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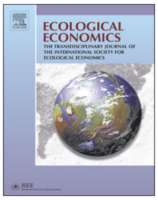

Pesticide lock-in in small scale Peruvian agriculture

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ABSTRACT

Despite decades of research into the negative impacts of synthetic pesticides, farmers in Latin America continue to use pesticides at high levels and at a high cost to social and environmental sustainability. In this paper, we present a case study of pest management strategies in small-scale agriculture, focusing on the unsustainable technological lock-in of synthetic pesticides. Of the 196 smallholder farmers we surveyed in the coastal Mala and Omas Valleys of Perú, 22% of respondents experienced pesticide poisoning themselves or by an immediate family member. Additionally, the two most common pesticide categories reported in use are potent neurotoxins. We hypothesized that the farmers in the valleys were locked into synthetic pesticides due to uncertainty, coordination and learning associated with adopting an alternative strategy. Logistic regressions revealed gender (male), consulting an agro-chemical technician, quantity of cultivated land, and apple as a primary crop to be important predictors of synthetic pesticide use. Our findings suggest that these predictors represent the lock-in of synthetic pesticides through network externalities, learning economies and adaptive expectations. We conclude with opportunities to transition to sustainable pest management strategies at the local level in Latin American communities through interventions countering the lock-in of synthetic pesticides.

1. Introduction

In the 25 years since the release of the World Health Organization's (WHO) report Public Health Impacts of Pesticides Used in Agriculture studies have continued to show the negative human health impacts of pesticide exposure and the pervasiveness of pesticide poisoning in developing countries (World Health Organization, 1990, Ecobichon, 2001, Jørs et al., 2006; Dasgupta et al., 2007; Bhat et al., 2010; Lee et al., 2010; Cole et al., 2011). Farmers in developing countries tend to use more pesticides more frequently, and apply more highly toxic varieties than their counterparts in developed countries (Ecobichon, 2001). Additionally, it has been shown that while short-term synthetic pest management strategies lower costs and boost yields on farms, in the long-term, synthetic pesticides can raise farmer costs and lower yield (Wilson and Tisdell, 2001). These global trends are born-out amongst smallholder farmers in countries across Latin America, including Costa Rica, Bolivia, Ecuador, and Colombia among others (Crissman et al., 1998; Jørs et al., 2006; Feola and Binder, 2010a,b, Galt, 2013). The well-known human health and economic risks of pesticide use in agriculture and the existence of alternative pest management techniques highlight the need for a better understanding of why smallholder farmers in Latin America continue to use highly toxic synthetic pesticides and in such high quantities.

A critical consideration is the challenge for farmers of adopting or moving to a new pest management technology in lieu of synthetic pesticides. Previous research has shown that the ability for farmers to move away from pesticide intensive practices in Latin America is hindered by farmers' lack of access to accurate information on pesticides and their alternatives, the limited markets available for organic produce, and inadequate community organization to implement alternatives (Cole et al., 2011). Additionally, at national and international scales, the pesticide industry influences and encourages pesticide adoption through low prices, ease of access, and availability of technological support (Galt, 2008).

Efforts have been made both globally and locally to address these barriers to adopting more sustainable alternatives. Sustainable pest management alternatives are those that seek to manage pests in a way that socially, economically and environmentally meets farmers' needs today without compromising the needs of future generations (Brundtland et al., 1987). International efforts such as the Rotterdam Convention and the Food and Agriculture Organization's (FAO) Code of Conduct on the Distribution and Use of Pesticides strive to ensure that pesticide products are labeled with accurate information on toxicity so that countries and farmers can make informed choices (Angelo, 2013). At the local level in many Latin American countries, government and non-government organizations have run programs to increase

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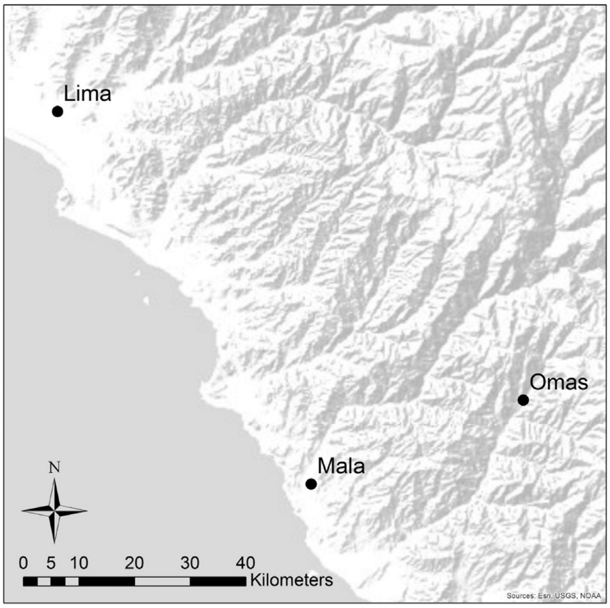

Fig. 1. Map of the cities of Mala and Omas on the Peruvian Pacific coast, located about 60 km south of Lima, Perú.

preventative practices amongst farmers and to build capacity in alternative strategies such as Integrated Pest Management (IPM) and organic pest management (Bazo Robles et al., 2010; Jørs et al., 2014; Carrión Yaguana et al., 2015). However, acute and chronic pesticide poisoning persists (Jørs et al., 2006). The sustained use of synthetic pesticides and the difficulty of adopting alternative practices suggest that many small-scale farmers in Latin America may be locked-in to using synthetic pesticides.

To explore local-level persistence of pesticide use and lock-in affecting small-scale agriculture, this study focuses on two rural agricultural communities in the Mala and Omas Valleys along the coast of Perú. In the summer of 2013, a survey was implemented in the valleys through a partnership between the Dartmouth Institute for Health Care Delivery Science and Instituto Huayuná, a Peruvian non-governmental organization that has been active in issues of community health and sustainable agriculture for over 30 years. In each valley, we examined the predictors of pesticide use, the level of interest among pesticide users for transitioning to organic pest management, and the barriers to transitioning. Finally, we investigated whether there is a case of maladaptive technological lock-in in the use of pesticides in the valleys and considered potential pathways for transition to more sustainable pest management practices.

In the following sections we first examine the phenomenon of technological lock-in and its application to the adoption of agricultural pest management technologies before introducing the case study site in section three. In section four we describe the study methods followed by results and discussion in sections five and six. Finally in section seven we acknowledge the limitations of our study and in section eight we offer the concluding remarks.

2. Technological Lock-in, Pest Management, and Agricultural Innovation

The theory of technological lock-in suggests that a technology becomes “locked-in,” or entrenched, when that technology gains dominance over alternatives due to a historical event or chance that enables it to capture a market (Kallis and Norgaard, 2010). The existence of technological lock-in is tied closely to the concept of increasing economic returns to adoption (Perkins, 2003). The adoption of synthetic pest management can be seen as a case of increasing returns due to the positive feedbacks associated with increased adoption (Cowan and Gunby, 1996). Technologies that demonstrate these increasing returns can become locked-in such that once adopted, it is difficult to switch to a superior alternative technique without a high switching cost. In cases of unsustainable lock-in, or lock-in to an inferior technology, ongoing costs, in this case, the social, economic and environmental costs of using pesticides, are higher than that of an alternative technology (Arthur, 1989).

