping in changing women's access to resources in **Table 7**. In line with our results in Table 5, we find that women in our treatment group have a 3.4 p.p. higher probability of having applied for a credit within the year prior to the endline survey and a 3.8 p.p. higher probability of having received a credit during the same period. Although we find that treated women are 2.9% less likely to have savings, they also demonstrate a 6 p.p. higher probability of generating their own income. This suggests that, even if we do not find significant effect in the income dimension of empowerment, certain differences in terms of female income-generating behavior do exist, and are potentially linked to the time spent on off-farm working activities as shown in Table 7.

Table 7: Results on Women's Resources

	Woman applied for credit (1)	Woman received credit (2)	Woman has savings (3)	Woman generated income (4)
Treated	**0.034***	**0.038****	**-0.029****	**0.060***
	(0.02)	(0.02)	(0.01)	(0.03)
Observations	1,382	1,382	1,382	1,382
Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).				

In **Table 8**, we further explore the potential influence of participation in the SigTierras program on intra-household decision-making dynamics, by examining the woman's possibility to generate their own off-farm income and investing in their own business. As these variables were available in both the baseline and the endline surveys, Table 9 reports the results of the DD with IPW estimation. When controlling for time trends, we do not find significative effects on a woman's likelihood of having their main occupation be outside the agricultural sector. Similarly, there are

no significant effects on the probability of earning a wage or investing in a business. Instead, results show that the SigTierras program significantly increased the off-farm wage income of the women in treated households by US$ 419. This result is in line with the results in Table 7 showing that treated women had a larger probability of generating income.

Table 8: Difference-in-Difference Results on Women's Wage and Investment Decisions

	Main occupation is non-agricultural (1)	Woman earned wage income (2)	Annual wage income (3)	Invested in own business in the last year (4)	Annual amount invested in own business (5)
Treated*Time	-0.007	0.032	**419.5***	-0.010	-39.63
	(0.04)	(0.02)	(231.20)	(0.03)	(33.63)
Treated	**0.072*****	-0.018	-85.340	**0.044****	20.98
	(0.02)	(0.01)	(54.77)	(0.02)	(24.83)
Time	**0.142*****	**0.073*****	**166.1*****	-0.003	23.71
	(0.03)	(0.02)	(60.74)	(0.02)	(22.25)
Observations	2,764	2,764	2,764	2,758	2,758

Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).

Until now, our results have shown that there are limited but important effects of the SigTierras program on women's empowerment that suggest the cadastral mapping activities affected the woman's ability to make financial and productive decisions. It is worth noting that these effects appear to pertain particularly to off-farm, non-agricultural activities, which suggests that women who enjoy a higher level of tenure security may be better able to dedicate their time and resources to income-generating off-farm activities. These results are consistent with evidence provided by a recent study by Schling & Pazos (2021), where higher levels of informal tenure security in Peru had a positive effect on women's empowerment, and similarly led to women dedicating an increased amount of time to off-farm work activities.

6.2. Intrahousehold dynamics

Of course, changes in the woman's access to financial resources on and off farm would likely affect intrahousehold bargaining dynamics, though it remains to be seen how these changes materialized. **Table 9** presents some such evidence supporting the hypothesis of the program shifting the dynamics within the household. As shown in column (1), increased tenure security provided by SigTierras does not appear to change the household's overall asset ownership, which is consistent with our findings for the woman's resource empowerment (see Table 5). Interestingly, as displayed in columns (2) and (3), men in the treatment group did experience a decrease in the probability of being disempowered in terms of asset ownership. Similarly, they also experienced an increase in their levels of empowerment in terms of resources (asset ownership) and leadership, with significant increases of 2.3 p.p. respectively. Tables A1 and A2 in the Appendix further expand on these findings to analyze changes in the man's access to credit and savings, as well as their off-farm income, wages, and investment decisions. Just as for women, men in the treatment group report significantly less savings and have a higher probability of indicating that their main occupation is outside of the agricultural sector. However, in contrast

to their female partner, treated men are less likely to generate off-farm income than their control counterparts, and no effects are detected with regards to off-farm business investments. Overall, this would suggest that the benefits that were derived from increased tenure security differed by gender, wherein the man tends to enjoy increased empowerment in resources and leadership, while the woman improved their access to credit and shifted their time use towards off-farm activities.

