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Infrastructure and Environment Sector

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# Estimating the Impacts of a Fruit Fly Eradication Program in Peru: A Geographical Regression Discontinuity Approach


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## Abstract

In this paper, we evaluate the short term impact of a Fruit Fly Eradication Program in the coastal areas of Peru. Exploiting arbitrary variation in the program's intervention borders, as well as precise geographic location data of farmer's households, we use a Geographical Regression Discontinuity (GRD) approach to identify the program's effects on agricultural outcomes. For this purpose, baseline and follow up surveys were collected for 615 households -307 treated and 308 controls- . Baseline data shows that producer and farm-level characteristics in treated and control areas are balanced. This confirms that the program's intervention borders were set only as a function of financial and logistic restrictions and independently of the pest incidence levels and/or other producer and/or farm characteristics. The results show that farmers in treated areas improved pest knowledge and are more likely to implement best practices for plague prevention and control. Beneficiary farmers also present increased fruit crops productivity and sales. The robustness of these findings is confirmed using placebo tests.



**Keywords:** Agricultural Productivity; Policy Evaluation; Geographic Regression Discontinuity; Vegetable Health; Peru.

**JEL Classifications:** H41; O12 ; O13 ; Q12; Q13; Q18.

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## 1. INTRODUCTION

Fruit production in Peru has increased constantly over the last decade. On average, the area harvested with fruit increased 2% each year between 2001 and 2012, while fruit production increased 3.5% each year for the same period (FAO, 2015). Since 1990, fruit and vegetable exports have increased at an average annual rate of 16 percent, a faster growth rate than Peruvian merchandise exports as a whole (FAO, 2009).

The fruit fly is one the most harmful agricultural plagues affecting horticultural crops in Peru. SENASA, the National Sanitary Agricultural Authority of Peru, estimates losses in total production due to fruit fly infestation of at least 30%; also, about 233,000 fruit producers in Peruvian coastal regions are directly affected by the pest (SENASA, 2009).

Damaged fruit crops -which results in lower agricultural income due to increased losses- is the most important effect of fruit fly infestation. However, high pest prevalence also increases production costs, influences farmers' crops rotation decisions, and affects access to international markets. Hence, eradication of the plague is expected to generate important economic benefits.

Private pest eradication by individual farmers poses serious challenges, which are mainly due to externalities, coordination failures and information asymmetries. Consequently, private investment is likely to be suboptimal and therefore insufficient to achieve definitive eradication.

Given the potential benefits of pest eradication and the challenges posed to private investment, the SENASA initiated a fruit fly eradication program in the coastal area of Peru with the support of the Inter-American Development Bank. The intervention comprises a package of complementary activities that include: i) farmers training in pest prevention and control, ii) sterile male releases to reduce fruit-fly population, iii) application of species-specific insecticides, and iv) the implementation of quarantine centers to monitor, detect and restrict access of infested fruit from untreated areas.

This program has been implemented in three phases from 1998 to 2014 covering more than one million hectares of agricultural land and 150,000 hectares of host crops in the coastal area (SENASA, 2015). The program started in 1998 in the most southern regions of the country (border with Chile) and has been gradually expanded to the northern

regions. For each phase, a region of intervention is defined and all agricultural valleys within the region are treated as leaving untreated valleys imposes serious risks in terms of plague prevalence. Once a phase finishes and the area is treated, a subsequent treatment region, adjacent to the previous phase, is identified to receive the treatment.

This implementation strategy continuously creates intervention borders or frontiers, with treated and untreated agricultural valleys at either side of the border. Therefore, the intervention border sets an allocation rule defined by a geographical discontinuity which allows us to use a Geographical Regression Discontinuity (GRD) approach to estimate the program impacts. This approach is valid as the determination of the program borders is unrelated to factors such as plague incidence, crop varieties, farmer's characteristics or interest groups. Specifically, the location of the border is purely determined by budget constraints and geographical continuity. This implies that selection into the program resembles a Randomized Control Trial (RCT) in the neighborhood of the intervention border. Therefore, it is expected that agricultural producers in the neighborhood close to the border are to be similar in terms of their observable and non-observable characteristics. In this paper we exploit pre-treatment data to show that relevant characteristics evolve smoothly at the intervention border, which validates using a GRD approach to identify the Fruit Fly Program impacts.

Other studies have tried to measure the impacts of fruit fly eradication programs in Peru. Barrantes and Miranda (2006) use gravitational equations to estimate the impact of the Fruit Fly Program on fruit exports in Peru. The authors find that the program increased the value of fruit exports (in dollars) between 197 and 327 percentage points in the period from 1994 to 2005. However, this is a country-level analysis and does not provide insights into the effects at the individual producer level.

At the micro level, GRADE (2010) uses Propensity Score Matching and Differences in Differences estimates to identify the program impacts on agricultural producers. The authors find that program participation increased fruit yields per hectare (118%), household agricultural income (220%) and self-reported value of the land (125%). Nevertheless, the study by GRADE presents several limitations. First, the authors defined as treated those framers who reported receiving information and/or training in fruit fly related issues from SENASA. However, self-reporting is likely to be biased by unobservable characteristics

which weakens causal identification. Also, as mentioned, the program treatment involves a wide range of activities beyond training and information. Finally, in several cases the control and treatment agricultural areas included in this study belong to geographically distant and therefore likely to be systematically different agricultural regions, hence the common trend assumption behind the *diff-in-diff* approach is unlikely to hold.

This study overcomes these issues by defining treated farmers as those who reside within the intervention region (set by SENASA following geographic continuity and budget availability) and comparing immediately adjacent geographic areas with similar pre-treatment characteristics. The results from this estimation show that the program was successful on promoting the adoption of preventative measures to control the plague, increasing value of production and improving income from fruit sales. On the other hand, use of insecticides does not seem to be reduced by program implementation.

Our results are based on a follow-up survey implemented in 2014 in the intervention border areas that correspond to the third phase (Phase 3) of the Fruit Fly Program. They are short term results in the sense that they measure outcomes corresponding to the agricultural year that immediately followed the program implementation in the treatment zone. Our findings suggest that farmers in treated areas objectively know more about the pest and are more likely to implement best practices for plague prevention and control. They also experience increased agricultural sales and productivity (measured as value of production per plant), which is driven by an increase in fruit crops output and fruits sales. The robustness of our findings is also confirmed by two placebo tests: first, these effects are only observed for fruit crops, .e. the ones affected by the eradicated pest; second, no similar patterns are observed in the pre-treatment period.

This paper develops as follows: Section 2 introduces the Fruit Fly Program; Section 3 describes the GRD methodology and assesses its validity; Section 4 discusses the data and analyses the pre-treatment characteristics in treated and control areas; Section 5 presents the short term results, and finally Section 6 concludes and discusses future research work.

## 2. THE SENASA FRUIT FLY INTERVENTION

The fruit fly (*Ceratitis Capitata and Anastrepha spp*) is one of the most damaging plagues that attack fruits and other plant crops in Peru. In fact, losses due to fruit fly infestation are estimated to be at least 30% of total host crops and about 233,000 fruit producers in Peruvian coastal regions are directly affected by the pest (SENASA, 2009).

Figure 2 details the fruit fly life cycle. The female fly, which can lay up to 500 eggs, deposits its eggs inside the host crop where the larvae develops. The larvae feed upon the pulp and thus destroy or damage the infested crop. After feeding, the larvae leave the fruit and seek for dry and dark cover where they transform into pupae (a resting stage). The adult flies emerge from the pupae, and are ready to reproduce in approximately two days.

The fruit fly affects agricultural producers by damaging agricultural production, imposing higher agricultural expenses due to implementation of plague control measures, reducing fruit quality and value, as well as restricting access to international and local markets due to sanitary restrictions imposed to infested areas. Other negative effects related to the prevalence of the fruit fly might include lower agricultural land value in infested zones. These problems reduce farmers' incentives to plant fruits and other hosts crops, known to have higher value than traditional crops, due to high risk of plague attack.

Challenges related to private eradication of the plague are threefold. First, the presence of information asymmetries impedes farmers from acquiring the proper knowledge about prevention and control measures, as well as the consequences related to high plague prevalence[1]. Second, maintaining low plague prevalence and presence of free zones requires constant monitoring and control of host products transportation, imposing serious coordination problems. Finally, the presence of externalities is likely to influence individual behavior. In fact, the payoff from implementing prevention and control measures by one farmer will strongly depend on the decision of nearby producers to implement similar measures.

Given the difficulties related to private eradication, SENASA –the Peruvian agricultural phytosanitary national authority- started the Fruit Fly eradication Program in

[1] As we will show later in the results section; untreated farmers seem to objectively know less about the plague than treated ones.

1998, which aims to declare the Peruvian coastal zone free from the plague[2]. The fruit fly program is a comprehensive intervention that involves the following activities: i) technical assistance to provide farmers with information about pest specific features as well as training on best practices for pest prevention and control; ii) installation of fruit fly traps to monitor plague prevalence, iii) application of fruit fly specific insecticides, iv) release of male sterile flies to prevent plague reproduction, and v) implementation of quarantine centers to monitor, detect and restrict the access of infested host crops into treated regions. All the activities were implemented by technical staff of SENASA exclusively.

As mentioned, the program is being gradually implemented by phases. During each phase a specific region in the coast of Peru is treated. The treated zones are determined based on geographic continuity and budget availability. Once the treatment has been completed in a specific area, the intervention begins to be implemented in the immediate adjacent area moving progressively from the most southern area of the coast towards the north of the country. Thus far, a total of three phases have been implemented. Phase 1 of the program started in the agricultural areas adjacent to the border with Chile (green area in Figure 3) and included the agricultural valleys in the Regions of Tacna, Moquegua and Arequipa, covering 19,084 hectares of host crops and 47,015 agricultural hectares. Phase 2 (in yellow) implemented from 2006 to 2009, covered 40,252 hectares of host crops and 249,597 agricultural hectares. Finally, phase 3 (in orange), implemented from 2009 to 2014, extended the program to the northern areas of the country and covered 95,381 hectares of host crops and 756,746 agricultural hectares. The areas colored in gray correspond to the currently untreated agricultural valleys that will be included in future stages of the program. This impact evaluation focuses on the phase 3 of the program, which was implemented in the agricultural valleys located in Lima, Ancash and La Libertad.

