Migration, Spatial Interactions and Household Activity Choice in the Valle Alto, Bolivia

By

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Introduction

The four chapters contained in this thesis investigate two distinct phenomena: the spread of peaches in Bolivia and changes in faculty research in the United States. The first two chapters consider migration, household behavior, and the effects of neighbors on peach adoption within the Valle Alto region of central Bolivia. One considers the peach adoption decision in a household framework; the second explores the increase of peach orchards within a larger watershed in the same region. The third and fourth chapters examine changes in the time allocation and research productivity of agricultural sciences faulty at U.S. land grant universities.

Between the late 1980s and 2010 there has been a rapid increase in the number of households (and parcels) growing peaches in the Valle Alto, Bolivia. Understanding the adoption of this agricultural technology requires analyzing and integrating many factors at the household level, including endowments, household characteristics and activities, and non-agricultural opportunities such as wage labor. The first chapter of this dissertation studies the interrelations between different types of international migration, technology adoption and human capital investments. Using primary cross-sectional and retrospective panel data collected in the Valle Alto, I test whether international migration leads to peach adoption, asset accumulation and educational attainment.

In this region, cash constraints do not appear to be the driving force limiting peach adoption—rather it appears to be shaped on the one hand by the family's ability of to monitor the orchard or the desire to return to a productive farm, and on the other the potential for higher returns to investments in labor for work beyond the Valle Alto. In the analysis, I distinguish between continental migration (to Argentina) and overseas migration (to the U.S. or Spain).

Using fixed-effects panel methods and seemingly unrelated regressions, I find that those households able to send a migrant overseas attain increased years of schooling among children and scale back their on-farm activities. Conversely, households with an emigrant in Argentina invest heavily in peach adoption and animal cultivation. This chapter is among the first papers to model the differential returns to two international destinations and is also unique in use of retrospective panel data to analyze a household's investments and accumulation path.

The second chapter also explores peach adoption within the same area, but from a broader perspective. I conduct a spatial analysis of land use change between 2003 and 2008 in the entire watershed containing the surveyed parcels. To do so, I use remotely-sensed data derived from two satellite overflight images and integrated into a GIS database. After establishing the presence of peach clusters in the study area, I estimate several discrete choice and spatial models to measure the effects of neighbor's crop choice on a given parcels likelihood to convert to peaches.

A key issue in understanding the crop choice on a particular parcel is distinguishing the ownership of nearby parcels. A nearby plot may be owned by neighbors or could be another parcel belonging to the same household, which introduces endogeneity. A methodological innovation devised in this chapter is the creation of a "donut" estimator which measures the number or area of nearby peach parcels but drops the adjacent and most proximal parcels, as they are much more likely to be owned by the household. The econometric results from spatial lag and discrete choice models show broad consistency of the role of neighbors in peach adoption—they exhibit a positive and diminishing effect. Having an additional neighbor either within the band between 50m and 100m increases likelihood of conversion by 3% to 4%. These results suggest that spatially diverse targeting could increase the spread of a new, desirable agricultural technology

The latter part of this dissertation contains two chapters examining the time allocation and research productivity of faculty in agricultural sciences departments at U.S. Land Grant universities. This line of research is empirically based on four rounds of a nationally representative survey of these faculty conducted in 1979, 1989, 1995 and 2005. The twenty-five years between the first and last of these surveys span major advances in computational and information technology, as well changes in the way university research is conducted, including an increase in competitive grants and a diminishment of organizational support staff and decentralization of administrative activities.

The third chapter, which is mostly descriptive, analyzes the evolution of time allocation of agricultural and life science faculty. It explores these trends with respect to time spent on research versus administrative activities, and shows about a 20% decline in the former and a more than doubling of time spent on the latter. Most of the research time decline is accounted for by increased pre and post-grant administrative efforts and other non-research administrative activities, rather than changes in teaching activity. Despite the substantial decrease in time available for research, other key research inputs and overall journal article output per faculty have remained relatively stable over that same time period. Similarly, the factors affecting promotion and raises have not fluctuated substantially either. Regression analysis shows that the time spent on research activities falls in each consecutive period relative to a 2005 baseline. Faculty spent 12% more time on research in 1979 but only 4% more by 1995. Finally, faculty in basic sciences have been spared some of this decline; the decrease in research time is more pronounced in applied sciences.

Finally, the fourth chapter measures changes in the productivity of faculty throughout this period. Delving into the trends presented in chapter 3, it regresses research output (journal articles and other publications) on a number of inputs (e.g., faculty research time, graduate students, post docs, and funding), while controlling for demographic and university characteristics. The major result is a significant increase after 1980 in faculty research productivity per unit time. This change is consistent and widespread, affecting all fields of study and types of universities. This paper uses pooled, cross-sectional data for each of the four years, as well as a smaller, panel dataset which contains information on 147 scientists who responded to both the 1995 and 2005 surveys. Using a negative binomial estimator, analysis from the larger dataset establishes significant changes between 1979 and 1989 and the most recent survey in 2005. We interact time dummies with the percent of time allocated to research and find statistically significant, negative coefficients. The results are robust when decomposing the dataset into top-ten and other universities, using university fixed effects, clustered and robust standard errors, and including either of two measures of research time. The increase in output per unit time is especially pronounced in non-top ten universities, as they have benefitted substantially from the lowering of collaboration costs. Fixed-effect, panel data analysis between 995 and 2005 shows that these changes are not due to a change in the composition of the dataset. Combined with the changes in research and administrative time, these results demonstrate that the these productivity gains have compensated for increases in the administrative burden on faculty, leading to consistent research output in an era of declining research time.

My approach in each of the papers is to compare data from two or more years, and analyze how behavior has changed over time. Three of the papers use household or individual surveys, while the fourth analyzes spatial data to model the spread of a cash crop. They all make effective use of cross-sectional and panel econometric techniques and offer significant empirical findings to important areas of research related to the study of migration, technology adoption, land use change, and university research.