Synthetic pesticide use can be traced to the expansion of the global synthetic pesticide market following the Second World War. Adoption following the war increased rapidly because of synthetic pesticides' effectiveness in lowering cost and boosting yield (Wilson and Tisdell, 2001). The positive feedbacks associated with synthetic pesticide use include: 1) economies of scale — a reduction in unit cost with increases in production and yield, 2) learning economies — cost decreases and performance increases as individuals gain more experience with applying pesticides, 3) adaptive expectations — a decrease in uncertainty about how or whether a pesticide will perform, and 4) network externalities — the benefits accompanying networks, infrastructure, associated technologies and other external structures that form around synthetic pesticides as adoption of the technology increases (Perkins, 2003, Kallis and Norgaard, 2010).

From the perspective of competing technologies with increasing returns, the early organosynthetic insecticides developed in the 1940s were in direct competition with non-synthetic pest control strategies based on pest biology and ecology (the precursors to today's organic and IPM strategies) (Kogan, 1998). Synthetic pesticides, in comparison with the ecologically-based pest control strategies, boasted high initial effectiveness in eliminating pests and corresponding high initial boost in yield. The first field trials with organochlorine pesticides in Perú in the 1940s, as with many trials across the globe, left farm operators amazed at the effectiveness of the products: no insects survived the application (Herrera, 2010). Synthetic pesticides were and continue to be relatively easier to use and implement than alternative strategies and do not require extensive information about the agricultural ecosystem (Waterfield and Zilberman, 2012). These attributes of synthetic pesticides, along with market pressure from synthetic producers and government policies to boost supplies and invest in research and development, led to their dramatic rate of adoption and entrenchment in the market, which continues today (Wilson and Tisdell, 2001).

Synthetic pesticides are seen as an important tool globally for increasing production to meet the food demands of a growing population (Waterfield and Zilberman, 2012). However, from a social and environmental perspective, a reliance on synthetic pesticides as the primary pest management technique may be inefficient (Wilson and Tisdell, 2001). Human poisoning is known to occur broadly through acute or chronic exposure during application of pesticides and environmental exposure to pesticide drift or contaminated soil, water or crops. In 1990, the World Health Organization estimated that pesticides are responsible for three million cases of acute poisonings, including suicides, and 220,000 deaths (World Health Organization, 1990). Additionally, certain pesticides may be associated with increased risks of chronic health impacts such as specific cancer types, reproductive and other health effects, and neurological effects (Miranda-Contreras et al., 2013; Muñoz-Quezada et al., 2013; Parrón et al., 2014). In many countries, governments have banned or restricted access to highly toxic pesticides to protect against exposure and poisoning (see Table A.1 in Appendix A for the number of countries that have banned pesticides found in the present study). Synthetic pesticides are also known to have adverse environmental impacts, including loss of beneficial pests, broader loss in biodiversity, and soil and water contamination (Wilson and Tisdell, 2001, Pimentel et al., 2005).

Awareness of the negative human health and environmental risks of an overreliance on synthetic pesticides arose as early as the late 1950s and inspired efforts to identify alternative pest management strategies, such as IPM and organic agriculture (Kogan, 1998). IPM as a strategy integrates biological and synthetic control, utilizing multiple techniques and methods to control pest populations, with the goal of benefiting farmers (economically), society (minimization of public health risks) and the environment (Kogan, 1998, Parsa et al., 2014). The adoption of IPM is associated with decreases in pesticide use and a corresponding decrease in the negative externalities of pesticide use (Carrión Yaguana et al., 2015). Farmers are trained to use target applications of pesticides only in instances that pose economic threats to the farmer. However, IPM techniques have low rates of adoption in developing countries (Parsa et al., 2014). Compared to a synthetic pesticide strategy, IPM is knowledge-intensive and requires a significant amount of time and financial investment to adopt (Waterfield and Zilberman, 2012). Additionally, many programs rely primarily on the appropriate application of pesticides as the principal management tactic (Kogan, 1998).

Alternatively, organic agriculture is defined as a system of agriculture that focuses on holistic ecosystem management through, among other things, supporting soil health, biodiversity, and biological cycles to promote healthy agro-ecosystems, as opposed to a reliance on external inputs (The Codex Alimentarius Comission and the FAO/WHO Food Standards Programme, 2007). In practice, and for organic certification, this typically requires that farmers do not use synthetic pesticides or fertilizers. The adoption of organic agriculture is also a knowledge-intensive process and usually takes multiple years to achieve certification. Organic pest management techniques allow for additional benefits for farms beyond IPM, including reduction in health risks, a price premium for produce, and improved long-term farm environmental conditions (Waterfield and Zilberman, 2012). It is important to note that some varieties of organic pesticides, although they do not contain synthetic compounds, are still highly toxic for farmers, such as the organic pesticide arsenic. Compared to synthetic pesticides and IPM, organic agriculture can be seen as a riskier pest management technology because it entails a more limited amount of pest control strategies (i.e., no synthetic inputs) (Waterfield and Zilberman, 2012).

In Latin America, while efforts have been made to introduce both IPM and organic agriculture across many countries, farmers have been shown to still over-apply pesticides and use pesticides banned in many industrialized countries (Eskenazi et al., 1999, 2007; Bjorling-Poulsen et al., 2008; Lesmes-Fabian et al., 2012). In particular organophosphate and carbamate pesticides, known to be potent neurotoxins, are still commonly used and poisoning incidents occur relatively frequently (Sherwood et al., 2005; Jørs et al., 2006; Pesticide Action Network, 2015).

Alternative pest management techniques such as organic and IPM have a hard time competing with synthetic pesticides because of the large cost of transitioning (e.g., network co-ordination, technological interdependencies, new work practices, skills and patterns of behavior) (Perkins, 2003). Using the language of Liebowitz and Margolis (1995), this could be considered a case of third-degree path dependence, where reliance on synthetic pesticides continues to be the dominant pest control strategy despite knowledge that it is a relatively inefficient strategy (Wilson and Tisdell, 2001). In this way, the different mechanisms that contribute to increasing returns to synthetic pesticides can be viewed as a barrier to adoption of a competing, superior technology, when this particular inferior technology is locked-in.

Trends in synthetic pesticide use in Latin America can reveal the existence of persistent problems like pesticide poisoning, but do little to describe the conditions that influence adoption and technological lock-in at the farm scale. To better understand farm-level pest management decisions, this study investigates the use of pesticides and occurrence of pesticide poisoning in two small-scale agricultural valleys in Perú. In the case of pesticide use and persistent poisoning in the two valleys, we examine the barriers to adoption of an alternative form of sustainable pest management.