## 3. EMPIRICAL METHODOLOGY

Geographic Regression Discontinuity (GRD) designs where the allocation variable that determines treatment status is multidimensional (latitude-longitude), constitutes a special type of the well-known Regression Discontinuity approach (Keele and Titiunik

[2] In Peru, the agricultural phytosanitary policies are exclusively designed and implemented by the national authority, in this case SENASA. The regional, provincial and district phytosanitary authorities depend directly from SENASA, and execute the SENASA’s national policies.

(2015)). GRD has been widely applied in the impact evaluation literature. For instance, Black (1999) exploits school district borders in the United States to assess parental valuation of school quality, and Dell (2010) uses arbitrary colonial administrative borders to identify the long-term impacts of extractive institutions (*Mitas*) in Peru. Mullainathan and Sukhtankar (2011) take advantage of arbitrary sugarcane selling zones -farmers living within a zone are forced to sell sugar to the mill designated to that zone- to assess how land ownership structures influence production, credit access and consumption of farmers in India. Lastly, Datar and Del Carpio (2009) exploit a discontinuity between areas in rural Peru affected by an irrigation project to evaluate its impact on farmers' agricultural production and economic welfare.

GRD designs have also been applied in the field of political science (Gerber et. al (2011), Huber and Arceneaux (2007), Krasno and Green (2008) and Posner (2004)). These studies exploit the general fact that laws, regulations, political parties and advertisement campaigns are strongly influenced by geographical borders. However, to the best of our knowledge, this study is the first that uses a GRD design to identify the impacts of a vegetable health program.

Figure 4 shows the intervention border corresponding to the third phase of the program (the area enclosed in the red circle in figure 3). The area in blue depicts the treated districts adjacent to the border, while the area in red shows the untreated districts adjacent to the program border. A section of the border represented in figure 4 is expanded in figure 5. The red and blue dots represent control and treatment villages respectively, the green dots represent individual producers, and the yellow dots correspond to the fruit fly traps installed by SENASA.

Figures 4 and 5 show that the program implementation strategy, based on geographic continuity, creates an intervention border with treated and untreated agricultural valleys (producers) at either side of the frontier. Therefore these intervention borders constitute a geographical allocation rule: at a given point in time, agricultural valleys located at one side of the boarder receive the treatment while valleys located at the opposite side do not receive treatment. These borders constitute a multidimensional discontinuity in latitude and longitude, which allows us to use a regression discontinuity approach to identify the causal impacts of the program.

However, the existence of an intervention border or frontier does not guarantee the validity of a GRD approach. In fact, two problems can be of concern when using this methodology: (i) endogeneity of the border placement; and (ii) endogeneity of producer’s location. The first problem would be troublesome if the border location was determined based on characteristics that might affect the outcomes of interest such as plague prevalence levels or presence of host crops. According to SENASA, the interventions borders corresponding to the third phase were set independently of pest incidence levels, vulnerable crop varieties or any other agricultural variable. Also, potential beneficiaries or interest groups (such as regional or provincial governments) did not have any role in determining or influencing the program’s coverage area as geographic continuity is a crucial factor to plague eradication. In fact, the area of intervention was solely defined on financial and logistic restrictions.

Despite this, the geography of the Peruvian territory might pose a problem to exogeneity of border placement. For instance, the border may coincide with abrupt geographical changes due to the presence of the Andean mountains. Hence, agricultural characteristics, plague incidence levels and market access are unlikely to evolve smoothly at the intervention border invalidating the GRD approach. Following Lee and Lemieux (2010), to corroborate exogeneity of border placement we tested that relevant factors vary smoothly at the intervention border using pre-treatment data. The next section explores this issue in depth.

The second problem, endogeneity of producer’s location, is related to the possibility that farmers might migrate from untreated to treated regions in order to receive the program. However, land markets in rural areas of Peru are thin and land transactions are difficult to conduct in short-term basis. Besides, there is a strong connection between land tenure and farmers’ social networks, particularly in the case of small landholders which is the focus of this study. Last and foremost, post-treatment data confirms that farmers’ mobility across treatment areas was not of concern.

Another issue that needs to be addressed is the possibility of geographical spillovers. Spillovers might occur because contaminated fruit is mobilized from untreated to treated areas reducing the effectiveness of the intervention. However, as part of the intervention, the SENASA implements quarantine centers that control and restrict the

mobility of infected host crops to treated areas. Also, spillovers might take place through peer-learning effects. Specifically, non-beneficiary farmers located close to the border might be likely to adopt preventative and control measures due to word-of-mouth or learning through observation. Although peer-learning effects are feasible, its impact is limited as it would not be accompanied by other activities included in the intervention package (i.e monitoring traps, insecticide use and quarantine centers). Besides, a knowledge test applied on the field confirms that beneficiary farmers are more knowledgeable about the plague features and control measures than control farmers. In either case, it is important to mention that the presence of spillover effects either through plague contamination from untreated areas or peer-learning would downward bias the estimates and therefore, the impact found would provide a lower bound estimate.

As mentioned, this study focuses in the intervention border that corresponds to the third phase of the program. As shown in Figures 4 and 5, there is relatively close geographic proximity between agricultural producers at either side of the border (in terms of distance). This fact is confirmed by GPS data which indicates that the average distance between a given farmer in one side of the border and his closest one in the opposite side is approximately 18 km (11.1 miles). The minimum distance is close to 0.5 km (0.3 miles) and the maximum is 39.5 km (24.5 miles). Also importantly, as in Dell (2010), the intervention border transects the Andes mountain region, and therefore agricultural valleys at either side of the boarder are located at similar altitude ranges. In the next section we analyze pre-treatment variables to corroborate that relevant agricultural features evolve smoothly at the intervention border, which validates using a GRD approach in this context.

Lastly, we restrict our empirical study to the treated and untreated areas that exclusively lie within La Libertad region. Given that other parts of the intervention border (not analyzed in this paper) coincide with administrative borders, this provides additional evidence to rule out the possibility of compound treatments biasing our estimates (Keele and Titiunic (2015)).

Given that border determination is based on geographic continuity and budget availability, and relevant characteristics evolve smoothly at intervention frontier, we use a GRD design to identify the causal impacts of the fruit fly eradication program. The following estimation equation will be estimated:

$$Y_{ij} = \alpha + \rho MF_j + \beta f_{ij}(geographic\ location) + \pi X_{ij} + \varepsilon_{ij} \quad (1)$$

In equation (1) $Y_{ij}$ represents the outcome variable of interest corresponding to producer $i$ in village $j$. The outcomes to be analyzed are: producers' knowledge of the plague, implementation of best practices on control and prevention, value of agricultural production, value of fruit sales, agricultural income and crops portfolio decisions. The term $MF$ is a dummy variable that takes the value of 1 if the producer's village is located within the treatment area and 0 otherwise. Therefore, $\boldsymbol{\rho}$ is the causal parameter of interest and captures the impact of the program. The term $f_{ij}(.)$ is the individual RD polynomial and is a smooth function of the producer´s geographic location. In this study various functional forms for this term are explored including lineal polynomial in latitude and longitude as well as quadratic polynomial[3]. The inclusion of the RD polynomial is crucial in order to separate the treatment effect from the smooth effects of geographic location (Dell, 2010). Also, proper specification of the RD polynomial avoids interpreting a non-linearity in the data structure as a treatment effect (Angrist and Pischke, 2009). Finally, the vector $X_{ijn}$ represents farmers' socio-demographic and agricultural characteristics.

## 4. DATA

The data used for this analysis is a panel data composed by two rounds. The baseline survey collected information for the entire agricultural cycle of the year 2011 and was collected from May to June 2012. This survey was applied in all the treated and untreated districts adjacent to the intervention border (districts in blue in Figure 4 and 5) to 680 agricultural fruit producers -336 treated and 344 controls- in 47 villages. The baseline survey contains relevant information related to household's agricultural activities such as cultivable land size, crops portfolio, agricultural output, agricultural inputs, agricultural income, access to credit, etc. It also captured information related to non-agricultural activities, household's composition, dwelling characteristics and membership in social organizations. Finally, the survey included a specific fruit fly section to capture farmers' knowledge on plague characteristics and adoption of preventative and control practices.

[3] Being $x$ and $y$ the latitude and longitude, respectively, a lineal polynomial in latitude and longitude is represented by $x + y + x \cdot y$, whyle a quadratic polynomial is represented by $x^2 + y^2 + x + y + x \cdot y$.

A follow up survey was collected between June and July 2014 capturing information about the agricultural activities conducted in the first half of 2014. The surveys gathered information for 615 households: 307 treated and 308 controls[4]. The survey questionnaire in the follow-up is identical to the baseline questionnaire. Yet, a Fruit Fly knowledge test was included in order to assess farmers' knowledge. This test contained 13 questions related to plague specific characteristics, and prevention and control measures. Note that, in the treated areas of this analysis, the program was implemented during the second and third quarters of 2013. Therefore, the estimation results should be interpreted as short term impacts of the intervention.

According to SENASA specialists, all the agricultural valleys included in the neighborhood assessed in this analysis constitute a relatively uniform geographical area. Moreover, this is the only region for which the intervention border does not coincide with an administrative border, both treatment and control groups are located within the same Department (La Libertad). The rest of the sample is located in areas in which the treatment border coincides with an administrative regional border separating La Libertad and Cajamarca departments (depicted by a green line in Figure 4). Therefore systematic differences between treated and control groups are more likely to take place. In future versions of this paper, we will expand the analysis to the rest of the neighborhoods located in the intervention border defined in Figure 4.