Migration, Peach Adoption, and Household Decision-Making in the Valle Alto, Bolivia

1 Introduction

Households owning productive farmland in less developed rural areas often have multiple routes to secure a steady income and accumulate assets. Frequently, the household must choose between a near-certain continuation of traditional farming methods and a potentially risky investment in cash crops. The cash crops have the potential for a greater return, but may require a significant upfront investment. In addition to risk, the household may be unable to secure income between the planting and harvest time, or lack the resources to meet a minimum level of consumption if the crops fail. Household decisions are often further confounded by the lack of well-functioning markets in many rural settings. Missing labor markets, for instance, may limit the household's ability to reap the benefits of a large harvest. Absent markets for land and irrigation rights can trap a household into an inefficient mode of production. If achievable, the switch into cash-crop agricultural production has the potential to greatly increase both the income and welfare of farmers in the developing world (Maxwell and Fernando 1989; Govereh and Jayne 2003; Masanjala 2006).

This chapter explores the on and off-farm activity choices of rural households. It extends and integrates several strands of literature to create an integrated portfolio model. Building on the agricultural household model, it directly addresses the effects of international migration episodes in developing countries, focusing on the differential returns to continental and overseas emigration. This work also considers human capital investments which do not payoff in the short or medium-term, but are nevertheless highly valued and offer an alternative path to development. With primary data collected in 2009–2010, I investigate the causal link between migration and peach adoption. Using cross-sectional data to test for this is challenging as the choice is endogenous over time, and there may be issues of simultaneity. I use a panel dataset to address the first concern, and a system of equations to address the second.

Previous work has explored how lifting credit constraints, offering insurance, and reducing risk (e.g. through technical assistance) may allow households to make on-farm investments and adopt new technologies (Udry 1994; Rosenzweig and Wolpin 1993; Fafchamps and Lund 2003). Agrarian households often do not have the necessary capital to invest in new farming techniques and may have difficulty obtaining such capital given the lack of credit and savings markets. In addition to monetary constraints, households also may need to secure land and water rights, obtain necessary knowhow, and have sufficient labor to harvest the crops. Because in most poor, rural areas production and consumption decisions are linked, changes in agricultural production have direct implications for household expenditures and well-being (Singh, Squire and Bank 1986).

Households optimize their expected return to agricultural and other investments while minimizing the associated risk and uncertainty. Migration and remittances affect this process in several ways. They can raise overall household income and allow the household to engage in a broader array of activities and make otherwise infeasible investments. For example, Mendola (2008) finds that international migration from Bangladesh leads to the adoption of new varieties of high-yield maize, while in-country (domestic) migration does not. The following analysis, which compares two international destinations, find that only one of them results in adoption of a new technology (planting peaches). Migration often plays a crucial role in spreading risk out of agriculture or into a different geographical area, thereby acting as an insurance mechanism. Associated remittances can also affect household budgeting: without the need for as many on-farm profits, households may be able to forgo child labor and pay school fees. Migration choices also affect households along two other dimensions. First, in communities where migration is prevalent, the departed migrants may diminish available labor at the margin. Also, the creation of migration networks in destination countries can and does facilitate future migration. Second, the difference in asset accumulation from remittances can change next-period decisions and transform the household's development trajectory.

Structure of the Chapter

This chapter enumerates options available to agricultural households, and investigates how international migration affects these choices, focusing on the differential returns to migrating nearby (within the continent) and migrating to the U.S. or Europe. After discussing relevant literature, Section 2 discusses migration and land use choices within a household framework that includes land and water endowments. Households may choose to grow a staple crop (maize) or a cash crop (peaches), the latter of which is more profitable, but riskier. This framework also includes households' investments in physical and human capital.

After discussing the survey and study area in Section 3, I apply this framework to the Valle Alto region of central Bolivia (see Figure 1), an area in which there has been traditional farming for centuries, and where the majority of all arable land in maize rotation. The area has been substantially reshaped due to three major changes occurring over the past few decades.

First, in the mid-1990s a dam and canal network was built allowing for more (and more reliable) water procurement. To further manage this scarce resource, the rules surrounding access to water were codified and water rights were allocated. Second, beginning only in the 1980s, there has been a widespread shift to planting peach orchards, with more than three quarters of all peach parcels in the study area planted after 1995. Third, although migration in the area had been underway for decades, a dramatic increase occurred in the number of people migrating, especially to the United States, starting around 1990 and growing steadily until the time of the survey.[1]

Figure 2 shows the growth of peach parcels and migration to both the United States and Argentina over this time period.[2] By inspection, it would seem that the driving force behind peach adoption is the takeoff in migration to the U.S. that commenced around 1992 and accelerated from 2000 until the present. One interpretation common in the cash crop literature is that families theretofore were constrained by available liquidity. That is, U.S. migration (and associated remittances) allowed households to overcome this constraint to make investments in peaches (Eswaran and Kotwal 1990). Regression analysis below will show that this is not necessarily the case. In fact, an alternative interpretation will be developed around the finding that peach investments are strongly driven by a distinctive migration experience, specifically migration to Argentina, which is often shorter in duration, more circular and less permanent, as compared with U.S. migration (Yarnall and Price 2010). These migration decisions result in distinctive patterns of investment for the sending households.

[1] The migration data are mostly retrospective and were collected at the household level between November 2009 and March 2010.

[2] Although there was some migration to Spain, migration to the U.S. and Argentina constituted over 90% of total migration.

In Section 4, two econometric models are developed to isolate the effects of migration on peach conversion and other household activities. First, I use a fixed effects panel data model to examine the determinants of peach conversion and maize production. Second, a system of cross-sectional models is employed to ascertain the causes of peach parcels, animal wealth, and educational attainment. The results in Section 5 show that the choice of whether and where to migrate is a major determinant of a family's agricultural and educational pathways. Families with migrants to Argentina tend to focus on increasing productive assets, such as peach orchards and animal husbandry. These households have a higher number of short-term migrants. Conversely, families that have sent one or more members to the United States do not develop these productive assets but instead focus on the accumulation of human capital and physical capital, primarily in the form of household wealth rather than agricultural investments. Section 6 discusses these results and concludes.