While it is therefore at first glance unclear how this may have affected the overall power balance between the couple within the household, results in columns (4) and (5) seem to suggest that these changes would not have come at the detriment of the woman, or of the couple's relationship: The gender gap inadequacy count remains unchanged for one, and couples among the treatment group reported a 4 p.p. decrease in the incidence of marital conflict.[14]

Table 9: Results on Household's empowerment dynamics

	Household is disempowered in:	**Man is disempowered in:**		**Partner relationship:**	
	D2: resources (asset ownership) (1)	D2: resources (asset ownership) (2)	D4: leadership (3)	Gender gap inadequacy count (4)	Experienced marital conflict (5)
Treated	-0.048	**0.023****	**0.023***	-0.040	**-0.040****
	(0.11)	(0.01)	(0.01)	(0.03)	(0.02)
Observations	1,382	1,382	1,382	1,316	1,334
Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).					

6.3. Food security and diversification of agricultural production

Table 10: Results on Food Security

	Woman makes decisions over food (1)	Woman pays for food (2)	Food security index (3)	Household is food secure (4)
Treated	**0.038***	**0.050*****	-0.193	**0.058***
	(0.02)	(0.02)	(0.16)	(0.04)
Observations	1,382	1,382	1,382	1,382
Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).				

Table 10 presents results for variables related to food security. As can be observed, no significant effect is found for the food security index as presented in column (3). However, results highlight that the woman's role in decisions and purchasing of food is affected by increased tenure security provided by SigTierras, as treated women are 3.8% more likely to make decisions over food, and 5% more likely to pay for food items for the household. This appears to translate into a higher

[14] A caveat of this result is that the sample excluded such households that experienced a change in who reported as household head between baseline and follow-up.

share of households moving from categories associated with higher levels of food insecurity to categories of lower food insecurity, as treated households are found to be 5.8% more likely to be considered food secure.

In terms of the diversification of agricultural production, **Table 11** presents results for our four indicators of diversification. For the two measures of the Simpson's index, results indicate that diversification among treated households did not increase when measured in terms of their spatial distribution but did experience a significant increase of 0.072 in terms of the production value of different crops. With regard to the Agricultural Richness and Agricultural Diversity Score, we do not find any significant effects of SigTierras. These results would suggest that households may not have added diversity to their farm through additional crops to sow during the agricultural cycle as a result of the program, nor through additional livestock. The lack of results on ADS also suggest that the program did not incentivize households to diversify their production in terms of the products' nutritional value. Instead, households may have sought diversification in terms of crop value due to SigTierras' impact on their intrahousehold decision making process, suggesting an increased preference towards market-oriented production[15]. At the same time, the higher diversification of crop value indicates a lowered risk of total crop failure, which could contribute to improvements in food security. In other words, this result implies that the treatment has made households more risk-averse in terms of their production, and they are less likely to "put all their eggs in one basket", instead diversifying their production portfolio on which their agricultural income relies. The lesser the risk, the lower the probabilities of experiencing food insecurity.

Table 11: Difference-in-Difference Results on Diversification of Agricultural Production

	Simpson's Crop Diversity Index (Hectares)	Simpson's Crop Diversity Index (Crops as market value)	Agricultural Richness Score	Agricultural Diversity Score
	(1)	(2)	(3)	(4)
Treated*Time	-0.015	**0.072*** **	-0.102	-0.078
	(0.028)	(0.026)	(0.445)	(0.159)
Treated	**0.044** **	-0.010	0.399	**0.442*** **
	(0.018)	(0.019)	(0.353)	(0.113)
Time	**-0.189*** **	**-0.078*** **	**-0.850** **	**-0.506*** **
	(0.019)	(0.019)	(0.364)	(0.117)
Observations	1,914	2,041	2,764	2,758

Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).

Various studies in the literature suggest that women's empowerment leads to a more diverse production (De Pinto et al, 2020), and to a bigger focus on household nutrition (Sraboni et al, 2014). Concretely, our results suggest that observed increases in women's empowerment, particularly the woman's increased likelihood to dedicate more time and additional resources to off-farm activities, contributes to her enhanced bargaining power within the household, which in

[15] Typically, households in our sample are not producing crops for their own consumption (40% of the households do not consume any of their crop production at baseline, while less than 3% of the sample consume half of their production or more during the same time period). In fact, households in our sample seem to be mainly market oriented, with 24% of the households selling the entirety of their crop production at baseline.

turns leads to significant changes in the household's production portfolio and related impacts on the household's food security.

7 Conclusions

There is vast work in theoretical and empirical economics pointing to the importance of providing women with tenure security, suggesting that owning land titles empowers women to participate more actively in household decision-making, which may not only benefit themselves, but the wellbeing of their entire family. However, in the context of smallholder farmer households in the developing world where legal tenure security remains uncommon, it is usually the case that ownership is determined in informal ways, and mostly enforced by communal and social rules. In these scenarios, informal but effective land ownership may be a sufficient substitute for formal title.