To corroborate the validity of applying a GRD methodology, we analyze the baseline characteristics for treated and untreated producers in the neighborhood along the intervention border. The importance of this comparison is twofold. First, if the border placement is exogenous, we must expect producers' baseline characteristics to be similar between treated and untreated areas. Further, this similarity must be stronger at closer distances from the border. Second, using pre-treatment data allows us to compare baseline values for the main outcomes of interest. That is, those variables that are expected to be influenced by the intervention. If outcome variables are similar for treated and control units

[4] A total of 65 households interviewed in the baseline could not be located during the follow up. This represents an attrition rate of 9.9%. The attrition rate considered during the sampling design was of 10%. Households that were not interviewed in the follow up are equally distributed among the treatment and control areas and not systematic pre-treatment differences were found between both groups. This suggests that attrition is randomly distributed and introduces no bias in our study.

in the baseline, then it is reasonable to attribute post-treatment changes to program participation. Following Keele and Titiunik (2015), instead of using Euclidian distance to the border, we define distance to the border as the distance between a beneficiary farmer and its closest control (located on the other side of the border). Figure 6 helps to clarify this. In this figure the dashed line represents the border, while points A, B and C represent three producers.

It is clear from Figure 6 that Euclidian distance to the border does not capture the real location of points *B* and *C* in the map, as it does not account for location along the border. Euclidian distance to the border will treat producers *B* and *C* as equally distant from producer *A* in the treatment area when in fact producer *B* is much closer to producer *A* than *C*. As Keele and Titiunik (2015) clearly point out, this problem worsens as the boundary lengthens, and using the perpendicular distance to the boundary as the score might mask important heterogeneity. Therefore, in order to obtain comparable treatment and control groups, and given the difficulties embedded in *naïve* linear distance, we exploit the precise GPS information in our baseline data and define our distance measure as the distance between a given producer and the closest producer in the opposite side of the border.

Table 1 presents a set of household (Panel 1A) and farm pre-treatment characteristics (Panel 1B) for the treatment and control groups. Following the approach by Dell (2010, 2015), we use the following arbitrary distances to define the comparison bandwidths: 6 km, 13 km and 34 km from the intervention frontier. These distances contain the 25%, 50% and 75% closest producers to the program border respectively. Panel 1A shows that, independently of the comparison bandwidth chosen, the age, sex and education of the household head, as well as access to home electricity, phone availability and total number of rooms in the dwelling, are balanced and very similar among control and treatment units. Panel A in Table 1 also shows that at the 34 km bandwidth, there are statistically significant differences between treatment and control in access to drinking water and household dependency ratio. However these differences become not statistically significant when closer to the border. In the case of water access, the difference also decreases in absolute size. Also in the neighborhood located at 6 km from the border, there are statistical significant differences between treated and controls in terms of household size, however this difference is relatively small (controls have 0.5 more members), and the

difference is not statistically significant using other bandwidths. In general, this suggests that beneficiaries are very similar to control farmers in household characteristics.

Panel 1B shows that control and treatment groups are also very similar in terms of farm characteristics. Comparing households at the 34 km bandwidth, farms have similar agricultural area (in hectares) allocated to fruit crops, similar access to modern irrigation, and present the same type of crop varieties (avocado and banana). They only differ in terms of the proportion of area allocated to fruit crops; but this difference diminishes and becomes statistically insignificant as we approach the treatment border. Also note from Panel 1B that all characteristics are statistically similar between treated and control groups when comparing them at the 6 km bandwidth. This corroborates that farmers located closer to the border are indeed similar.

Panel 2A in Table 2 compares treated and control groups in terms of pest knowledge, adoption of pest prevention and control measures, and access to fruit fly training by SENASA. The proportion of treatment and control units that report adopting control or prevention measures is very similar in all comparison bandwidths. This is also the case for the proportion of farmers who reported receiving fruit fly training. Nevertheless, there are some differences. The proportion of farmers who reported having heard about the pest is higher in control than in treated areas (although this difference is only statistically significant at the 10% level and at the 6 km bandwidth). Also, control units are more likely to report being affected by the plague during the baseline year, although this difference is not statistically significant at the 13 km distance range. To account for these initial differences, these variables were included in the econometric estimations.

Table 2, Panel 2B compares variables related to farmers' agricultural outcomes. This table shows that agricultural output (production in kgs per hectare) is very similar between treatment and control groups at all bandwidths. Also this difference diminishes at a closer distance from the border. A similar pattern is observed for total fruit production, total fruit sales and proportion of fruits to total crops sold as differences between control and treatment groups diminish when approaching the border and disappear at the smallest bandwidth. Lastly, total non-fruit production, fruits value of production ( US$ per

productive plant), non-fruit crops value of production (US$ per hectare), total agricultural sales, fruit crop losses and insecticide use are balanced throughout the different bandwidths.

Panel 2C also shows that there are not statistical significant differences in the price received per kilo of fruit sold between both groups. This suggests that fruit quality and market access is similar between both groups.

The results in Tables 1 and 2 confirm that control and treatment units are very similar in household and agricultural characteristics as well as outcome variables in the pre-treatment period. Also, similarities become stronger in closer areas to the intervention border. Although there are few variables for which differences are still present, they are included as control variables in the econometric estimations in order to account for initial differences.

Overall, these comparisons suggest that relevant pretreatment characteristics, other than treatment status, evolve smoothly at the intervention border. This validates using a GRD approach in this neighborhood of the intervention frontier in order to identify the program short-term impacts.

## 5. GEOGRAPHICAL REGRESSION DISCONTINUITY ESTIMATES

### *5.1. RESULTS*

For the regression discontinuity approach to be valid, we should observe some sort of discontinuity of the outcome variable at or near the cut-off point. Results for the main outcome variables can be seen in the panels of figure 7[5]. All the panels in Figure 7 show the distance to the border (measured as the distance to the closest neighbor in the opposite group) in the X-axis. Following Calonico et. al. (2015a), points at the right of the cut-off (value of cero) correspond to the average value of the outcome for treated units for each binned sample means, and points to the left of the cut-off contain values for the controls. We use a third order global-polynomial to approximate the population conditional mean functions for control and treated units.

For all the four response variables shown, the “jump” at the cut-off indicates that the change in the location of the household at the intervention border generates a discontinuity

[5] The graphics for the rest of the variables are available upon request.

for the outcome variable. Compared to the control group, households located in the treated region are more likely to implement fruit fly prevention and control measures, have greater scores in the fruit fly knowledge test, show greater sales of fruit crops and greater value of production per fruit plant.

This “jump” at the cut-off can be interpreted as the causal impact of the Fruit Fly program on the outcomes. The location of the intervention border was set exogenously and only as a function of financial and logistic restrictions (the balancing of pre-treatment data in section 4 supports this exogeneity), and we rule out any endogeneity in the location of beneficiary and control farmers. All this suggests that the program allocation rule approximates a randomized process in the neighborhood of the intervention border, and the assignment of treatment is the only factor that generates this “jump” in the outcome variable at the cut-off. In what follows we estimate the RD equation defined in (1) to identify the Fruit Fly Program causal effects. Considering that the Program was implemented during the second and third quarters of 2013, and the follow-up data was collected for the first semester of 2014, the results should be interpreted as short term impacts of the intervention.

Table 3.1 explores the Fruit Fly Program effects on farmers’ pest knowledge, as well as on farmers’ self-reported adoption of prevention and control measures. The regressions in Table 3 are estimated at the same comparison bandwidths that were defined in Section 3: 6 km, 13 km and 34 km from the border (these arbitrary distances contain the 25%, 50% and 75% closest producers to the border respectively). Two functional forms are estimated at the 6 km bandwidth: in column 1 we only control for treatment status, while in column 2 we also control for latitude and longitude. At the 13 km bandwidth we control for latitude and longitude. Finally, at the 34 km bandwidth we include a quadratic polynomial in latitude and longitude[6].

These different specifications were chosen according to the number of observations at each bandwidth. As Dell (2010) points out about a multidimensional RD polynomial, one drawback is that some of the necessary datasets do not provide enough power to precisely

[6] We also estimated the same regressions with a polynomial with the linear distance to the border for the 6 km. bandwidth, and with quadratic polynomial in distance to the border for the 13 km. and 34 km. bandwidths. All the coefficients and statistical significances stay robust among the different specifications. These results are available upon request.

estimate a very flexible specification. The multidimensional RD polynomial also increases concerns about over-fitting at the discontinuity, as a given order of a multidimensional polynomial has more degrees of freedom than the same order one-dimensional polynomial. Following Gelman and Imbens (2014), we estimate a linear polynomial in latitude and longitude for the 6 km. bandwidth (with only 151 observations) and for the 13 km. (with 299 observations), while we estimate a more flexible RD polynomial (a quadratic polynomial in latitude and longitude) for the 34 km bandwidth, that contains 382 observations.

One of the main activities implemented by the program is the diffusion of pest information and technical assistance by SENASA specialists. In line with this, the first row in Table 3.1 shows that treated farmers are 10 percent more likely to report having some type of knowledge about the fruit fly . Although this result is only significant at the 6 km bandwidth, the coefficient size is relatively stable among all specifications (with the exemption of column 3).

In order to objectively assess the effect of the program provision of information and technical assistance on producers' pest knowledge, together with SENASA, we designed a Fruit Fly test which was applied to farmers in both treated and untreated areas. This test includes 13 questions: 6 questions related to the plague particular characteristics such as its reproductive cycle and behavior (theoretical section); the other 7 are related to the plague specific prevention and control measures such as traps installation and adequate disposal of infested fruit (practical section). Rows 2 to 4 in Table 3.1 show the program effect on total test score[7]. The results for the test score(Row 3 in Table 3.1) suggest that treated farmers answer correctly more questions than control ones, although this result is only significant for the 34 km bandwidth in which we control for a quadratic polynomial in latitude and longitude.

Given that producers in treated areas seem to have improved their pest knowledge, it is also expected for them to have improved pest management at their farms by implementing prevention and control practices. The results in Table 3.1 confirm this hypothesis. Specifically, treated farmers are 34 to 35 percentage points more likely to implement pest prevention and control measures relative to the control group.