2 Literature and Conceptual Framework

The framework developed herein explores the tradeoffs rural households face making choices over land use, migration, and physical and human capital investment. In the study area in central Bolivia, and for much of the developing world, there are several distinct and often mutually exclusive pathways to development. Investment in on-farm technology or agricultural inputs can preclude the household from accumulating savings or paying school fees. Children who are needed to tend to the fields cannot attend school as frequently as they otherwise might. Those who have migrated are unable to work off-farm or participate in child care. Families face an intertemporal optimization problem with risk and irreversibility inherent in many of the choices. This chapter contributes to the literature by employing a framework which examines the interplay between migration, technology adoption and education while explicitly considering two international migration destinations. In addition, it uses a retrospective panel to measure the effects of migration episodes on households' activities and investments.

This chapter will show how the combination of these choices and household endowments may shape the activity patterns observed years later. I construct this framework around the high-altitude farming communities in central Bolivia, but the choices are similar in other areas where new crops or methods supplant traditional cultivation in rural households looking for a higher return on agricultural activities. In addition to risk and return, the individual farm or household decision may be affected by, *inter alia,* liquidity constraints, labor endowments, learning, sunk costs, and other household characteristics. Communities will also face other constraints, including limits on the amount of total available water and missing land or labor markets. Here, I focus on the household's choices around crop choice, migration and education. In the next chapter, other social and spatial considerations are dealt with explicitly.

For most rural households, the choice to grow different crops is a paramount consideration. In the economics literature, this choice is often framed as a technology adoption decision. In many areas, the potential return to switching to new crops will be higher than sticking with traditional cultivation. However, poorer individuals with identical preferences will often choose a safer—and therefore less lucrative—portfolio due to an absence of available credit and the inability to self-insure *ex post* (Foster and Rosenzweig 2010). Rather than adopt the new crop technology, these households will diversify to limit their exposure to crop failure by growing less risky crops, raising animals, or working off-farm. They may be unable to afford the conversion outright, may deem it too expensive, or be unwilling to accept the additional risk it entails. Households with poor access to credit may not only be unable to invest in a risky proposition, and even choose to become wage workers to mitigate the negative consumption shock caused by a poor agricultural outcome (Eswaran and Kotwal 1990; Rosenzweig and Binswanger 1993). Household wealth portfolios, specifically liquid asset holdings, directly affect their investment activities, where households which lack assets that can be used to smooth consumption will instead opt for lower-risk, lower-return activity. Savings, in the form of capital, land, or livestock are pursued in order to guard against a large crop failure. Poor households may additionally be unable to undertake activities where a lumpy investment is needed, pricing them out even though they are willing to accept the associated risk (Dercon 1996; Dercon 1998). In the Bolivian study area, it was more common for those households considering converting parcels to peaches to lack sufficient endowments or fear the possibility of a bad outcome than be strictly unable to afford the investment.

Although migration may often be an individual’s choice, considering the family’s decision under the rubric of the New Economics of Labor Migration (NELM) model we can conceptualize a migration episode to be an intertemporal contract between the migrant and her family (Stark 1991). Individuals choose to maximize their expected earnings by staying home or migrating to a new locale. If it is viable, families may favor a strategy where they manage risk by sending members abroad. In addition to typically being greater than local wages, the earnings of the migrant are not necessarily correlated with the income of the sending family and therefore the family is more protected from a negative shock (Stark and Bloom 1985). Households in the Valle Alto often contain several generations and frequently include returned migrants.

Individual migrants have multiple reasons for sending home money. The primary reasons are to increase the well-being of or provide insurance for those who remain. Migrants often also do so to repay a loan, secure their social standing within a community, and perhaps to increase their likelihood of a receiving an inheritance, sometimes referred to as "enlightened self-interest." Investments in physical and productive capital may serve dual purposes, providing assets the migrant can use when they return and showing the remaining family members that they are altruistic (Lucas and Stark 1985; de la Briere 2002; Rapoport and Docquier 2006). Migrants financing capital investments at home may also want to be able to more directly monitor their investments, contribute some technical assistance, or guard against moral hazard.[3] This may provide a basis for understanding why certain investments are supported by migration in distinctive locations, for instance why Argentinian migrants invest more in assets tied to their household in the home community. Relative to those in the U.S., migrants in Argentina are more likely to eventually return home and, if needed, come back temporarily. In addition, in nearby locales information coming from home communities may be of higher quality and therefore provide better guidance for ongoing investments.[4]

Some household choices may affect other members of the community indirectly or have implications for future generations. The effect of migrating household members on the farms and communities they have left behind is a subject of considerable research (Taylor, Rozelle and De Brauw 2003; Yang 2008; Mendola 2012). Since those who migrate tend to be young, healthy, and male, farms may experience a decrease in the amount of labor available, raising the price of hired-in labor. Alternatively, remittances may allow households to overcome liquidity constraints, and make on-farm investments which raise their yields or allow farms to convert to another, more lucrative, technology. Recent studies have found that migration increases farm

[3] Many past studies have focused on the role of moral hazard in terms of the migrant remitting to cover the expenses it took to finance his emigration (Rapoport and Docquier 2006). The rationale described herein reverses the information asymmetry.

[4] In a different context, (Gubert 2000) finds that some migrants in the home community have gone as far as to create fictitious natural disasters in order to increase remittances.

productivity; remittances increase returns to land through increased inputs (Mendola 2008; Taylor and Lopez-Feldman 2010). In another there was an initial decrease in farm profits due to lost labor, but increased returns in the medium-term once remittances become available (Rozelle, Taylor and DeBrauw 1999).