3. Study Area

The Mala river basin stretches from the Peruvian Pacific coast, where the city of Mala is situated on the Panamericana highway, up to its headwaters in the western range of the Andes. Likewise, the Omas River runs parallel to the Mala River, about 20 km to the south. Both basins are situated in a coastal subtropical arid climate, featuring low levels of precipitation and high humidity in the low altitudes of the basins (Alba, 2004).

The Mala Valley is home to approximately 40,000 inhabitants, the majority located near the coast (Bazo Robles et al., 2010). Omas Valley is much less populated than Mala, with a little over 12,000 people (Perú Instituto Nacional de Estadística e Informatica, 2012). The city of Mala is a commercial agricultural hub for the region, both for local consumption and for transport to markets in Lima and to the south (Alba, 2004). The primary economic activity in the valleys is agricultural production from small-scale farms.

Prior to the Peruvian Agrarian Reform in 1969, agriculture in the coastal region was dominated by large plantations growing cotton for export in the lower elevations of the valleys, and peaches and grapes at higher elevations. Within the plantation structure small-scale farmers worked the land as sharecroppers (Kay, 1982, Alba, 2004). The Agrarian Reform of 1969 transitioned the plantations to worker-owned Agricultural Production Cooperatives. However, in the decade following the Agrarian Reform, farmers abandoned the cooperative model and began dividing parcels up among farm workers. Today, there are no remaining agricultural cooperatives in either of the valleys, and instead the valley is made up of smallholder farms. In our sample, the average farm size in the Mala and Omas Valleys was 2.5 ha, as reported in Table 1.

An important remnant in the valleys of both the plantations and cooperatives is the use of synthetic pesticides. The large plantations of the '50s and '60s utilized agro-chemicals early on, primarily persistent organic pollutants (Bazo Robles et al., 2010). Interestingly, the large cotton plantations in the nearby valley of Cañete were also one of the earliest adopters of a form of IPM in the 1950s because of their first-hand experience with pesticide resistance and pest resurgence with the early organochlorine pesticides (Herrera, 2010). Unfortunately, this process of IPM was interrupted and lost in the 1970s with the Agrarian Reform (Herrera, 2010).

During the period of the 50s and 60s, fruits grown higher up in the valleys (peaches and grapes) were plagued by scale insects (of the families Diaspididae, Coccidae, and Pseudococcidae). Production became unprofitable because of the impacts of pests and farmers began to move away from these crops. When the Delicia apple, later known as the "Delicia de Viscas," was introduced in the 1960s to the higher altitudes in Mala valley and thrived, farmers throughout the region, including those at lower altitudes, began installing orchards. The cultivation technique introduced and adopted with the Delicia apple included the use of pesticides and fertilizers, with intense pruning and planting density. By the mid-1990s more than half of the agricultural land in Mala valley was in apple production.

Today, small-scale farms continue the tradition of agro-chemical use in fruit production, with a high proportion still growing apples despite decreases in their profitability. According to agronomists at Instituto Huayuná, yield of apples per hectare has been declining for the last two decades. The principle pests of economic importance are the San José scale (*Quadraspidiotus perniciosus*) and the fungus *Lasiodiplodia theobromae*, as well as powdery mildew, bull beetles, and the codling moth.

Aside from the dominate crop of apples, the other main economic crops grown in the valleys as found in our study are maize, alfalfa, banana and grapes, which are impacted economically by pests to varying degrees. Maize is significantly affected a stalk borer, the fall armyworm (*Spodoptera frugiperda*), and corn earworm (*Helicoverpa zea*). Grape growers in the region deal with a fungus that causes powdery

Table 1
Variables including descriptive statistics, description of the variable and categories or units.

Variable name	Description	Categories	N (%)	Mean ± SD
Omas valley	Valley of residence	Mala; Omas	137 (73%); 51 (27%)	–
age	Age of respondent	Years	–	56.8 ± 15.4
education	Education level of farmer	Only primary; at least some secondary education	72 (38%); 116 (62%)	–
female gender	Gender of respondent	Male; female	158 (84%); 30 (16%)	–
land	Hectares of land cultivated	Hectares	–	2.5 ± 2.6
land tenure	Primary condition of land tenure	Bought or inherited; rented; shared ownership	142 (76%); 21 (11%); 25 (13%)	–
pesticide	Uses synthetic pesticides	No; yes	33 (18%); 155 (82%)	–
organic	Uses or interested in using organic agricultural techniques	No; yes	68 (36%); 120 (64%)	–
crop diversity	Effective species diversity, range in sample: 1.00 to 8.00	Index of crop diversity	–	1.7 ± 1.0
technician	Receives information about pesticides from an agro-chemical shop	No; yes	72 (38%); 116 (62%)	–
huayuna	Receives information about pesticides from Instituto Huayuná	No; yes	175 (93%); 13 (7%)	–
farmers	Receives information about pesticides from other farmers	No; yes	168 (89%); 20 (11%)	–
poison	Experienced pesticide poisoning personally or in immediate family	No; yes	146 (78%); 42 (22%)	–
traps	Use of non-synthetic pesticide traps	No; yes	166 (88%); 22 (12%)	–
apple	Apple as primary commercial crop — greater than 50% of cultivated land in apple.	No; yes	90 (48%); 98 (52%)	–
registry	Keeps records of crops and inputs	No; yes	136 (72%); 52 (28%)	–
equipment	Wears protective equipment when applying pesticides	No; yes	93 (49%); 95 (51%)	–
storage	Stores pesticides in an appropriate location	No; yes	53 (28%); 135 (72%)	–

mildew of grape (*Oidium tuckeri*). Bananas have many pests, mainly nematodes, but farmers do not tend to apply pesticides against them and instead replace the plant when needed. Finally alfalfa, in the region is plagued at times by the red spider (*Tetranychus urticae*), but harvesting process removes the pest and therefore is not particularly damaging.

Since the initial IPM efforts in Cañete's cotton plantations, the Peruvian government has tried numerous efforts to introduce biological pest management techniques. In the 1960s, the national Center for Insect Breeding and Research Tools (CICIU) focused on efforts to introduce exotic species for pest control. In the 1990s, these efforts passed hands to the National Agrarian Health Service (SENASA) and their National Biological Control program. Since 2001, SENASA has promoted biological control on many thousands of hectares, however, these efforts were primarily aimed at the large agricultural productions in the country (Valdivieso Jara, 2011).

Separate from the state's endeavor, Instituto Huayuná implemented an IPM program in the Mala and Omas valleys in the 1990s, but neither the state nor the local effort saw much success in the adoption of the technique by small-scale agricultural producers. Additionally, those farmers that did attempt to implement IPM in the valleys tended to rely on synthetic pesticide application as the primary pest control strategy, rather than the strategy of last resort. Following the IPM program in the 1990s, a small group of farmers in the valleys, concerned with the number of severe pesticide poisonings and deaths in the community, decided to transition to organic agriculture. Since then, Instituto Huayuná has been supporting farmers in transitioning to organic agriculture and training farmers in organic techniques through farmer schools and an experimental organic farm. Because of Instituto Huanyuná's focus on promoting organic techniques, the challenge of measuring degree of implementation of IPM, and the institutional difference between organic techniques and synthetic techniques (i.e. price premiums for crops and certification) that do not exist for IPM, we focus this study on the use of two pest management strategies in the Mala and Omas Valleys: synthetic pest management and organic agriculture.