[7] Not significance was found separately for either theory or practical sections.

Table 3.2 presents the same regressions including additional control variables, the results are very similar[8].

So far the evidence presented suggests that treated farmers have improved their pest knowledge, and are more likely to implement pest prevention and control practices. In what follows, we will explore whether households' improved pest knowledge and management, combined with other activities implemented by SENASA in treatment areas (such as pest specific pesticide applications), have translated into improvements in agricultural production and income.

The program effects on agricultural outcomes are analyzed in Table 4.1, which has the same structure as Table 3.1 in terms of the comparison bandwidths as well as geographic RD polynomials. The first row in Table 4.1 presents the effect of the program on total agricultural production (measured in kilos). The coefficient point estimates indicate that treated farmers increased their total production in approximately 100 to 145 percentage points (0.70 to 0.92 log points) compared to the control group. At the 6 km bandwidth, the effect is statistically significant in both specifications, and it remains significant at the 13 km bandwidth at the 5% significance level. When we move to the 34 km bandwidth, the effect is not statistically significant. Regarding sales, treated households have higher agricultural sales than untreated ones. The effect on this variable is relatively stable across all specifications, and it is statistically significant at the 13 and 34 km bandwidths (in all cases at the 10% significance levels). At these comparison bandwidths, the effect of treatment on total agricultural sales ranges from 230 to 380 percentage points (1.20 to 1.57 log points).

To confirm that the increment observed in total production and sales is driven by the program impact on fruit crops (which are the ones affected by the pest), table 4.1 show the program impact on fruit production, fruit sales, the proportion of fruit to total sales ratio, and productivity (measured as the value of production of fruit per productive plant).

The results show that treated farmers have greater agricultural output of fruits (65%), greater fruit sales (266%) and higher proportion of fruit sales with respect to total

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[8] Control variables include household, head of household characteristics, total agricultural area with fruit crops, baseline values for the outcome variable and variables unbalanced in panel 2A of table 2 (whether the household has heard about the plague and whether the production was affected by the Fruit Fly).

sales (19%). Finally, the program also has a positive impact on fruit productivity. The results show that the program increased value of production by 15% on average.

We do not find significant impacts of the program on fruit crop losses or insecticide use (value or quantity applied). However, the estimates for insecticide use have the expected negative sign, stable across all specifications.

Table 4.2 presents the results to the regressions shown in Table 4.1 including additional control variables[9]. The results are very similar to those presented in table 4.1.

Lastly, results in tables 3.1 through 4.2 are consistent with the ones obtained by bootstrapping the standard errors[10]. However, it is worth to acknowledge the fact that, as the comparison bandwidth narrows, the number of observations decreases. Therefore, this can increase the standard errors and decrease the precision of the point estimates. In this case, however, the significance is still present despite the reduction in the sample size.

Given that beneficiaries lacked perfect control over the assignment variable (the intervention frontier), and that relevant pre-treatment characteristics evolve smoothly as we get closer to the frontier, the results in Tables 3 and 4 can be interpreted as the short term causal effects of the program. Henceforth, the fruit fly program implemented by SENASA has been successful at improving not only plague knowledge and adoption of control and prevention practices, but also fruit production, productivity and agricultural income generated by fruit sales.

### *5.2. PLACEBO TESTS*

To confirm that effects obtained in the estimations represent true causal impacts of the Fruit Fly Program instead of systematic differences between treatment and control areas, we perform some placebo tests. First, we evaluate the effect of the program on pre-treatment outcomes using baseline values as dependent variables (Table 5.1). These results indicate not impact of the program on any pre-treatment outcomes. Second, we test the different specifications using outcomes for non-fruit crops as variables of interest (Table 5.2). As the program must have affected fruit crops only, it is expected to have non-

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[9] Control variables include household, head of household characteristics, total agricultural area with fruit crops, baseline values for the outcome variable and variables unbalanced in panel 2A of table 2 (whether the household has heard about the plague and whether the production was affected by the Fruit Fly).

[10] These are available upon request.

significant impacts in outcomes related with non-fruit crops. Specifically, we use non-fruit output, non-fruit sales and the value of production of non-fruit crops per hectare as dependent variables. Again, not impacts are found. These placebo tests confirm that the impacts found in fruit production crops are capturing true causal effects instead of systematic or uncontrolled differences between treatment and control units. Finally, because all the observations in this study fall within the same administrative region (La Libertad), we can rule out that our results can be confounded by the presence of compounds treatments or characteristics that vary with administrative region.

## 6. Concluding Remarks

In this paper we exploit the intervention borders defined by a nationwide pest eradication program to design a GRD approach in order to identify the program effects on agricultural outcomes. Given that intervention borders were set arbitrarily and that pre-treatment characteristics of treated and control units evolve smoothly at the intervention border, the results obtained using GRD present the causal impacts of the Program.

These findings confirm that the Fruit-Fly Program has been successful at reaching its short term objectives. Specifically, producers in treated areas have a better knowledge of the plague as well as measures for prevention and control. As result of this, they are also able to implement improved plague management at their own farms. Improved plague knowledge and management combined with other activities implemented by SENASA (trap installation and organic pesticide applications), have significantly influenced agricultural production and sales income. In particular, treated farmers increased total production and agricultural sales. These results are driven by the program impact on fruit crops. Explicitly, we find impacts in total fruit production, value of production per plant, total fruit sales and proportion of fruit sold with respect to total sales.

Henceforth, we can confidently conclude that the fruit fly program implemented by SENASA has been successful at improving not only plague knowledge and adoption of control and prevention practices, but also fruit production and agricultural income generated by fruit sales.

The results are robust to different specifications and not likely to be driven by systematic differences between treated and control areas as tested using placebo analysis.

## 7. REFERENCES


Angrist, J. and Pischke, J. (2009). “Mostly Harmless Econometrics: an Empiricist’s Companion.” Princeton University Press.

Banco Interamericano de Desarrollo (1997). Documento del proyecto Programa de Desarrollo de la Sanidad Agropecuaria. Contrato de Préstamo 1025-OC/PE BID.

Barrantes, R. and Miranda, J. J. (2006). Impacto del Proyecto de Control, Supresión y Erradicación de la Mosca de la Fruta en las Exportaciones Peruanas: Un Análisis Empírico. En SEPIA XI. Perú el Problema Agrario en Debate (pp. 377-410). Seminario Permanente de Investigación Agraria.

Black, Sandra. (1999). Do better schools matter? Parental Valuation of Elementary Education. Quarterly Journal of Economics, 114 (2), 577–599.

Calonico, S., Cattaneo, M. D., and R. Titiunik. (2015a). Optimal Data-Driven Regression Discontinuity Plots. Journal of the American Statistical Association, forthcoming.

Datar, G. and Del Carpio, X. (2009). Are Irrigation Rehabilitation Projects Good for Poor Farmers in Peru? The world Bank, Policy Research Working Paper 5154.

Dell, M. (2010). The persistent effects of Peru's mining mita. Econometrica, 78(6), 1863-1903.

Dell, M., Lane, N. and Querubin, P (2015). State Capacity, Local Governance and Economic Development in Vietnam. Working Paper.

Food and Agriculture Organization if the United Nations (FAO). Statistics Division.

Gerber, A. S., Kessler D. P. y Meredith, M. (2011) The Persuasive Effects of Direct Mail: A Regression Discontinuity Based Approach. Journal of Politics 73 (01): 140-155.

Grupo de Análisis Para el Desarrollo (GRADE) (2010). Evaluación Final del Programa "Control y Erradicación de la Mosca de la Fruta en la Costa Peruana". Lima: GRADE. Documento de trabajo, 74.

Hahn, J., Todd, P. y van der Klaauw, W. (2001) Identication and Estimation of Treatments Effects with a Regression-Discontinuity Design. Econometrica 69 (1): 201-209.

Huber, G. A. y Arceneaux, K. (2007) Identifying the Persuasive Effects of Presidential Advertising. American Journal of Political Science 51 (4): 957-977.

Imbens, G. y Lemieux, T. (2008) Regression discontinuity designs: a guide to practice. Journal of Econometrics 142 (2): 615–635.

Imbens, G.W. y Wooldridge, J.M. (2009) Recent developments in the econometrics of program evaluation. Journal of Economic Literature 47 (1): 5–86.

Keele, L. J., and Titiunik, R. (2015). Geographic Boundaries as Regression Discontinuities. Political Analysis, 23(1): 127-155.

Krasno, J. S. y Green, D. P. (2008) Do Televised Presidential Ads Increase Voter Turnout? Evidence from a Natural Experiment. Journal of Politics 70 (1): 245-261.

Lee, D. y Lemieux T. (2010) Regression Discontinuity Designs in Economics. Journal of Economic Literature 48 (2): 281-355.

Mullainathan, S. and Sukhtankar, S. (2011). Ownership Structure and Economic Outcomes: The Case of Sugarcane Mills in India. International Growth Centre, Working Paper Series.