The effects of migration on asset holdings can hold major implications for a household's future development. Whether due to differences in remittance income or because of generations-old endowments, the development of asset inequality can also create long-standing divisions within a society. In Bolivia, this is clearly evident in the homes of remittance recipients. Asset inequality can lead less well-off individuals to develop an inferior slate of on-farm activities, due to risk management. Because they can self-insure in order to smooth consumption, richer households may acquire a higher-yielding portfolio. In this way, these initial land and labor endowments can lead to different development paths. Over time, distinct classes may emerge, due to moderate initial differences in working capital. Even given the same preferences and ability, this difference in assets will cause some households to engage solely in wage labor, leave others with small farms, and create a small set of capitalist employers (Eswaran and Kotwal 1986; Zimmerman and Carter 2003). For families with limited asset holdings, because a bad crop outcome may lead a household to reduce consumption, these households may choose not to invest properly (e.g. foregoing fertilizer use), decreasing yields and landing them in a poverty trap scenario. In addition to more complete credit markets, programs which can pool risk or provide insurance will allow households to make more lucrative investments, leading to higher yields.

Both on-farm profits and remittances are used to finance the next generation's education. Schooling incurs both registration fees and, depending on the age of the child, a reduced amount of available on-farm labor. In Latin American and other contexts, remittances have been shown to encourage schooling and decrease absenteeism (Calero, Bedi and Sparrow 2009; Bansak and Chezum 2009). The potential gains to education are large and established. Investment in children's education can lead to sustained higher incomes through increased opportunities for off-farm labor (Glewwe and Kremer 2006). In the agricultural context, education can be considered an input to on-farm production, facilitating technology adoption (Foster and Rosenzweig 1995). On the other hand, returns to educational attainment allows some families to diminish (or sever) their dependence on agricultural production, so they are less adversely affected by a negative shock. In broad surveys of the literature, Psacharopoulos (1994), and Psacharopoulos and Patrinos (2004) show high private returns to education through increased earnings. However, the social returns and antipoverty benefits of education are less clear.

Framework

This framework depicts household decision-making in an area where both migration and the potential to adopt a high-risk high-return crop are available. A utility-maximizing household will consider both of these decisions (and their future implications) simultaneously. Households which are cash and credit constrained, or who are risk averse, may only be able to finance one of these two activities. In the context of the Valle Alto, agents face three primary decisions: they may choose to (a) send a family member abroad; (b) exercise the option of converting some or all of their lands to peaches (or leave them in maize); and, (c) chose to invest in their children’s schooling.[5,6]

[5] This framework is informed by Deaton (1991), Dercon (1996), and Bryan, Chowdhury and Mobarak (2013), where the household makes a decision today which maximizes consumption across this and future time periods.

[6] Off-farm labor is another option, but this choice is not observable and this framework will still capture the effects of migration decisions at the margin.

Those migrating families in the Valle Alto must decide where to migrate, and how to spend accumulated assets and allocate labor for those remaining at home. In this framework the household can chose to opt out of migration or send one or more family members abroad to the U.S. or Argentina.[7] Migration to the U.S. involves higher upfront costs, more commitment (most migrants stay longer), and may be feasible only with an established family network. Alternatively, migration to Argentina is cheaper, shorter in duration, and movement back and forth is less costly. In the Valle Alto there are well-established networks in Buenos Aires, the Washington, DC metro area and, more recently, in Spain (Dandler and Medeiros 1988; Strunk 2013; Jones and de La Torre 2011). These networks serve not only to establish a migrant in her new locale but also to keep the migrant connected to the Valle Alto through cultural events such as holidays, celebrations, and soccer games (Yarnall and Price 2010). This, of course, has implications for the next generation, which will be more likely to migrate if they, too, have family members who are abroad.

Migration in the Valle Alto is widespread and allows for the household to engage in higher-return activities, or for risk to be spread between farming, local wage labor, and the migrant's non-agricultural activities. Remittances spur investments that would not be otherwise possible and can produce a marked improvement in a household's standard of living (Yarnall and Price 2010). Many of these choices are not easily reversible, thereby committing the household to a particular path for multiple years. A preponderance of households have a recent active international migrant, domestic migration is not considered.[8]

[7] Within the sample, all but one migrant went to the either U.S., Argentina or Spain.. Because migration to Spain is relatively new and affects only a small number of households, I only consider migration to the U.S. (see Table 2 for more details).

[8] In a study of Valle Alto households with active migrants in 2007, Jones and de La Torre (2011) find that of a mean household size of 5.11, 3.13 members live in the household, 1.89 live abroad and only 0.09 live

At home, the household also chooses between converting some or all of its parcels to peaches or keeping the land fallow or in maize. Maize production uses a relatively small amount of capital and requires little new knowledge; most families have been cultivating it for generations and the expected output from a maize field is generally known.[9] Conversely, peaches require large upfront costs to establish the orchard (planning and planting the trees), take multiple years to bear fruit, and demand considerable labor at the time of harvest. Peaches are more susceptible to frosts and pests, and may produce zero or negative profits in a bad year. However, because interventions can be effective when households know when to expect such frosts, and peaches will yield a better return if they are monitored by migrants at home or in Argentina. Although the empirical evidence is ambiguous as to whether more educated growers receive higher returns to peaches, one study in the Valle Alto found that education increased creativity (Chávez and Hartwich 2011). While maize has cultural significance in this area outside of its economic value, I focus on its use for consumption, animal feed, and sale.[10]

Education also plays a crucial role in determining both the costs and returns to migration. There is a well-established wage premium to education for migrants in the United States (de la Briere 2002), and work elsewhere has shown that though education may be negatively correlated with education along the extensive margin, there is a strong positive effect along the intensive margin (Ramos and Matano 2013). This is partly due to the increased wages commanded by better-educated immigrants, and also may be that migrants pay back their educational investment

elsewhere in Bolivia.

[9] Although a small number of other crops are grown in the area, within the households surveyed, maize and peaches were the only crops with significant value. Nearly all lands not used for these crops were part of a maize rotation.

[10] In areas where traditional varieties are not readily available in the market, shadow prices for certain maize varietals may significantly differ from the market prices. Household decision-making is based on the shadow value of the crop, and choices may appear sub-optimal if market prices are used (Arslan and Taylor 2009).

or there are lower search costs for migrants with more years of schooling.(Chiquiar and Hanson 2002). The motivations of the migrants also play a role. While more educated migrants who are remitting for exchange purposes may send less remittances, there is evidence to support that in strategic and investment motives, more education leads to high remittances (Rapoport and Docquier 2006).