4. Methods

4.1. Data Collection

To investigate pesticide use, pesticide poisoning, and the adoption of alternative pest management strategies in the Mala and Omas Valleys, we completed 196 semi-structured interviews in-situ during a four-week period in July and August 2013, with 142 interviews in Mala and 54 in Omas. We conducted the sampling for the interviews in multiple stages and included cluster, purposive, snowball, and convenience-based elements because a full list of farmers was not available for each valley. First, in consultation with community health workers associated with Instituto Huayuná, we identified clusters of farmers that lived in districts and annexes within each valley. Then, within a district or annex, we approached local residents to identify farmers to interview and asked interviewees to suggest additional farmers to interview within the region. Due to our sampling methodology, we cannot claim that the sample is statistically representative of farmers living in the study region.

Prior to the interviews, we developed a questionnaire through our collaboration with Instituto Huayuná and several community health workers (see Appendix B for the full questionnaire). Six broad topics were covered in the questionnaire: home attributes, health problems, land and livestock, agricultural activities, external interactions, and agricultural associations. Additionally, the questionnaire was intended to collect data on the types of pesticides used by farmers in an annual farming cycle, including the pesticide names, active ingredients, crop/s on which the pesticides were applied, and the quantities applied. We also assessed history of acute pesticide poisoning incidents by asking respondents to describe any time that they, or someone in their family, has been poisoned. For each acute pesticide poisoning incident recounted, we recorded the date, the relation (self or other family member), the severity of the incident (light or severe), the pesticide responsible and finally whether the respondent sought care at a clinic. The questionnaire was divided into sections according to the six topics above and each section includes a combination of dichotomous, nominal, ordinal, and open-response questions.

Interviews were conducted in Spanish by a fluent speaker: either a local interpreter or a community health worker in the Mala Valley, or a local farmer in the Omas Valley. The community health workers had previous experience in conducting interviews for a local census. Interviewers were trained on the questionnaire, participated in practice interviews, and were compensated for their time. After the completion of the surveys, we reviewed each of the questionnaire's responses with the interviewers to ensure accurate interpretation of the data and responses.

This study was approved by the Internal Review board at Dartmouth College. Before beginning each interview, participants were notified of the intent of the study, ensured that all data collected would be kept confidential and asked if they would like to participate. Upon completion of the data collection, identifying information was separated from responses both within the survey instruments and the database. Identifying information is stored in a separate, secure location to protect the anonymity of the respondents.

4.2. Data Analysis

Following data collection, the data was cleaned, coded, and entered into a Microsoft Access Database (2013). In cleaning the data, we removed observations from family members of the interviewers and incomplete interviews from the database, resulting in 188 unique farmer responses. See Table 1 for a list of all variables included in the analysis and a summary of their values in our sample.

To categorize respondents as conventional pesticide users versus non-conventional pesticide users for the binary variable pesticide, we coded all the pesticides reported in the questionnaire, over 650 unique mentions, as non-synthetic or synthetic pesticide products. We categorized general classes of pesticides (i.e., organophosphates, carbamates, pyrethroids) through consultations with a local agro-chemical shop in the city of Mala and the Peruvian Ministry of Agriculture's pesticide registration documents (Servicio Nacional de Sandidad Agraria, 2014). Then we considered all pest management inputs reported by each respondent and coded a respondent as a conventional pesticide user (value of "1" for variable pesticide) if the respondent reported using at least one conventional pesticide in the past year. We coded a respondent as a non-synthetic pesticide user if they only reported to use non-synthetic pesticides (value of "0" for variable pesticide).

In addition to the pesticide variable, we also calculated effective species richness per respondent. In our models, we used effective species richness per farm (the crop diversity variable), to assess the degree to which crop diversity interacts with pesticide use and interest in organic pest management techniques. We drew upon the respondent's reported total cultivated land (land variable in Table 1), and each respondent's self-reported crops cultivated, which included crop type and area of land or number of plants associated with each crop. If cultivated land and crop area were reported in number of plants, we translated the number of plants into hectares with assistance from a member of Instituto Huayuná. The effective species richness, or eH', is the exponentiation of the Shannon Weiner Diversity index, H' (Tilman et al., 2001). The Shannon Weiner Diversity index was calculated by taking the proportion of a farmer's land occupied by each crop reported (Pi), multiplying each crop proportion by the natural log of that proportion ($Pi * \ln(Pi)$), and then summing this value for all crops listed by a respondent to attain a single diversity index value for each respondent (Keylock, 2005). The effective species richness index allowed for a comparison between respondent's crop diversity based purely on frequencies, such that the variable displayed an intuitive doubling property, i.e. twice the number of species results in a crop diversity value twice as large (Jost, 2006).

We analyzed the data using Stata and R statistical software, and we calculated descriptive statistics for all variables (Table 1). We then ran multiple logistic regression models. In these models, we estimated the explanatory power of demographic, agricultural, and informational variables on a farmer's use of synthetic pesticides (Model 1), and on a farmer's interest in organic agriculture (Model 2). For both Model 1 and Model 2 we ran a single logistic regression simultaneously including all variables with a hypothesized relationship. Our hypotheses for the expected relationships in each model are shown in Table 2. For those variables listed in Table 2 with a hypothesized positive relationship in Model 1 ("M1" in Table 2), we expected that an increase in the value of the variable was associated with an increased likelihood that the respondent was a conventional pesticide user. Similarly, for those variables listed in Table 2 with a hypothesized positive relationship with Model 2 ("M2" in Table 2), we expected that an increase in the value of the variable was associated with an increased likelihood that the respondent was interested in organic pest management techniques. We hypothesized the relationships for Models 1 and 2 using both Latin American literature and global literature on small-scale agricultural pest management strategies. Table 2 also lists any economies of increasing returns to adoption associated with each variable, so that the models simultaneously investigated the existence of factors contributing to technological lock-in. In our analysis we focused on economies of learning, adaptive expectations, and network externalities, and not economies of scale, to draw attention to non-monetized increasing returns to adoption. Model 2 was run with a subset of the data to investigate conventional pesticide user's interest in organic agricultural techniques. The Model 2 sample subset included only those 155 respondents who qualified as a conventional pesticide user according to the variable pesticide.

Finally, we qualitatively coded open-ended responses regarding the difficulties of using organic pest management strategies according to categories identified in the responses to this question. Only a subset of respondents was asked the question on organic pest management difficulties or barriers. The logic of the questionnaire instructed the interviewer to ask only those who responded in the affirmative to "use or interest in organic techniques," which resulted in 114 responses to this question. In our coding of responses, a single response could fall into more than one category and would be categorized as a response in each category. The coded responses to this question were not included in either of the logistic regression models. Rather, we utilized these qualitative descriptions in our discussion section to interpret the results of Model 1.