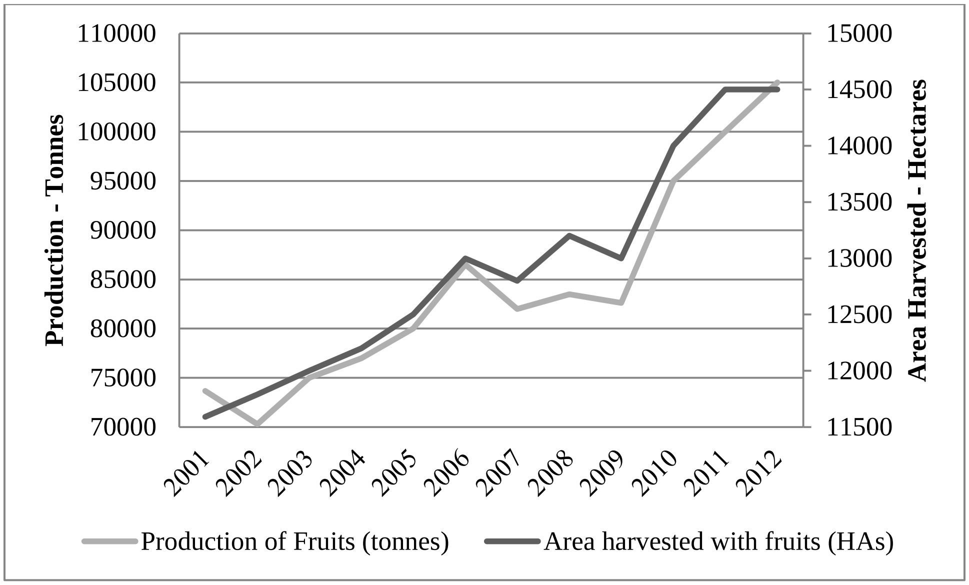
Posner, D. N. (2004) The Political Salience of Cultural Difference: Why Chewas and Tumbukas Are Allies in Zambia and Adversaries in Malawi. The American Political Science Review 98 (4): 529-545.

Servicio Nacional de Sanidad Agropecuaria - SENASA (2009). “Erradicación de moscas de la fruta (Ceratitis capitata y Anastrepha spp.) en las regiones de Lima, Ancash y La Libertad.” Documento no publicado. Lima: SENASA- Ministerio de Agricultura.

Thistlethwaite, D. y Campbell, D. (1960) Regression-Discontinuity Analysis: An Alternative to the Ex-Post Facto Experiment. Journal of Educational Psychology, 51, 309–317.

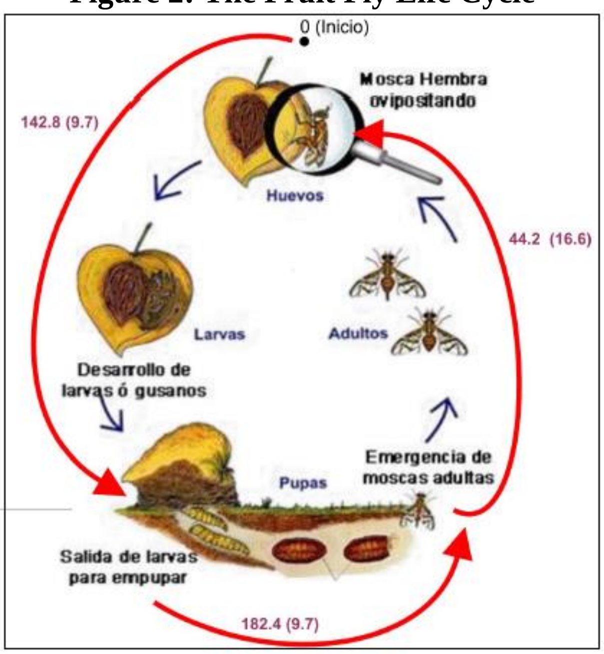
## FIGURES

**Figure 1. Fruit Production in Peru**



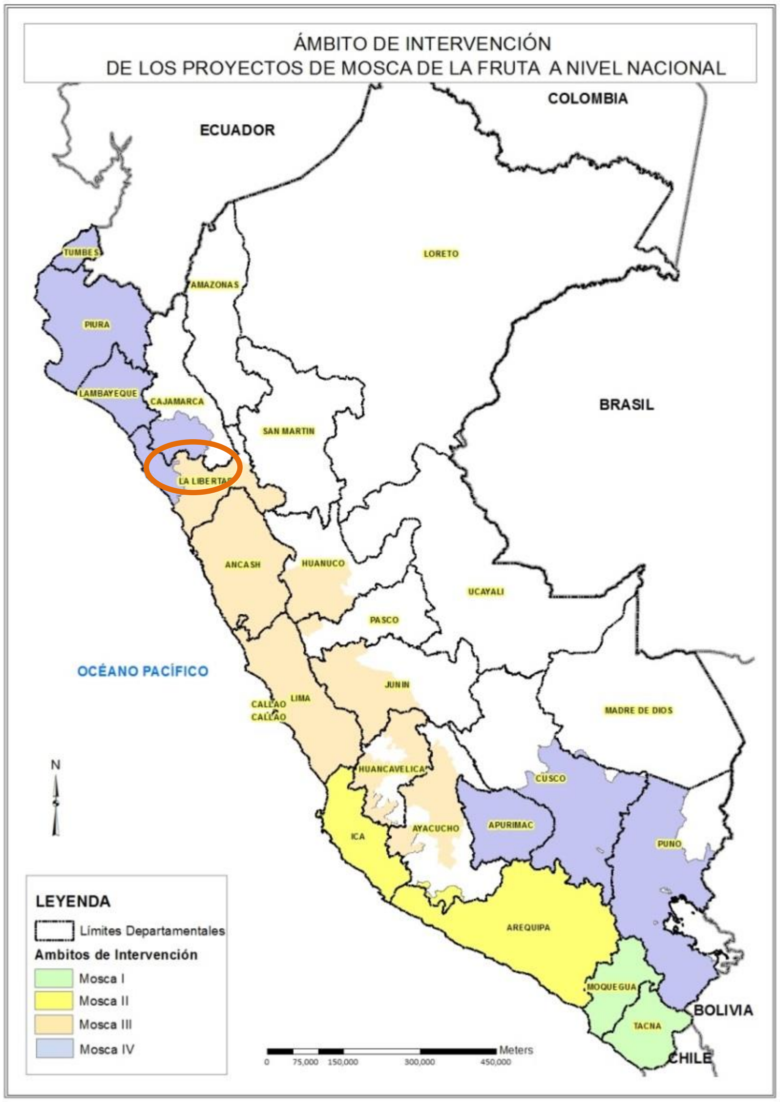

Source: FAO

**Figure 2: The Fruit Fly Life Cycle**




**Source: SENASA**

**Figure 3: The Fruit Fly Implementation Stages**




**Source: SENASA**

**Figure 4: The Fruit Fly Program Border – Phase III**

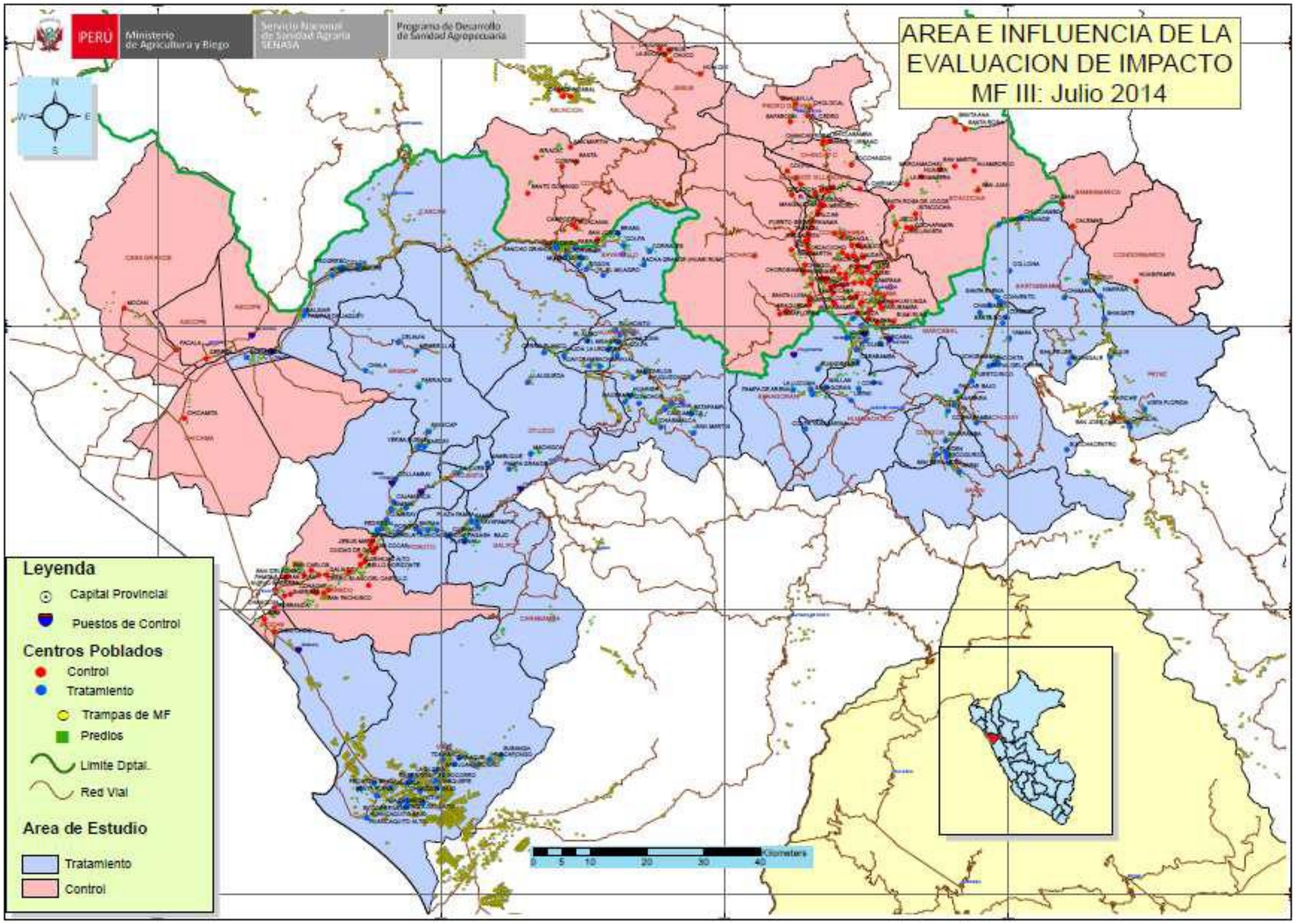


**Figure 5: Section of the intervention border corresponding to Phase 3 of the Fruit Fly Program (treated area in blue)**