Figure 3 shows migration pathways, and potentially associated activates for households that begin with little accumulated capital or off-farm income.[11] In this formulation, households choose whether or not to migrate, and then select a destination based on their assets and preferences. Those emigrating to Argentina are more likely to return or maintain close relations with their families in the Valle Alto. They are expected to grow peaches and may save up additional capital to migrate to the United States at a later date. Conversely, families with migrants in the U.S. are more likely to focus on investments in human capital, although many will send other remittances home, which will be placed in farm activities and physical assets.

Hypotheses

Households, then, will make migration decisions based on their available capital, risk preferences, and levels of income. These choices will also be shaped by land holdings and associated water rights, available labor, the social context, and the level of farming expertise. As seen in Figure 3, growing annual (traditional) crops and raising animals are low-capital input activities likely to be good options for households that lack funds to grow peaches or migrate. This leads to the following hypotheses:

[11] Although it is depicted as a stepwise process, of course many of these decisions are made simultaneously. In the regression analysis below, this is dealt with explicitly.

1a) *Migration to the United States leads to investment in peaches and animals*

If the main constraint to converting land to peaches is lack of capital or unease in taking on additional risk, families with migrants in the U.S. will be able to spread risk across continents and finance this conversion using remittances. The additional resources will be used to pay conversion costs and to maintain an adequate level of consumption before the trees bear fruit. However, given the infrequency of visits (given costs and the greater difficulty moving back and forth between the U.S.) these migrants may be less inclined to put their assets into peaches and more likely to prefer animals, which offer some return but do not carry the same risk.

1b) *Migration to Argentina leads to investment in peaches and animals*

The Argentinian migrant will be more likely to finance the growing of peaches. First, the migrant will have a higher yearly income than non-migrant. This allows for the lifting of liquidity constraints. Second, because of the relative proximity of the destination to Bolivia, some monitoring of the peach orchards can take place (decreasing the possibility of failure through mismanagement), and the migrant can return home to help with the harvest; therefore, the probability of success is not lower. Finally, a large percentage of Argentinian migrants return home more able to make use of the productive asset. The latter two reasons do not apply to a migrant to the U.S., even if they are able to finance the conversion. Similar logic applies to investments in animals which could act as an alternative option for households unable to grow peaches.

2) *Migration to the U.S. fosters investment in education*

The presence of a migrant in the United States will induce investment in human capital for several reasons. An increase in education pays off for migrants in the U.S. The children of families with a migrant in the U.S. face lower migration costs and are more likely to emigrate themselves, increasing schooling's value as an investment. Additionally, (as is documented below) migrants to the U.S. are more highly educated themselves, and value their children's education for its own sake. Finally, these families are able to more readily finance the education of younger relatives through remittances because their earnings streams are more likely to be larger and sustained.

3a) *Migration to the United States results in increased house values*

Wealth invested in houses is illiquid, but increases the quality of life of family remaining in Bolivia. Migrants may choose not to invest in productive assets—which are difficult to monitor—and may prefer instead to save the transfers. Although migrants may have access to banks in the U.S., in the Valle Alto there do not exist commercial savings institutions, so wealth is often stored in houses or other properties.

3b) *Migration to Argentina results in increased house values*

On the other hand, because migration to Argentina yields increased returns to labor among a population which is largely planning to come home, they will want to improve the homestead and create savings in the community by investing in houses or other physical assets. As noted above, they will also be more likely to invest in productive assets.

4) *Households with few or no migrants will continue to grow maize and cultivate animals*

Finally, families which are unable to send a migrant abroad, due to lack of send-off capital, available migrants, or appetite for the associated risk, will instead maximize their agricultural assets. They will often either be trapped into or prefer engaging in low-risk, low-return activities, such as maize.

3 Context

This section describes the area of Bolivia where the survey was conducted, gives an overview of land use patterns, and discusses the population living therein. The study area is located in the Valle Alto, a region southeast of the city of Cochabamba, in the central highlands of Bolivia. A majority of the plots contained in the valley are fed by a generations-old irrigation system which was significantly upgraded in the mid-nineties after the construction of a dam.[12] Within the watershed, the main local governing authority is the Irrigators Association of Laka Laka, which oversees the allocation of water from the reservoir created by the dam. Each of the canals (*suyos*) has its own director who administers the consumption of water by plots serviced by their particular sub-canal. In addition to the presence of clearly delineated water rights, the region was selected for two main reasons. First, as mentioned above the area has undergone a major change in the composition of cultivated crops, with many households switching from traditional maize crops to peach orchards. Second, the area has seen a sharp rise in migration over the same period, with many households sending family members to foreign countries (see Figure 2).

To better understand these phenomena, a survey was conducted within the study area. Data were collected during the period from October 2009 to March 2010. The survey was conducted by local undergraduate students, some of whom were conversant in the local Quechua language.[13] The sample of plots was drawn from a spatial database, created by remote sensing

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[12] The dam was financed largely by the Canadian government through a cooperative agreement between the two nations. In 1993, the dam opened, and for the following years, canal infrastructure was improved and various irrigation techniques were tested. Operation of the dam was given to the local governing authority. The total cost was US$6.1 million (Bustamante 2004).

[13] While almost all households had at least one member who spoke c*astellano* (Spanish), knowledge of the local language proved important for gaining the trust of a minority of households.

using an over-flight image of the watershed. Peach and maize parcels were chosen to ensure a sample with plots from peach clusters and non-peach clusters. However, the original sampling strategy had to be revised due to the winnowing down of parcels in the original sample.[14] In total, information on 240 parcels belonging to 92 households was collected. Demographic summary statistics for these households are shown in Table 1.