5. Results

5.1. Summary Statistics

Table 1 presents the summary statistics for all variables included in both Model 1 and Model 2. With regard to acute pesticide poisoning incidents, 22% of respondents reported that they or their family had ever experienced an acute poisoning incident. It should be noted that some respondents reported more than one acute pesticide poisoning incident for themselves or for their immediate family members. In total, 50 individual acute pesticide poisoning incidents were reported by the respondents from 1970 to 2013 (the year the survey was fielded). Of these 50 incidents, 28 were reported to have occurred since the year 2000, and 14 of those 28 were reported to have occurred between 2010 and 2013.

Most respondents, 82%, used conventional synthetic pesticides. Of the 510 unique synthetic pesticides in the data set, the top pesticide classes reported in use by respondents were carbamates (active ingredient Methomyl) and organophosphates (active ingredients Dimethoate, Methamidophos and Chlorpyrifos). Respondents also reported the use of many other categories of pesticides, including triazoles, cyanides, pyrethroids, and glyphosate, see Table A.1 in Appendix A for frequency of pesticide categories reported and active ingredients. Only a small portion of respondents, 12%, reportedly used targeted, or pest-specific, non-synthetic traps, as represented by the traps variable.

Sixty-four percent of respondents expressed an interest in using, or already used, organic agricultural techniques. With regard to pesticide preventative practices, 72% of respondents stored pesticides and empty pesticide containers in an appropriate location, 51% of respondents wore protective equipment or clothing while applying pesticides, and 28% of respondents kept records of pesticide inputs and crop data. Finally, the majority of respondents, or 62%, used agro-chemical shops or pesticide technicians as sources of information on pest management techniques, while only 7% and 11% of respondents cited Instituto Huayuná and other farmers respectively, as sources of information on pest management.

5.2. Regression Analyses

The results of Model 1, predicting conventional pesticide use are shown in Table 3 and the correlations between variables in Model 1

Table 2
Expected relationships for Model 1 (M1) with dependent variable “pesticide” and Model 2 (M2) with dependent variable “organic.”

Variable	Hypotheses[a]		Explanation	Related economies[b]
	M 1	M 2		
Omas valley	+		Mala Valley respondents are situated closer to a commercial center, Mala City, which may increase access to pesticide shops and technicians as compared to Omas (Cowan and Gunby, 1996).	NE
crop diversity	−	+	Crop diversification can reduce vulnerability to climate and market variation, thus it may also allow farmers to take greater risks in implementing new technologies (Cole et al., 2011; McCord et al., 2015).	LE
education	−	+	Increased education has been found to be associated with farmer awareness of the harms of pesticides (Hashemi et al., 2012).	
age	+	−	Younger farmers may be more likely to consider pesticides as harmful (Isin and Yildirim, 2007).	
female gender	−		More equal household gender relations, in which women participate in farm business (as represented by female respondents) are associated with reduced pesticide use (Nkamleu and Adesina, 2000; Cole et al., 2011).	
technician	+		Agro- technicians are likely to promote pesticide use along with information about how to use the product (Wilson and Tisdell, 2001; Feola and Binder, 2010a; Sherwood and Paredes, 2014).	NE and AE
land	−	+	Larger farms may have more flexibility and capital to try new technologies which resembles a broader trend for farm conservation behavior suggesting that larger farm operators may be more willing to invest in new technologies (Daloğlu et al., 2014)	AE
poison		+	A farmer who has experienced poisoning knows first-hand the health risks of pesticide use (Hashemi et al., 2012).	
traps	−		If a respondent uses non-synthetic pest traps the respondent is already using alternative techniques and learning through experience (Cowan and Gunby, 1996).	LE
apple	+	+	Apples are intensive to grow in Mala and Omas and rely on heavily synthetic inputs, however, apple growers have a high degree of exposure to pesticides and potentially the negative impacts of using them.	NE and LE
tenure	+	−	Farmers who do not own the land outright, through inheritance or purchase, are less likely to consider the health and long-term effects of synthetic pesticide use on the land and soil (Nkamleu and Adesina, 2000).	AE
registry		+	Keeping a registry of pesticide applications implies awareness for quantities and toxicities of pesticides applied (Cowan and Gunby, 1996).	
equipment		+	Wearing pesticide protective equipment is generally a hindrance and is associated with greater understanding of the health risks of pesticide spraying (Feola and Binder, 2010b).	
storage		+	Storing pesticides in a safe location reflects an awareness for health risks of pesticides (Cowan and Gunby, 1996).	

[a] “+” represents an increasing likelihood, or an odds ratio greater than one, and “−” represents a decreased likelihood, or an odds ratio of less than one.
[b] Under related economies, NE represents Network Externalities, LE represents Learning Economies, and AE represents Adaptive Expectations.

are shown in Table 4. In Table 3, an odds ratio greater than one is indicative of an increased likelihood that the respondent was a conventional pesticide user, whereas an odds ratio of less than one is indicative of a decreased likelihood that the respondent was a conventional pesticide user.

According to the results of Model 1 in Table 3, gender (male), having a technician as an information source, higher quantities of cultivated land, having apples as a primary crop, a rented state of land tenure, and residing in Omas valley were indicative of conventional pesticide use. Model 1 appears to have good model fit (chi-square = 52.13, df = 12, $p < 0.001$) and explanatory power (McFadden's $R^2 = 0.32$). The relatively strong correlations between gender and pesticide ($r = -0.18$) and technician and pesticide ($r = 0.36$) shown in Table 4 reflected these findings. Additionally, the correlation matrix in Table 4 shows a number of relationships worth noting in the data. The variable crop diversity was positively correlated with valley ($r = 0.28$), such that we would expect to see higher crop diversity in Omas as compared to Mala. The variable *age* was negatively correlated with education ($r = -0.51$), such that younger respondents tended to be more highly educated. The variable land was positively correlated with Omas valley ($r = 0.38$) and crop diversity ($r = 0.27$), such that we would expect respondents with more land to be more likely to live in Omas and have more crop diversity on their farm. Finally, the variable apple was negatively correlated with valley ($r = -0.30$) and positively correlated with poison ($r = 0.21$), such that those respondents who grew apples were more likely to live in the Mala valley and more likely to have experienced pesticide poisoning in their family. The variance inflation factor for each variable in Model 1 is below 2, indicating that multicollinearity was not an issue for Model 1.

Table 3
Model 1 logistic regression predicting farmer use of synthetic pesticides.