In this paper, we evaluate the impact of SigTierras, a rural land administration program implemented in Ecuador between 2012 and 2016. The program was unable to provide a significant number of farmers with land titles by the end of project execution, but did achieve the completion of a comprehensive cadaster sweep and mapping, which resulted in the provision of georeferenced and community-assented maps of each parcel within the project area that helped clarify effective landownership. While a study by Corral and Montiel (2022) focused on evaluating the productive impacts of SigTierras at the household level and found no notable effects besides a significant increase in household income, our analysis focuses on the impacts that SigTierras may have had on intra-household dynamics pertaining to women's empowerment.

Although we find no effects of SigTierras on aggregate levels of empowerment and most of its dimensions, female beneficiaries did appear to become more empowered in the resources dimension, particularly in terms of applying for and receiving credit. Program participation also significantly affected women's time use, as beneficiary women spent more hours working outside of the household. This was reinforced by findings indicating that treated women were more likely to participate in non-agricultural activities, investing in their own businesses, and generating off-farm wages. These results point to the fact that increased informal tenure security may enable women to shift their focus away from on-farm activities, allowing them to generate their own income and reinforcing their bargaining power within the household. This is in line with findings by Twyman et al. (2015), who analyzed the dynamics between women's participation in agricultural decision-making and bargaining power for the Ecuadorian context, and found that a woman's choice to dedicate her time to off-farm work is linked to higher levels of security in their property rights. A recent study by Schling & Pazos (2021), who found that Peruvian women who owned land dedicated significantly less time to agricultural work, freeing up time for them to engage in other activities. It is possible that by increasing women's tenure security, they feel more empowered to leave the home in pursuit of additional income generation. We also find that the program reduced the probability of experiencing marital conflicts, which could be another indication that the woman has effectively improved her better position within the household. These findings highlight the importance of considering non-agricultural variables to allow for a complete gender analysis of farmer households.

We also find that participating in SigTierras significantly increased household food security and the household's diversification of their agricultural production, wherein treated households' production portfolios shifted significantly towards crops and livestock products that are both of higher market value and cover more food groups required to maintain a balanced and nutritious diet. This suggests that women empowered by enhanced tenure security indeed make choices

that contribute to their household's welfare. This should not be surprising, as evidence shows that if women have access to their own resources and income, they are more likely to dedicate their personal resources towards investments in the well-being of their family and children, relative to the man (Skoufias, 2005; Allendorf, 2007; Sraboni et al., 2014).

Overall, these results contribute to growing evidence that improving tenure security through cadastral mapping may enhance female empowerment, which enables them to increase their bargaining power within the household in order to improve their own and the family's overall welfare. For instance, Deiniger et al. (2008a) analyzed a first-stage land certification program in Ethiopia and found that being issued such a certificate (which does not amount to a formal title) significantly increased longer-term land investments among female-headed households. To our knowledge, ours is the first study to examine this issue in a Latin American context, and to examine empowerment and food security impacts in the context of informal tenure security. The results suggest that any national land rights regime must first carefully assess preexisting customary land tenure systems at the local level, and understand how regularization efforts interact and fit into these preexisting norms. In the case of the SigTierras Program, the slow rate of finalizing the regularization process was in part ascribed to the high economic and opportunity costs that farmers faced to obtain formal title (IDB, 2018). Given that some of the Program's advantages, such as access to public programs or credit, could be realized once a georeferenced parcel map was obtained, it is likely that the benefits of this informal document sufficiently outweighed the additional cost of obtaining a title. It should be noted, however, that only formal legal title can maximize benefits of tenure security, particularly if legal ownership is required as proof in a court of law in case of land conflicts, or in order to improve the efficiency of land market transactions. To further understand the potential tradeoffs between full legal title and a lower-cost alternative to formal title, future research should focus on the adoption of an evaluation design that makes it difficult to assess the differences in women's empowerment of two treatment groups: having a parcel map versus a formal land title in the name of both spouses/partners.

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Appendix

Table A1: Results on Man's Resources

	Man applied for credit (1)	Man received credit (2)	Man has savings (3)	Man generated income (4)
Treated	-0.009	-0.012	**-0.046****	**-0.032***
	(0.03)	(0.03)	(0.02)	(0.02)
Observations	1,382	1,382	1,382	1,382

Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).

Table A2: Results on Man's Wage and Investment Decisions

	Main occupation is non-agricultural (1)	Man earned wage income (2)	Wage income (3)	Invested in own business (4)	Amount invested in own business (5)
Treated	**0.062***	0.050	399.1	0.012	1.561
	(0.03)	(0.03)	(256.10)	(0.02)	(40.32)
Observations	1,382	1,382	1,382	1,380	1,380

Note: Robust standard error in parentheses. Differences are non-zero if the p-value is significant at confidence levels of 99(***), 95 (**) or 90 (*).