The survey was composed of 8 modules, which collected both household and parcel-level information. For the household, information was collected on family composition; farmer-farmer interaction; migration and remittances; revenues and costs of all crops grown; household wealth, including livestock holdings; and, access to credit. For each parcel, I collected data on the physical characteristics of the plot; which crops were grown in previous years (also for adjacent plots); details on the water and soil characteristics, as well as any on-parcel investments. For peach crops, I gathered additional information on the share of harvest lost to frosts (which are prevalent in the area) and any methods used to combat the frosts. The area is a global hotspot for maize agrobiodiversity, and we inquired about the uses of various maize varieties, some of which were inputs to home businesses. We also asked non-peach growers which constraints prevented them from growing peaches.[15]

The tabular data contained in the survey is augmented by spatial data. For roughly 140 of the 240 plots, the exact coordinates of the plot location were recorded. For the others, the part of the canal from which they draw water is identified, but not the exact location. A large map of the canal structure of the watershed was digitized, allowing for calculation of spatial proximity and

[14] Plots had to be excluded mainly for two reasons. First, the plot was owned or cultivated by someone already in the sample. Second, not all families were willing to participate in the survey. In January 2010, a resampling method was devised for the random selection of adjacent parcels.

[15] To improve the accuracy of the transcription, data were manually inputted twice and any discrepancies were resolved. The data were collated and cleaned at the UW-Madison.

to observe clustering patterns. From the spatial data, I calculated distance from the dam (following waterways), and distance to canals and roads.

Agriculture in the region is comprised almost entirely of maize rotations and peaches. Within the sample collected, all families had at least one parcel in active production. Nearly two-thirds of households grew peaches and the same amount cultivated maize. About 46% of households grew both crops. To improve overall yields, many of the non-maize parcels were part of a maize rotation, especially potatoes and fallow lands.[16] Alfalfa and wheat were grown by 4 households each.

Among households surveyed, all emigration has been to three countries: Argentina, the U.S., and Spain.[17] In the 1960s and 1970s, more than 80% of emigration was to Argentina. In later decades, the U.S. became a more frequent destination, accounting for two-thirds of all out-migration between 2000 and 2009. Emigration to the U.S., however, did not take off until 1990, accounting for only 17% of migration events taken before that year. As expected, given the high cost of international migration, 84% of migrants stayed two years or longer; surprisingly, they have spent roughly the same amount of time in the U.S. and Argentina.[18] The analysis below finds that groups most associated with distinct household development strategies are those that go to Argentina for a few years or to the U.S. more permanently. In the entire sample, the largest number and percentage of Bolivians moved to the United States, where 91 of 161 migrants (57%) stayed as long-term residents.[19] Of the 121 residents who went to Argentina, 58 (48%)

[16] The most common rotations were Maize-Maize-Potato and Maize-Maize-Maize-Potato.

[17] There was a solitary emigrant in Brazil, but that observation is excluded in this analysis.

[18] This may be due to the fact that 2009, the year data were collected, effectively truncated the trip of more migrants living in the United States.

[19] I count as long-term any migrant who has stayed for more than six years and short-term any migrant who stayed for less time. Migrants who left after 2004 and had not returned at the time of the survey are not

were long-term residents, staying for an average of 18.1 years. 7% of emigrants went to Spain. Figure 4 shows the emergence of U.S. and Spanish emigration since 1970. A sharp increase in migration events to the U.S. began in the 1990s, while emigration to Spain did not occur until the end of that period; 94% of the Spain-bound migrants left in 2000s. Contrary to U.S. and Spanish departures, Argentinian emigration rose gradually in the 1970s and early 1980s, and has been relatively unchanged since 1985. Table 2 shows select characteristics of the emigrants. Across the sample history, migrants to Argentina were younger at the time of departure and, at the household-level, less likely to have remitted money while away. Overall, roughly half of all individual emigrants sent remittances, reaching two-thirds of households. The average remittance received by households was roughly $2,000, though the amount ranged from zero to $50,000.

Educational characteristics of emigrants and families vary substantially when compared across migration destinations. Table 3 shows the educational attainment levels of short-term and long-term emigrants, those present in their household, and of their extended families. Short-term migrants to United States are the most educated, with 6 more years of schooling than short-term migrants to the Argentina. However, among family members present at the time of survey, average household education was only one year higher for households with a history of U.S. migration, as compared with Argentina. In Argentina and Spain, long-term migrants were better educated than their short-term counterparts, and, except for those in the United States, short-term migrants are significantly less educated than those who do not migrate at all, suggesting that the cost to migration is high and/or that returns to labor in the destinations is considerably higher than in Bolivia.[20]

included.

[20] I cannot observe whether some migrants returned for a short amount of time during their stay abroad. However, this is less likely for those living in the United States, and has become more difficult in the last

In the sample, 54 of 92 household heads (59%) emigrated; 45 went to Argentina, 10 to the U.S. and 2 to Spain. Of those who traveled to Argentina, one-third of spouses emigrated, while 9 of 10 spouses of U.S. emigrants also went to the United States. Migrating children are considerably more likely to choose the same destination as their parents. Table 4 shows the breakdown of children's destinations, split between the locale that the head of household emigrated to (if any). Strikingly, there is only one child of a household head who went to the U.S. or Spain, who subsequently emigrated to Argentina; yet 45% of the offspring of Argentine migrants emigrated to the United States and 9% went to Spain. Conversely, 17% of migrating children whose parent went to Argentina also migrated there. By destination, there are no significant differences in the patterns of children whose parents emigrated to Argentina as compared with those who did not emigrate at all. Parents' migration choices not only affect their children's migration patterns, but also the future activities and development paths of the household.

Demographics

Table 1 shows summary statistics for certain demographic variables. Nearly all of the households surveyed had lived in the area for many years, indeed the average age of the household head, 59.8, is quite high. Roughly 20% of households had a female head. On average, female-headed households had a third as much land in peaches. Although the total income is not statistically different for female-headed households, on-farm revenue was considerably less. Households contained 5.26 people on average, with 2.7 of those active in agriculture. To provide additional

decade due to more stringent border security measures following 9/11.

labor, family members living outside of the Valle Alto often return to assist with cultivation especially during harvest times.