Variable	OR (95% CI)	p
Omas valley†	2.71 (0.76–9.67)	0.13
crop diversity	0.92 (0.57–1.49)	0.73
education	0.86 (0.27–2.77)	0.80
age	0.97 (0.94–1.01)	0.20
female gender†	0.30 (0.10–0.88)	0.03
technician†	6.51 (2.53–17.98)	0.00
land†	1.27 (0.96–1.68)	0.09
poison	0.59 (0.18–1.98)	0.39
traps	0.38 (0.11–1.35)	0.14
apple†	2.66 (0.94–7.52)	0.07
tenure (rent)†	5.61 (0.59–53.20)	0.13
tenure (shared)	1.99 (0.22–18.14)	0.54

Variable significance: † = highly suggestive odds ratio and 95% confidence interval; n = 188; Log Likelihood = −61.27 (df = 13); chi-square = 52.13 (df = 12), $p < 0.001$; McFadden's $R^2 = 0.32$.

In Model 1, a female respondent was about three times less likely to use conventional pesticides than a male respondent (odds ratio of 0.30, CI = (0.10, 0.88)). Additionally, respondents with more cultivated land had nearly a 30% increased likelihood of using pesticides per added hectare (odds ratio of 1.27, CI = (0.96, 1.68)).

Also the results of Model 1 suggest that respondents who relied on a pesticide technician or agro-chemical shop for pest management information were over six times more likely to use conventional pesticides (odds ratio of 6.51, CI = (2.35, 17.98)) and respondents who grew apples as a primary crop were two and a half times more likely to use conventional pesticides (odds ratio of 2.66, CI = (0.94, 7.52)). The variables technician and apple both show fairly high odds ratios, but wide confidence intervals. As the confidence intervals' lower bounds for these variables are near one (apple) and well above one (technician), and they both have a relatively high upper bound, we interpreted these results to suggest a good likelihood that growing apple as a primary crop and relying on a pesticide technician had positive relationships with the use of conventional pesticides. However, given the wide confidence intervals, we could only interpret the odds ratio associated with these positive relationship as suggestive.

Finally, Model 1's results mildly suggested that the valley in which a respondent lived and whether the respondent rented their land may be important in predicting pesticide use. If a respondent lived in Omas, as compared to Mala, the respondent was more likely to use conventional pesticides (odds ratio of 2.71, CI = (0.76, 9.67)). Similarly, if a respondent rented land, as compared to owning land, the respondent was more likely to use conventional pesticides (odds ratio of 5.61, CI = (0.59, 53.20). Both of these variables demonstrated wide confidence

Table 4
Correlation matrix for variables in Model 1.

Variable number	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	*Omas valley*	1.00											
2	*crop diversity*	0.28	1.00										
3	*education*	0.01	0.13	1.00									
4	*age*	0.02	−0.02	−0.51	1.00								
5	*female gender*	0.09	−0.04	0.01	0.02	1.00							
6	*technician*	−0.09	−0.09	−0.08	−0.11	−0.10	1.00						
7	*land*	0.38	0.27	0.03	−0.08	−0.07	0.05	1.00					
8	*poison*	−0.24	0.03	0.11	−0.06	−0.09	0.13	−0.02	1.00				
9	*traps*	−0.04	0.15	0.12	−0.04	0.07	−0.12	0.05	0.00	1.00			
10	*apple*	−0.30	−0.33	−0.10	0.02	−0.08	0.21	−0.05	0.21	0.12	1.00		
11	*land tenure*	0.23	0.09	0.16	−0.34	−0.09	0.06	0.16	0.00	−0.10	−0.05	1.00	
12	*pesticide*	0.12	−0.09	0.01	−0.18	−0.18	0.36	0.17	0.01	−0.14	0.17	0.19	1.00

intervals, with the lower and upper bounds spanning one, so we have interpreted these relationships as only mildly suggestive.

According to Model 1, crop diversity, education, age, history of pesticide poisoning, and use of non-synthetic pest traps did not appear to be important predictors of conventional pesticide use in the two valleys.

The results of Model 2, predicting interest in organic techniques (*organic*), are shown in Table 5. Table 5 shows that the only variable found to have power in predicting interest in organic practices amongst pesticide users was the variable equipment. Model 2 suggests that any individual that wore protective equipment while applying pesticides was about two times more likely to be interested in organic pest management than those that did not wear protective equipment (odds ratio of 2.02, CI = (0.95, 4.30)). As with Model 1, the variance inflation factor for each variable in Model 2 was below 2, indicating that multicollinearity was not an issue for Model 2. However, Model 2 appears to have low explanatory power (McFadden's $R^2 = 0.07$) and poor model fit (chi-square = 12.50, df = 10, p = 0.25). For this reason, we interpreted the results of Model 2 as inconclusive.

Both those respondents that had an interest in organic techniques and those that already used them reported their perceived difficulties in adopting the techniques. The responses fit into four categories of perceived difficulties with organic techniques (percent of respondents):

1. Lack of sufficient information and/or training on using organic method (67%)
2. Lack of sufficient physical resources (time, energy, funds) (13%)
3. Perception that organic practices wouldn't be able to address an issue that conventional methods can (e.g. a fungus) (11%)
4. Lack of coordination among farmers – perception that conventional methods of neighbors will be problematic for organic growers (9%).

Table 5
Model 2 logistic regression predicting interest in organic techniques amongst pesticide users.

Variable	OR (95% CI)	p
registry	1.41 (0.63–3.16)	0.40
equipment†	2.02 (0.95–4.30)	0.07
storage	0.80 (0.33–1.93)	0.62
land	1.06 (0.92–1.22)	0.44
age	0.99 (0.96–1.02)	0.39
education	1.10 (0.49–2.47)	0.82
apple	1.24 (0.58–2.65)	0.58
crop diversity	1.24 (0.76–2.02)	0.40
tenure (rent)	1.52 (0.51–4.53)	0.45
tenure (shared)	2.36 (0.75–7.38)	0.14

Variable significance: † = highly suggestive odds ratio and 95% confidence interval, n = 155; Log Likelihood = −96.23 (df = 11); chi-square = 12.50 (df = 10), p = 0.25; McFadden's $R^2 = 0.07$.

6. Discussion

The results presented above suggest that conventional pesticide use in the Mala and Omas Valleys is a case of unsustainable technological lock-in. Despite the availability of alternative techniques promoted by Instituto Huayuná, we found pervasive use of highly toxic conventional pesticides in the two valleys and persistent acute pesticide poisoning incidents. Nearly a quarter of respondents had either themselves suffered an acute pesticide poisoning incident, or had a close family member that suffered one. The 24 reported poisoning events since 2000 suggest that pesticide poisoning was still a common occurrence in these communities. This number likely represents an underestimation of broader pesticide exposure in the sample because we did not test for chronic exposure levels via blood testing (Jørs et al., 2006). In this section, we examine the dynamics of the unsustainable technological lock-in of conventional pest management strategies in the Mala and Omas valleys as suggested by results of our models.