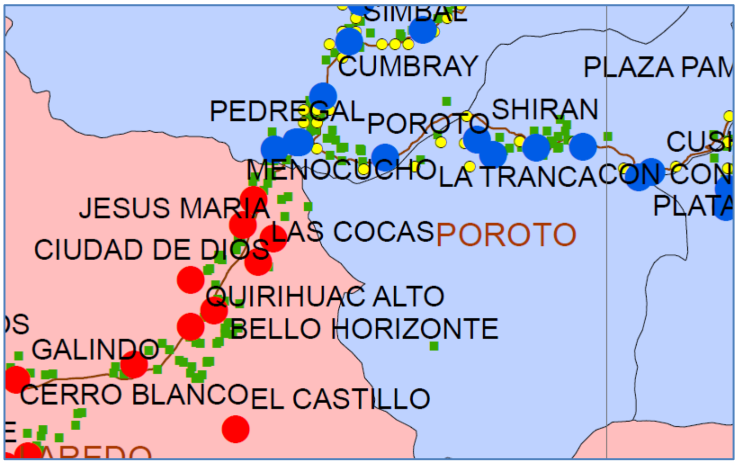



**Figure 6: Estimation of Geographical Distance**

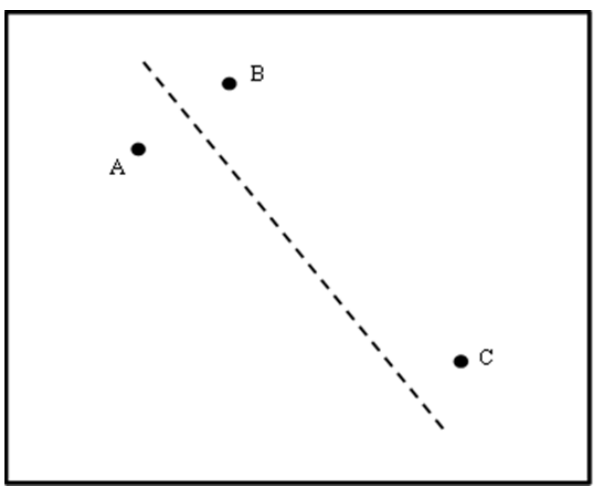
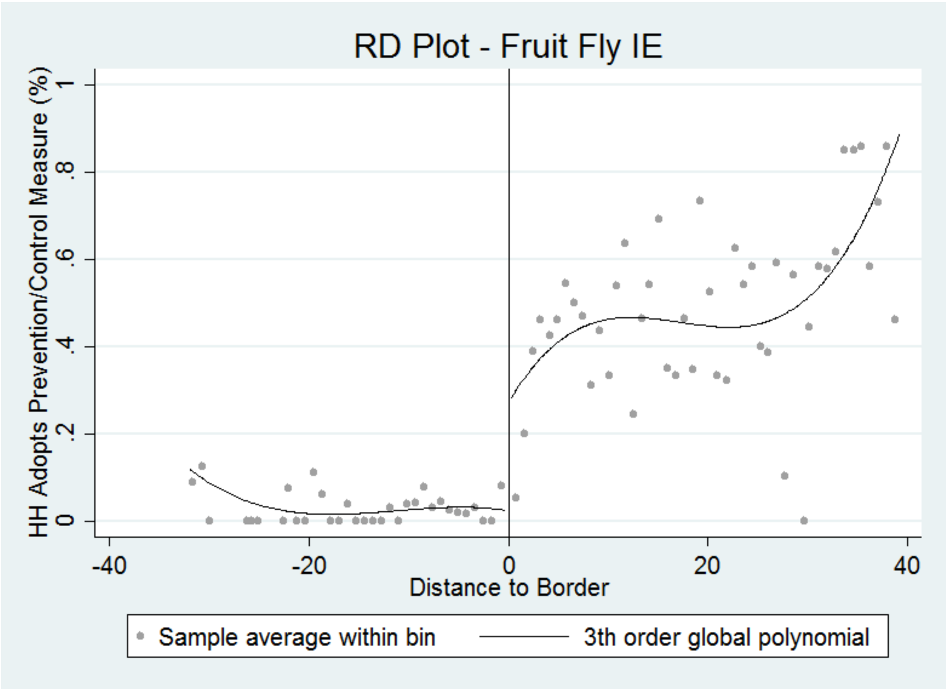
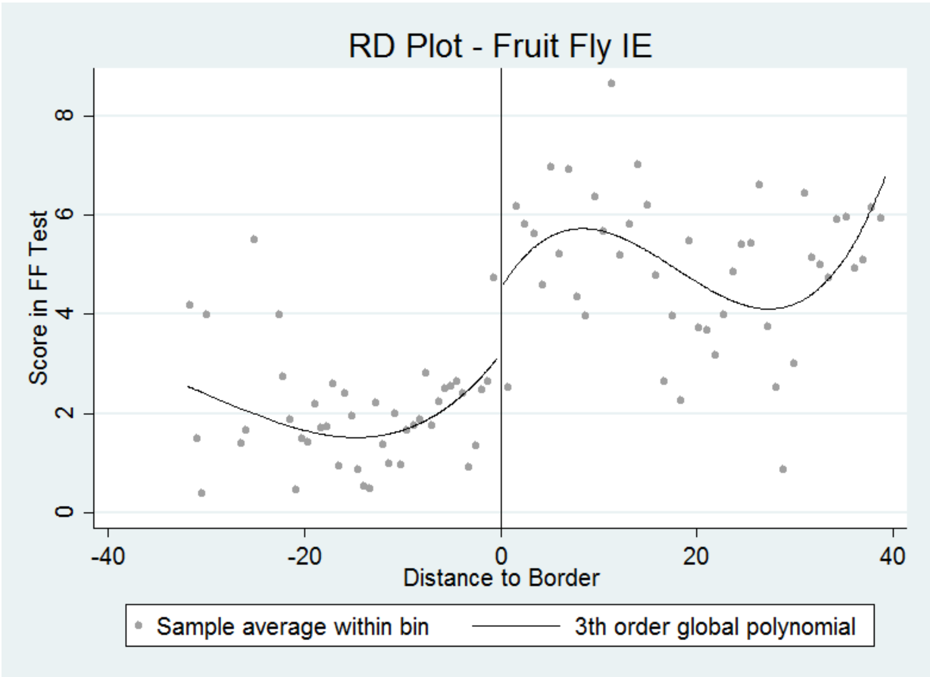


**Figure 7. Discontinuity at the cut-off for main outcomes**

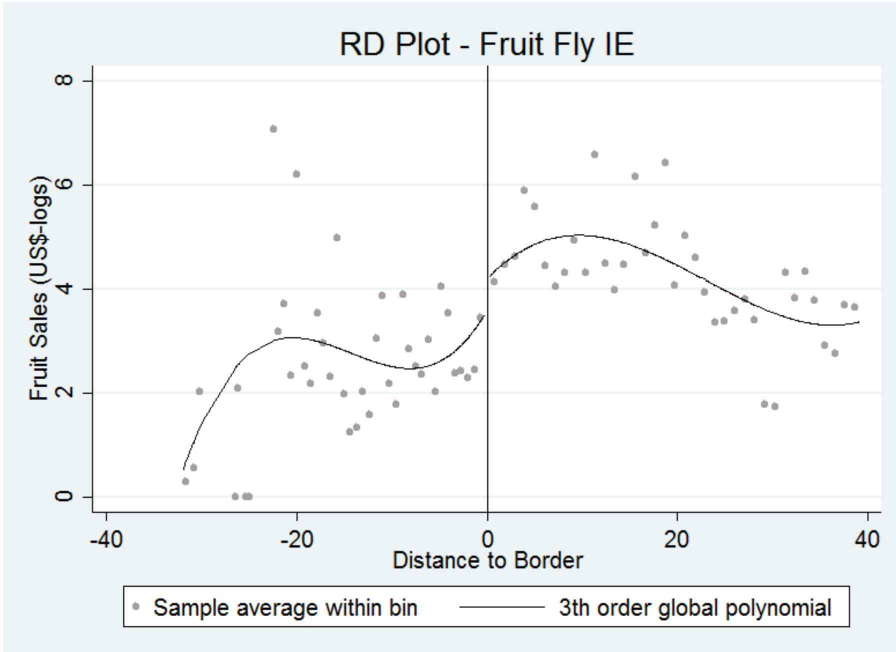
**Panel A – Prevention/Control Measures**