Irrigation

Water is a critical and often limiting input to agricultural production. Within the sample collected, most of the parcels surveyed are part of the Laka Laka irrigation system. The system is based on a system of water rights (*acciones*) which are plot-specific and owned by a household. The irrigators association keeps tight control over the market, not permitting transactions except in rare circumstances. Of the households surveyed, 88% have at least one water right in this system of canals; others are irrigated through wells and rainwater management. In total, the system contains over 4km of primary canals, which are lined with cement. A larger amount of secondary canals are dirt-only and less efficient for water transport.

Rights to water were allocated at the time of the dam's construction and in the following years. Those who had rights to water under the previous system received similar access under the new regime, though they were required to contribute manual labor during the construction of the system to secure these rights. In the 1990s, water rights were available for purchase; currently the granting of new rights is not possible due to a shortfall of available water for those with extant rights. To maintain the water rights, a household must pay 2 Bs. ($0.30) per month to the irrigators association and is required to contribute several days of labor to the maintenance of the system each year.

Those who do have access to the canals system are granted the right to irrigate half of an *arrobada* (each *arrobada* is 0.36 hectares) for each water right which they possess. Water is stored in the reservoir behind the dam and released in several dispersals during the growing seasons. For each dispersal (*lagrada*), enough water is released to irrigate each plot along the canal for a fixed period of time, usually 1–1.5 hours. The irrigators association closely oversees the flooding on each parcel in order to make sure farmers do not take more than their allotment. Those who violate the rules of the system are subject to escalating fines, and, in rare cases, may lose their water rights altogether. The reservoir, which was 16 years old at the time of the survey, has accumulated silt and mud sedimentation, shrinking its capacity. In combination with climatic changes, this has sharply reduced the amount of water available for irrigation. The number of water dispersals from the dam has fallen from eight at the time of the dam's construction to 3–4 at the time of the survey and as few as 1–2 for some canals in the 2010 growing season.[21]

Peaches and Frosts

Peaches are grown by a large proportion of the population in the Valle Alto. In 2008, 15.8% of total parcels were in peaches. Due to oversampling, 65 of 92 households in the survey had at least one peach parcel with those households maintaining an average holding of 0.77 hectares in 1.6 parcels. As shown in Figure 2, peach adoption has increased substantially over the last fifteen years with over 30% households planting their first parcel in the five years preceding the survey. A broad cross-section of the households grows peaches. Those with orchards include families with migrants to all destinations and non-migrants, with many or few children, and those who are poorly or well-educated. There is no clear relationship between a family’s educational attainment and their propensity to grow peaches. The average or maximum years of schooling of a

[21] While the irrigators association strives to give the same amount of water to all parcels along the canals, in practice those with parcels closer to the dam receive more consistent allotments. Due to the decrease in reservoir size, at the peak of the rainy season the dam overflows providing water when it is not needed and diminishing the amount in reserve. Maintenance would solve this problem at a relatively low cost. However, the irrigation association lacks necessary funds and there is a problem of collective action among participating agents; no canal group wants to finance improvements in the dam, unless the other groups contribute equally.

household or extended family does not appear to affect the likelihood of adoption. However, the education of the household head does matter somewhat: those with above-average years of schooling are more likely to plant peaches (77% vs. 66% of the sample), and better educated heads of household who do adopt cultivate more peach parcels. Though growing peaches is a complicated undertaking, it is also a risky one; in the year sampled additional schooling did not increase revenues or profits.

Those who entered into peach growing had highly variable profits during the survey period. Among the 102 peach parcels, gross receipts ranged from none (for those whose harvest had succumbed to frosts completely or whose trees were not yet mature enough to bear fruit) to over $25,000 for one household, a very large sum for production on small plots this region of Bolivia. Costs were likewise substantial but the most proficient farmers earned multiple times their seasonal expenses during the survey year.

In the data collected for the 2008–2009 growing season, though peaches were a lucrative endeavor for some families, roughly 45% of households lost money, primarily due to bad frosts. In comparison, less than 20% of maize growers lost money over the same period.[22] Frosts have become more prevalent in the area, with damage from frosts in the sample increasing a third from 45% of total fruit harvest lost in 2007 to 60% in 2009.[23] Yet, the possibility for outsized

[22] Some of the negative profits were due to investments in lands in maize rotation, which lay fallow every two or three years.

[23] Frosts have become increasingly common and damaging to the fruit. In October and November, the frosts are most harmful to the peach blossoms. The peach tree blooms three times a year. Until the mid-2000s, frost would affect only the first two, allowing the final blossom to develop into harvestable fruit. Now, in the worst cases, all three blossoms are severely affected by frost. There exist various measures to combat the frosts though they are not yet universally adopted. The main countermeasures are: creating small fires and allowing the smoke to warm the trees; placing small gas or electric heaters throughout the orchards; and, spraying the trees with water to provide a protective coat of ice to form around the blossom. These methods have proven effective when they are put in place before the frost; however, several respondents noted that there did not exist widespread and reliable meteorological information necessary for them to be deployed in a timely manner.

profit exists, with the top quartile of households selling more than $1,200 of peaches and the highest 10% receiving between $5,000 and $25,000 dollars in revenues (in total).

Education

There exists a wide range of educational attainment both within and between households in the survey area. In addition to schools in the Valle Alto, ample educational opportunities are accessible in Cochabamba, the nearest major city, a 45 minute drive away. Although emigration plays a big role in determining education, children are educated locally—there are only a few families whose children emigrated before they had completed their schooling. Within the sample, families have between zero and twenty years of education, with an average of nine. Those remaining in the households within the Valle Alto have six years of schooling, while the family members living abroad at the time of the survey have completed 12.5 years. Families growing only maize had, on average, 8.4 years of education as compared with 10 years for non-growers, but there exists no similar pattern among peach farmers. Likewise, education varies little between canal groupings, though those households in the Mamanaca canal group have significantly lower educational attainment. Surprisingly, those households which do not belong to any irrigation group have the most years of schooling both at the household level and among extended family members, suggesting a tradeoff between on-farm activities and human capital investment. Education levels do not correlate with total land holdings or the value of housing stock; however, they are strongly negatively correlated with animal holdings.