Model 1, presented in Table 3 above, examined the predictors of conventional pesticide use by farmers in the valleys and suggested factors associated with this technological lock-in. Using the framework of competing technologies and technological lock-in, Model 1's results suggest that economies of network coordination, learning, and adaptive expectations are contributing to the lock-in in the Mala and Omas communities (Cowan and Gunby, 1996, Kallis and Norgaard, 2010). As described in Table 2, we proposed that many of the variables in Models 1 and 2 reflect these different forms of increasing returns to adoption. These variables include quantity of cultivated, consulting an agro-chemical technician, growing apple as a primary crop, living in Omas valley, and renting land, which are five of the six variables suggested by Model 1 as predictors of conventional pesticide use. Additionally, the barriers to transitioning to organic pest management, as described by respondents (e.g., lack of information and training, lack of physical resources, perception that organic techniques will not work and lack of farmer coordination), align with the barriers one would expect to see when attempting to transition away from a technology entrenched through increasing returns. Although the results of Model 2 were inconclusive for predicting interest in organic agricultural techniques amongst conventional pesticide users, it is important to note that the majority of pesticide users did express interest in switching to the alternative technology (Pimentel et al., 2005). In the following paragraphs, we discuss the role of network externalities, learning economies, and adaptive expectations in the lock-in to synthetic pesticides in the Mala and Omas Valleys and consider them each individually as barriers to transitioning to organic pest management.

The difficulty of network coordination amongst farmers and neighbors to switch to organic, as noted by synthetic pesticide users, may reflect the strong influence of agro-chemical technicians in the region. This is in line with Model 1's results which suggest that respondents who consulted agro-chemical technicians were more likely to use conventional pesticides. Mala City is host to ten agro-chemical specialty shops, which is more than two times the number of shops that were present in the city in the late 1990s. Respondents consistently reported visits and community meetings with agro-chemical technicians. These technicians typically represent a specific agro-chemical brand or line and therefore have strong incentives to encourage the use of synthetic pesticides and reinforce the agro-chemical network. This reflects a similar finding in Ecuador where Sherwood and Paredes (2014) found evidence of agro-chemical vendors promoting the use of highly toxic varieties of pesticides at higher application rates than necessary in order to reach sales quotas. Additionally, farmers who consistently used pesticides had strong incentives to continue asking and receiving information from agro-chemical technicians as they continued to purchase pesticide products. In an attempt to break this cycle of dependence, Instituto Huayuná and two small organic cooperatives in the valleys are working to build an organic market infrastructure that connects to a biofería, or farmer's market, in the Lima Region. Currently, however, this network exists at a dramatically smaller scale than the agro-chemical network. This improvement in coordination amongst organic growers may resolve some of the risk and uncertainty that currently stands as a barrier to transitioning.

The high odds ratio associated with apples in Model 1 also suggests that network coordination amongst conventional pesticide users may have been a large barrier for farmers who grew apples as a primary crop. Parsa et al. (2014) found that with regard to adoption of IPM, experts in developing countries cited lack of "collective action within a farming community" as the most important obstacle to its adoption. Apples are a very popular crop in the region, and switching from a conventional apple product, with extensive market infrastructure, to an organic apple product with a less established market network, is very risky. The alternative network of the two organic cooperatives is striving to create a market for organic produce and avenues to reach this market. The coupling of a local market for organic produce and new consumer demand for organic produce could greatly reduce the risk of transitioning to organic. Developed countries, such as the United States have seen dramatic increases in organic agricultural production driven by consumer demand (Klonsky, 2000). This effort in Mala and Omas, if successful, will improve network coordination amongst organic users and may lower the barrier of transitioning from conventional pesticides.

With regard to network externalities it is also worth noting that in Table 2 we hypothesized that because Omas is physically located further away from the agro-chemical stores in Mala, respondents from Omas would be less connected to the Mala City pesticide network and therefore less likely to use conventional pesticides. Instead, Model 1's results mildly suggest that respondents in Omas were more likely to use pesticides than those in Mala. Due to the low level of respondents in Omas that did not use conventional pesticides and the wide range in the confidence interval associated with the odds ratio for Omas valley in Model 1, we are cautious of interpreting network economies from this result. It is possible that due to the ease and frequency with which farmers in Omas accessed Mala city and agricultural wholesalers from Mala visited Omas, physical distance from market centers was not an important factor in pesticide use.

The learning economies associated with synthetic pesticide use are a barrier for farmers to transition to organic agriculture. As suggested by conventional pesticide users in the study, farmers in the valleys faced uncertainty in the time, energy and funds required for organic techniques. This barrier may also be reflected in the increased likelihood for apple growers to use synthetic pesticides, as seen in Model 1. Many farmers in the region used synthetic defoliants, herbicides, and pesticides to reduce the amount of labor required for the intensive process of producing apples in the regional climate. Transitioning to more labor-intensive practices will require investments of time and energy and may require additional on-farm workers. It may be difficult for farmers to recruit additional workers to the farm because of the high opportunity costs associated with on-farm labor (Beckmann and Wesseler, 2003). Furthermore, it may be difficult to find and train new workers in the techniques required for organic practices. Both the transition to a more labor-intensive practice and the associated learning curve may be a difficult barrier to overcome for apple farmers interested in organic practices.

We propose that economies of adaptive expectations can be seen in farmers work with agro-chemical technicians, quantity of land cultivated and variation in land tenure arrangements. A farmer's own past experience using synthetic pesticides reduces uncertainty in the current use of the technology. In addition, agro-chemical shops and synthetic technicians offer information and services to further reduce uncertainty as farmers may be facing a new pest. This may partially explain why in Model 1 we saw farmers who consult an agro-chemical technician as more likely to use conventional pesticides. While these sources of information may be biased and there may be superior methods for combating a particular pest in the long term, agro-chemical shops and technicians do serve to assure farmers that use of a pesticide will resolve the farmer's issue of concern in the short term. This reduction in the uncertainty with using pesticides creates a barrier to switching to an alternative practice where a farmer may not understand exactly how the technology is going to work. This is reflected by respondents' perception that organic practices would not be able to address an issue that conventional pesticides could.

In Table 2 we hypothesized that quantity of land cultivated would be negatively associated with conventional pesticide use, however, the results of Model 1 showed a positive relationship, such that the more land a respondent cultivates, the more likely they are to use conventional pesticides. In hypothesizing this relationship, we expected larger farms to have relatively greater flexibility in management techniques due to greater production capacity and access to capital. We related this to a broader trend in conservation agriculture, which may or may not be appropriate for smallholder agriculture, that sees farm size as representative of farm capacity in that you would expect larger farms to have greater economies of scale and more capital to invest in adopting new practices (Prokopy et al., 2008). However, the results of Model 1 suggest that the opposite may in fact be true in Mala and Omas. An explanation for this result may be the relative size of farms that we are considering in this study (0.04 to 13 ha). Amongst the smallholder farmers in Mala and Omas, it is likely that the larger farms represented market-oriented small farm systems, while the smaller farms practiced more subsistence agriculture. In this case, adaptive expectations related to transitioning to organic pest management techniques may have been a greater barrier for small market-oriented farms as compared to subsistence-oriented farms.