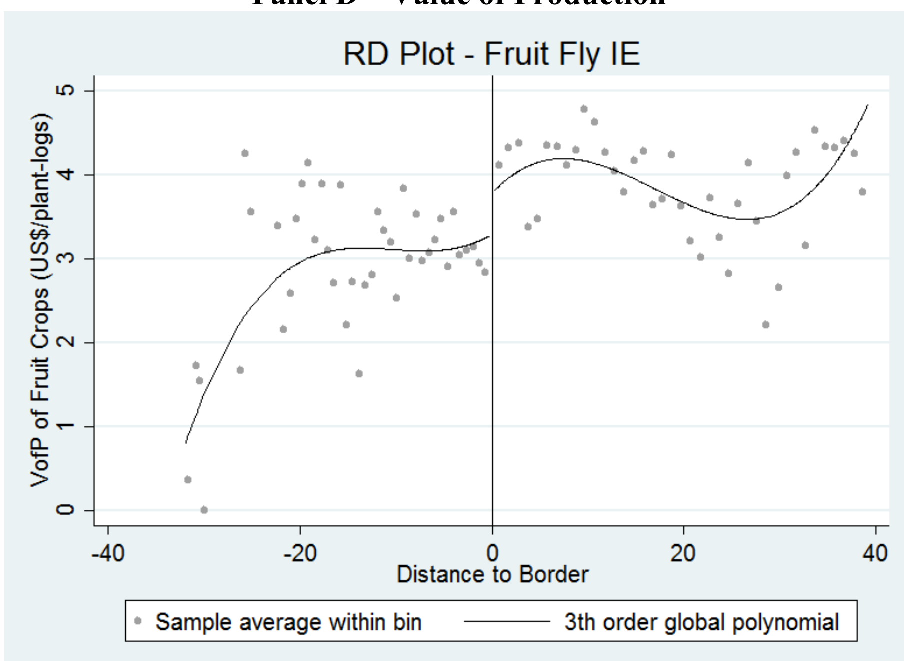

**Panel B – Score in Test**



**Panel C – Fruit Sales**




**Panel D – Value of Production**



## TABLES

**Table 1: Household and farm pre-treatment characteristics**

| | 6 km to the border | | | 13 km to the border | | | 34 km to the border | | |
|---|---|---|---|---|---|---|---|---|---|
| | 25% closest to border | | | 50% closets to border | | | 75% closest to border | | |
| | **C** | **T** | **p-value** | **C** | **T** | **p-value** | **C** | **T** | **p-value** |
| **Attrition rate** | 0.09 | 0.08 | 0.38 | 0.11 | 0.10 | 0.59 | 0.12 | 0.09 | 0.62 |
| **Panel 1A; Household Characteristics** | | | | | | | | | |
| Household head sex (male = 1) | 0.16 | 0.09 | 0.24 | 0.17 | 0.13 | 0.28 | 0.16 | 0.14 | 0.48 |
| Household head age (years) | 59.57 | 58.42 | 0.63 | 59.36 | 58.82 | 0.75 | 59.47 | 58.33 | 0.41 |
| Household size | ***4.04*** | ***3.45*** | ***0.05**** | 4.14 | 3.82 | 0.16 | 4.14 | 3.96 | 0.31 |
| Dependency Ratio | 0.49 | 0.60 | 0.15 | ***0.52*** | ***0.64*** | ***0.02***** | ***0.53*** | ***0.63*** | ***0.02***** |
| % household heads that at most completed primary ed. | 0.58 | 0.70 | 0.16 | 0.59 | 0.60 | 0.85 | 0.61 | 0.55 | 0.19 |
| % household heads that at most completed secondary ed. | 0.26 | 0.23 | 0.70 | 0.24 | 0.24 | 0.98 | 0.26 | 0.21 | 0.21 |
| % have electricity at home | 0.93 | 0.96 | 0.39 | 0.90 | 0.94 | 0.34 | 0.88 | 0.88 | 0.91 |
| % have drinking water at home | 0.98 | 0.96 | 0.53 | 0.96 | 0.96 | 0.84 | **0.96** | **0.88** | **0.01**** |
| % have telephone at home | 0.15 | 0.17 | 0.81 | 0.17 | 0.23 | 0.15 | 0.18 | 0.18 | 0.91 |
| Number of rooms | 4.07 | 3.79 | 0.25 | 4.07 | 4.15 | 0.66 | 4.04 | 4.11 | 0.64 |
| **Number of observations** | **98** | **53** | | **174** | **125** | | **185** | **246** | |
| **Panel 1B. Farm Characteristics** | | | | | | | | | |
| % of households that have modern irrigation | 0.01 | 0.00 | 0.48 | 0.01 | 0.01 | 0.77 | 0.02 | 0.00 | 0.21 |
| Number of hectares with fruit crops | 0.47 | 0.37 | 0.45 | ***0.44*** | ***0.63*** | ***0.06**** | 0.45 | 0.54 | 0.22 |
| % of hectares with fruit crops | 0.58 | 0.56 | 0.85 | ***0.54*** | ***0.65*** | ***0.02***** | ***0.53*** | ***0.61*** | ***0.03***** |
| Total number of fruit plants | 161.61 | 176.16 | 0.80 | ***178.98*** | ***282.17*** | ***0.04***** | 205.59 | 275.04 | 0.12 |
| Household has avocado plants installed | 0.86 | 0.89 | 0.61 | ***0.82*** | ***0.89*** | ***0.09**** | ***0.80*** | ***0.86*** | ***0.10**** |
| Household has banana plants installed | 0.45 | 0.53 | 0.35 | 0.44 | 0.46 | 0.84 | 0.43 | 0.40 | 0.53 |
| **Number of observations** | **98** | **53** | | **174** | **125** | | **185** | **246** | |

| Table 2: Fruit Fly and Agricultural Production pre-treatment characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **6 km to the border** | | | **13 km to the border** | | | **34 km to the border** | | |
| | **25% closest to border** | | | **50% closets to border** | | | **75% closest to border** | | |
| | **C** | **T** | **p-value** | **C** | **T** | **p-value** | **C** | **T** | **p-value** |
| **Panel 2A. Fruit Fly** | | | | | | | | | |
| % who know/have heard about the fruit fly | ***0.79*** | ***0.64*** | ***0.06**** | ***0.75*** | ***0.62*** | ***0.02***** | ***0.74*** | ***0.63*** | ***0.01***** |
| % affected by the fruit fly during the 2011 agricultural year | ***0.85*** | ***0.69*** | ***0.03***** | 0.78 | 0.72 | 0.22 | ***0.78*** | ***0.66*** | ***0.01***** |
| % adopts fruit fly prevention / control practices | 0.16 | 0.14 | 0.72 | 0.19 | 0.20 | 0.89 | 0.19 | 0.18 | 0.77 |
| % received fruit fly training in the 2011 agricultural year | 0.00 | 0.02 | 0.17 | 0.01 | 0.01 | 0.79 | 0.01 | 0.01 | 0.77 |
| **Panel 2B. Agricultural production** | | | | | | | | | |
| Total agricultural production (kg) | 2864.59 | 2913.58 | 0.95 | 3231.13 | 3566.08 | 0.61 | 3762.77 | 4325.80 | 0.36 |
| Total fruit production (kg) | 996.39 | 1456.98 | 0.21 | ***1065.03*** | ***1919.91*** | ***0.00****** | ***1319.55*** | ***1872.79*** | ***0.04***** |
| Total non-fruit production (kg) | 1884.54 | 1428.40 | 0.53 | 2128.58 | 1624.49 | 0.34 | 2471.60 | 2407.19 | 0.90 |
| Value of production of fruit crops (US$ per plant) | 59.62 | 63.21 | 0.41 | 58.64 | 65.70 | 0.32 | 61.08 | 67.88 | 0.25 |
| Value of production of non-fruit crops (US$ per hectare) | 1402.36 | 1509.36 | 0.62 | 1397.58 | 1493.27 | 0.78 | 1424.26 | 1512.32 | 0.61 |
| Total agricultural sales (dollars) | 727.45 | 879.50 | 0.48 | 789.52 | 1024.84 | 0.15 | 922.47 | 1181.68 | 0.12 |
| Total fruit sales (dollars) | 409.39 | 486.86 | 0.64 | ***363.22*** | ***654.75*** | ***0.01***** | ***402.06*** | ***613.40*** | ***0.03***** |
| Fruits sales / total sales ratio | 0.46 | 0.56 | 0.20 | ***0.44*** | ***0.61*** | ***0.00****** | ***0.43*** | ***0.59*** | ***0.00****** |
| Fruit crop losses (kg) | 94.34 | 104.00 | 0.45 | 89.33 | 103.52 | 0.26 | 77.08 | 69.34 | 0.30 |
| HH uses insecticides | 0.30 | 0.32 | 0.71 | 0.27 | 0.23 | 0.15 | 0.25 | 0.24 | 0.74 |
| Value spent in insecticides (dollars) | 160 | 9.23 | 0.31 | 14.29 | 9.67 | 0.25 | 12.22 | 8.19 | 0.14 |
| **Number of observations** | **98** | **53** | | **174** | **125** | | **185** | **246** | |

**Table 3.1: Program Impact on Fruit Fly Knowledge and adoption of Prevention and Control Practices**

| | 6 km to the border | | 13 km to the border | 34 km to the border |
|---|---|---|---|---|
| | 25% closest to border | | 50% closets to border | 75% closest to border |
| | (1) | (2) | (3) | (4) |
| Households has some knowledge about the fruit fly plague (Yes =1) | **0.10**** | -0.05 | 0.06 | 0.08 |
| | (0.05) | (0.09) | (0.07) | (0.05) |
| Number of correct answers in the fruit fly test | 0.63 | 0.36 | 0.32 | **0.97*** |
| | (0.83) | (0.89) | (0.80) | (0.59) |
| Producer implements fruit fly prevention and/or control best practices (Yes=1) | 0.14 | 0.19 | **0.35**** | **0.34***** |
| | (0.15) | (0.15) | (0.13) | (0.11) |
| **N** | **151** | | **299** | **431** |

Notes: standard errors are clustered at the village level. As it is standard *, ** and *** indicate statistical significance at the 10%, 5% a 1% significance levels. Two functional forms are estimated at the 6 km bandwidths: in column 1 we only control for treatment status, in column 2 we control for a lineal polynomial in latitude and longitude. In column 3, for the 13 km bandwidth we control for a lineal polynomial latitude and longitude. In column 4, for the 34 km comparison bandwidth we include a quadratic polynomial in latitude and longitude.

| Table 3.2: Program Impact on Fruit Fly Knowledge and adoption of Prevention and Control Practices (controlling for household characteristics and baseline outcome values) | | | | |
|---|---|---|---|---|
| | **6 km to the border** | | **13 km to the border** | **34 km to the border** |
| | **25% closest to border** | | **50% closets to border** | **75% closest to border** |
| | **(1)** | **(2)** | **(3)** | **(4)** |
| Households has some knowledge about the fruit fly plague (Yes =1) | **0.12**** (0.05) | 0.02 (0.07) | 0.09 (0.07) | **0.10**** (0.05) |
| Number of correct answers in the fruit fly test | 0.78 (0.77) | 0.88 (0.81) | 0.16 (0.86) | **0.96*** (0.57) |
| Producer implements fruit fly prevention and/or control best practices (Yes=1) | 0.14 (0.15) | 0.19 (0.16) | **0.37**** (0.15) | **0.36***** (0.12) |
| **N** | **151** | | **299** | **431** |