The presence of renters as a mildly suggestive factor in predicting pesticide use in Model 1 may also be an example of technological uncertainty contributing to unsustainable technological lock-in. We are cautious to interpret the odds ratio associated with renting land in Model 1 due to the wide confidence interval. However, one potential interpretation for the mildly suggestive relationship between renting land and conventional pesticide use is that renters and the landowners they rent from face split-incentives. Organic practices serve as a long-term investment in the land that may increase the value of the land for the landowner, but the cost of transitioning falls primarily on the renter who may not have guaranteed long-term access to the land. Additionally, farmers who rent land in the valley, as opposed to farmers who bought or inherited land, may have less capital available to invest in alternative agricultural techniques that may not give an immediate return on investment. Therefore, it may be that farmers who primarily rent land may have a more difficult time transitioning away from synthetic pesticides.

Gender was the final variable found important in Model 1 for predicting conventional pesticide use. As predicted in Table 2, female respondents were less likely to use pesticides than males. This finding supports Orozco et al.'s (2011) finding that amongst Andean Ecuadorian small-scale farmers, women's participation in farm decision making and more equality in household roles is associated with less use of toxic pesticides. We must note that in our study we were not able to differentiate between female farmers that may have been widowed or single, and female farmers that participated in the household's farming with their spouse. The relationship between gender in household equality and technological lock-in of pesticides would be a fruitful area for future research, as it appears to be an important factor in predicting the use of pesticides.

7. Study Limitations and Future Research

In this paper we have shown that pesticide use and poisoning are continuing in the Mala and Omas Valleys and that agro-chemical technicians, quantity of cultivated land, gender (male), growing apples, and renting land, are important predictors of conventional pesticide use that support the technological lock-in of conventional pesticides. More broadly, our research demonstrates the continuing reliance on highly toxic synthetic pesticides in smallholder agriculture in Latin America, and contributes a new case study context to the building literature describing this phenomenon.

We acknowledge a number of limitations to our study including the unrepresentative sample, use of self-report survey methodology, and potential for omitted variables in our regression analyses. Because we cannot claim a representative sample of the Mala and Omas Valleys, there may be limited generalizability to our results. Additionally, our data is potentially skewed by participant recall bias due to the use of self-reported methods for gathering health and farm management data. Finally, we recognize that it is possible we overlooked other important variables, such as income, in our model selection for Model 1 and Model 2. Future research can build upon our study to examine the degree to which the variables identified as important predictors of pesticide use in the Mala and Omas valleys explain pesticide use and lock-in in other contexts.

We also acknowledge that the binary presentation of pest management techniques as either synthetic-based or organic in the pesticide variable is an oversimplification of a broad spectrum of pest control strategies that includes varying degrees of IPM. For future research, an exploration of this spectrum of ecologically-based pest management techniques (including degrees of IPM and organic) would help to determine whether organic pest control is simply one end of a spectrum that includes IPM or categorically different from the farmer perspective (due to certification requirements and price premiums).

Finally, we would like to note that the scope of our study was explicitly a local level analysis of farming in the Mala and Omas Valleys, and therefore we acknowledge that we do not address the interactions and influences of regional, national, and international institutions on the observed farming behavior and results (Agrawal, 2001). Future research can build upon the local level analysis completed in this study to investigate the interface between Peruvian market dynamics, government regulation and the unsustainable use of synthetic pest management in the Mala and Omas Valleys. This broader perspective could shed light on market and government interventions that could assist farmers in transitioning to more sustainable pest control technologies and reduce negative human and environmental externalities at the farm level.

8. Conclusions

This paper demonstrates the utility of applying technological adoption theory to questions of local level sustainable agriculture and important public health problems in order to identify barriers to transition and opportunities for action. Local government, farmers and NGOs in the Mala and Omas Valleys and across Latin America could strategically address the technological barriers associated with uncertainty, coordination and learning to support a transition to more sustainable pest management strategies. As mentioned previously, Instituto Huayuná has been working to grow a network of organic farmers, host trainings for farmers, and create new market opportunities for farmers in the valleys. Further interventions can focus on decreasing the influence of agro-chemical technicians on farmer pest management decisions, and on targeting renters and pesticide-intensive crop growers (such as apple growers) to introduce programs to reduce the risks of learning, reduce the initial financial investment and build infrastructure around organic agriculture and other sustainable pest management techniques.

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Appendix A

Table A.1
Pesticide categories and active ingredients of unique pesticides recorded.

Pesticide category[a] and active ingredient	Unique instances recorded in survey[b]	WHO classification[c]	Number of countries that have banned[d]	Banned in Perú[d]
Carbamate	99			
Carbofuran	2	Ib	46	No
Methomyl	96	Ib	11	No
Carbaryl	1	II	32	No
Organophosphate	99			
Dicrotophos	1	Ib	33	No
Dimethoate	63	II	4	No
Azinphos-methyl	1	Ib	36	No
Methamidophos	19	Ib	47	No
Chlorpyrifos	13	II	1	No
Methyl parathion	2	Ia	26	Yes
Triazole	84			
Tebuconazole	4	II	NA	No
Propiconazole	33	II	NA	No
Penconazol	33	III	NA	No
Bitertanol	1	U	29	No
Triadimenol	12	II	NA	No
Triadimefon	1	II	NA	No
Cyanide	79			
Hydrogen cyanide	79	FM	1	No
Pyrethroid	41			
Permethrin	1	II	29	No
Cypermethrin	32	II	NA	No
Alpha-cypermethrin	4	II	NA	No
Deltamethrin	2	II	NA	No
Chitin synthesis inhibitor	28			
Buprofezin	3	III	NA	No
Lufenuron	25		NA	No
Glyphosate	18	III	1	
Petroleum-based oil	12			
Dithiocarbamate	7			
Propineb	2	U	NA	No
Mancozeb	5	U	1	No

[a] 510 individual conventional pesticide products were reported in use in the survey. The 467 pesticide counts included in this table represent all categories with more than 5 unique mentions by respondents. In addition, respondents mentioned 29 individual pesticides from 15 other categories, and 14 individual pesticides recorded as “herbicide”, “insecticide”, etc.

[b] Because some individual pesticides were reported at the level of the pesticide category, not all reported active ingredient sum to the total number of individual pesticides reported per pesticide category.

In the table, pesticide categories are listed in normal font. The active ingredients belonging to a pesticide category are listed in the rows below each pesticide category in italics.

[c] World Health Organization's recommended toxicity levels (Chemicals and W. H. Organization, 2010): Ia — extremely hazardous, Ib — highly hazardous, II — moderately hazardous, III — slightly hazardous, FM — fumigant not classified, and U — unlikely to present acute hazard in normal use.

[d] According to the Pesticide Action Network's Consolidated List of Pesticide Bans 2015 (Pesticide Action Network, 2015).

Appendix B. Data Collection Instrument

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ecolecon.2016.05.013.

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