Notes: standard errors are clustered at the village level. As it is standard *, ** and *** indicate statistical significance at the 10%, 5% a 1% significance levels. Two functional forms are estimated at the 6 km bandwidths: in column 1 we only control for treatment status, in column 2 we control for a lineal polynomial in latitude and longitude. In column 3, for the 13 km bandwidth we control for a lineal polynomial latitude and longitude. In column 4, for the 34 km comparison bandwidth we include a quadratic polynomial in latitude and longitude. All regressions in this table also control for household and head of the households characteristics, for the total household agricultural area with fruit crops, and the baseline value for the outcome variable.

| Table 4.1: Program Impact on Follow up Agricultural Outcomes (Short Term) | | | | |
|---|---|---|---|---|
| | **6 km to the border** | | **13 km to the border** | **34 km to the border** |
| | **25% closest to border** | | **50% closets to border** | **75% closest to border** |
| | **(1)** | **(2)** | **(3)** | **(4)** |
| Total Agricultural Output (log) | **0.70*** (0.38) | **0.77**** (0.38) | **0.92**** (0.40) | 0.47 (0.37) |
| Total Agricultural Sales (log) | 0.72 (0.82) | 0.96 (1.00) | **1.57*** (0.88) | **1.20*** (0.70) |
| Total Fruit Output (log) | **0.90**** (0.38) | 0.39 (0.49) | **0.70*** (0.42) | **0.50*** (0.36) |
| Total Fruit Sales (log) | 0.93 (0.76) | 0.85 (0.89) | **1.56*** (0.86) | **1.33**** (0.67) |
| Fruit Sales / Total Sales ratio | 0.15 (0.10) | 0.14 (0.12) | **0.19*** (0.11) | **0.19**** (0.09) |
| Value of production of fruit crops (US$ per plant-log) | 0.10 (0.08) | 0.12 (0.09) | **0.16**** (0.05) | **0.14*** (0.06) |
| Fruit crop losses (kg-log) | 1.26 (0.82) | 0.78 (0.53) | 0.88 (0.66) | 0.62 (0.40) |
| HH uses insecticides | 0.04 (0.11) | -0.06 (0.15) | -0.20 (0.21) | -0.12 (0.27) |
| Value spent in insecticides (US$ - log) | -0.01 (0.38) | -0.48 (0.49) | -0.74 (0.51) | -0.31 (0.36) |
| **N** | **151** | | **299** | **431** |

Notes: standard errors are clustered at the village level. As it is standard *, ** and *** indicate statistical significance at the 10%, 5% a 1% significance levels. Two functional forms are estimated at the 6 km bandwidths: in column 1 we only control for treatment status, in column 2 we control for a lineal polynomial in latitude and longitude. In column 3, for the 13 km bandwidth we control for a lineal polynomial latitude and longitude. In column 4, for the 34 km comparison bandwidth we include a quadratic polynomial in latitude and longitude.

| **Table 4.2: Program Impact on Follow up Agricultural Outcomes (controlling for household characteristics and baseline outcome values)** | | | | |
|---|---|---|---|---|
| | **6 km to the border** | | **13 km to the border** | **34 km to the border** |
| | **25% closest to border** | | **50% closets to border** | **75% closest to border** |
| | **(1)** | **(2)** | **(3)** | **(4)** |
| Total Agricultural Output (log) | **0.71*** | **0.99**** | **0.88**** | 0.38 |
| | (0.39) | (0.41) | (0.40) | (0.39) |
| Total Agricultural Sales (log) | 0.76 | **2.23**** | **2.01**** | **1.37*** |
| | (0.75) | (0.60) | (0.84) | (0.73) |
| Total Fruit Output (log) | **0.89**** | **0.90**** | **0.90**** | **0.60*** |
| | (0.33 | (0.37) | (0.36) | (0.33) |
| Total Fruit Sales (log) | 0.75 | 1.37 | **1.56**** | **1.23*** |
| | (0.59) | (0.84) | (0.77) | (0.62) |
| Fruit Sales / Total Sales ratio | **0.16*** | 0.16 | 0.169 | 0.14 |
| | (0.08) | (0.12) | (0.12) | (0.09) |
| Value of production of fruit crops (US$ per plant-log) | 0.11 | 0.09 | **0.13*** | **0.10**** |
| | (0.10) | (0.06) | (0.04) | (0.02) |
| Fruit crop losses (kg-log) | 1.37 | 0.99 | 1.10 | 0.49 |
| | (0.83) | (0.57) | (0.72) | (0.44) |
| HH uses insecticides | 0.06 | -0.06 | -0.25 | -0.09 |
| | (0.56) | (0.17) | (0.19) | (0.11) |
| Value spent in insecticides (US$ - log) | -0.05 | -0.57 | -0.98 | -0.23 |
| | (0.90) | (0.48) | (0.51) | (0.33) |
| **N** | **151** | | **299** | **431** |

Notes: standard errors are clustered at the village level. As it is standard *, ** and *** indicate statistical significance at the 10%, 5% a 1% significance levels. Two functional forms are estimated at the 6 km bandwidths: in column 1 we only control for treatment status, in column 2 we control for a lineal polynomial in latitude and longitude. In column 3, for the 13 km bandwidth we control for a lineal polynomial latitude and longitude. In column 4, for the 34 km comparison bandwidth we include a quadratic polynomial in latitude and longitude. All regressions in this table also control for household and head of the households characteristics, for the total household agricultural area with fruit crops, and the baseline value for the outcome variable.

| Table 5.1: Program Impact on Pre-Treatment Agricultural Outcomes | | | | |
|---|---|---|---|---|
| | 6 km to the border | | 13 km to the border | 34 km to the border |
| | 25% closest to border | | 50% closets to border | 75% closest to border |
| | (1) | (2) | (3) | (4) |
| Total Agricultural Output (log) | 0.33<br>(0.37) | 0.11<br>(0.60) | 0.13<br>(0.55) | 0.02<br>(0.40) |
| Total Agricultural Sales (log) | 1.04<br>(0.68) | -0.51<br>(1.09) | -0.29<br>(0.95) | -0.18<br>(0.69) |
| Total Fruit Output (log) | 0.47<br>(0.34) | 0.38<br>(0.55) | 0.28<br>(0.47) | 0.15<br>(0.36) |
| Total Fruit Sales (log) | 1.05<br>(0.68) | 0.26<br>(1.03) | 0.23<br>(0.87) | 0.06<br>(0.68) |
| Fruit Sales / Total Sales | 0.11<br>(0.10) | 0.06<br>(0.14) | 0.08<br>(0.11) | 0.09<br>(0.08) |
| **N** | **151** | | **299** | **431** |

Notes: standard errors are clustered at the village level. As it is standard *, ** and *** indicate statistical significance at the 10%, 5% a 1% significance levels. Two functional forms are estimated at the 6 km bandwidths: in column 1 we only control for treatment status, in column 2 we control for a lineal polynomial in latitude and longitude. In column 3, for the 13 km bandwidth we control for a lineal polynomial latitude and longitude. In column 4, for the 34 km comparison bandwidth we include a quadratic polynomial in latitude and longitude.

| Table 5.2: Program Impact on Non-Fruit Outcomes | | | | |
|---|---|---|---|---|
| | 6 km to the border | | 13 km to the border | 34 km to the border |
| | 25% closest to border | | 50% closets to border | 75% closest to border |
| | (1) | (2) | (3) | (4) |
| Total non-fruit output (kg-logs) | -0.76<br>(0.38) | -0.32<br>(0.53) | 0.08<br>(0.51) | -0.29<br>(0.43) |
| Total non-fruit sales (kg-logs) | -0.45<br>(0.43) | 0.10<br>(0.57) | 0.47<br>(0.47) | 0.21<br>(0.44) |
| Value of production of non-fruit crops (US$ per hectare) | 0.26<br>(0.31) | 0.28<br>(0.29) | 0.24<br>(0.18) | 0.19<br>(0.12) |
| N | 151 | | 299 | 431 |

Notes: standard errors are clustered at the village level. Two functional forms are estimated at the 6 km bandwidths: in column 1 we only control for treatment status, in column 2 we control for a lineal polynomial in latitude and longitude. In column 3, for the 13 km bandwidth we control for a lineal polynomial latitude and longitude. In column 4, for the 34 km comparison bandwidth we include a quadratic polynomial in latitude and longitude. All regressions in this table also control for household and head of the households characteristics, for the total household agricultural area with fruit crops, and the baseline value for the outcome variable.

## ANNEX 1: IMPACTS IN AVOCADO AND BANANA PRODUCTION

| Table A1: Program Effect over Avocado and Banana Production (34 km bandwidth – 75% closest observations to the border) | | |
|---|---|---|
| | Avocado | Banana |
| Total Output (log) | 0.62<br>*0.42* | **1.75****<br>*0.80* |
| Total Sales (log) | **1.40****<br>*0.59* | **2.675*****<br>*0.88* |
| Price per kilo sold | 0.13<br>*0.09* | **0.30*****<br>*0.11* |
| **N** | **382** | **249** |
| Notes: Standard errors are clustered at the village level. As it is standard *, ** and *** indicate statistical significance at the 10%, 5% a 1% significance levels. We include a quadratic polynomial in latitude and longitude. | | |

In order to obtain more insights on the channels that explain increasing fruit sales value, table A1 explores the program effects on the two most common fruit crops in the area: avocado and banana. The results analyzed correspond to the 34 km bandwidth (75% closest observations to the treatment border), where we control for a quadratic polynomial in distance to the border. As we can observe, treated households have increased their production of banana, as well as their total sales for this two crops. Also, for the case of banana, producers in treated areas seem to obtain a better price per kilo sold.

One possible explanation for this finding is that as a result of the program, local buyers have increased their demand for fruit produced in the treated areas, which have had a positive effect on prices. Another complementary explanation is that treated farmers are able to provide a fruit of better quality; which has a lower risk of being contaminated by fruit fly larvae, and therefore is priced higher.