Along with physical asset accumulation, education can be one of the most reliable ways for families to invest in the future. Households with higher levels of education have more diversified income portfolios and may be better able to withstand shocks. More educated residents have better options for off-farm employment and those emigrating may command a higher wage. Within the sample, families earn increasing amounts of off-farm income as the average years of schooling increases: the half of families with education less than the median (6.75 years) is $230, as compared with $2,577 for those above it. While educational attainment does not systematically vary by agricultural activities, it is affected by migration patterns. Overseas emigration spurs a virtuous circle of remittances, increases in next-generation educational attainment, and future emigration. The educational level of the household head is one of the strongest determinants of average family and household education.

Housing Components, Livestock, and Household Wealth

Given variability in crop cultivation, off-farm income, and remittances, the Valle Alto contains appreciable differences in the household wealth of its citizens. Some of the houses are multi-story buildings with satellite dishes and high fences, while others are small brick or adobe edifices, with dirt floors and roofs of corrugated iron. Survey respondents estimated their home values as ranging from a few thousand dollars up to $200,000, averaging $26,400. In addition, some households own multiple houses, which are often vacant and used either as a savings mechanism or maintained as a place for returning migrants to live. Almost all farming households lived in houses they owned. House structures differed in their construction. Roughly half of the houses were brick, with the rest constructed of either adobe (40%) or a combination of brick and adobe (10%). Roofs were primarily made of corrugated iron (47%), tiles (30%) or reinforced concrete (10%). One-third of the sample had dirt or tile floors; the majority of floors (60%) were concrete. About 10% of households obtained their drinking water from wells, the rest from were connected to piped water.

For many households, livestock and other animals were a significant source of household income and store of wealth. All but ten households within the sample raised animals. The most frequent animals owned were bulls, chickens, donkeys and calves. A full-size cow or heifer could yield US$400–$500 at the time of sale. Most households with animals profited on their holdings. The average income from animals for a household in the survey year was US$723.

Access to Credit

For many in Bolivia, especially in rural areas, formal banking is not available, and loans of any type are difficult to secure. Due to occasionally insecure land rights throughout the country, although land transactions are not uncommon, use of land as collateral for a loan is quite rare. Farmers in the Valle Alto do not typically put their assets into a bank account (due to a lack of accessibility, trust, and custom) but rather reinvest in their own land and agricultural holdings. Thus, many people own multiple houses and plots of land, or agricultural equipment from which they can collect rents.

For those looking to borrow money in the Valle Alto, options are limited. While some individuals may be able to secure a commercial bank loan, most will need to turn to other sources. If they do not secure a loan from friends or family, there are professional money lenders (*prestamistas*) who will make short-term loans. Some households are also able to obtain loans from state agencies, but this is also rare. In our sample 13% of households currently had a loan while another 11% had one at some point during the last 5 years. In sum, there is relatively poor access to credit in the study area. To make costly on-farm investments, families need to either save the money or receive it in the form of remittances from abroad.

4 Econometric Setup

The primary objective of this empirical analysis is to measure the effects of international migration on rural households' assets and accumulation paths. Since the 1960s, households in the study area have engaged in a number of income-generating activities, including agricultural production, animals, and on- and off-farm wage labor and then made decisions about how to spend or invest the proceeds. Along with gifts and remittances, the combination of these activities and investments has created the asset portfolios observed today. The focus of this analysis is to understand migration as a mechanism for peach adoption and also to place that major investment decision in the context of broader household portfolio choices, such as human or physical capital investment. I find that each past Argentine migrant increases the likelihood of converting a parcel to peaches in a given year by roughly 5%, and that U.S. migration significantly contributes to investments in other household portfolio choices but not peach conversion.

Although a household's initial land or capital endowment is not observed, retrospective data on demographics, migration and land acquisition allows for identification of household asset investments, including peach cultivation, development of human capital, and the accumulation of agricultural and physical goods. While controlling for household and plot-level characteristics, I investigate the role of migration in determining the composition of current household wealth holdings and assessing which activity choices have been successful. Estimating the effect of migration on household assets is complicated by the endogeneity of the migration decision, as many variables collected at the time of the survey will be influenced by past migration. Our main areas of concern with respect to endogeneity include omitted variable bias, reverse causality, and selection bias. For this reason, most migration studies of this kind use instrumental variables to address potential endogeneity concerns. Although I have not found credible instruments which satisfy the exclusion restriction, I am able to address these issues using a panel data approach and by creating historical variables which are less likely to be influenced by past migration.

A major concern is unobservable attributes of the household, such as entrepreneurial spirit, family cohesion, scholastic aptitude, or "insurance" in the form of rich relatives which might influence any of the portfolio of household choices. These unobservable household characteristics could affect both the choice of migration and the activities the household undertakes after the decision to migrate. What appears to be migration fueling investments in schooling, for instance, might in fact be a result of these unobservable characteristics. Using a fixed-effects panel estimate helps to address unobserved heterogeneity which is potentially correlated with the regressors. Another potential concern is endogeneity due to factors which affect both conversion and the migration decision. This includes off-farm opportunities (such as investment opportunities) and circumstances which affect the opportunity cost of labor. Some changes over time (such as the employment rate) are captured in the time trend or year fixed effects. In addition, Argentinian migration will fluctuate according to the prevailing wage rate, thereby capturing a household's response to off-farm labor opportunities.

Reverse causality may occur if peach adoption (or another dependent variable) causes migration, rather than the opposite. Because I am able to identify the year which the migration decision was made, and since much migration took place before the adoption of peaches became common, this problem is mitigated.[24] Reverse causality could also be an issue when regressing educational outcomes or measures of wealth on past migration. In the cross-sectional analyses,

[24] See robustness checks in Section 5.4 which further test for reverse causality.

using historical data on migration should address some of these endogeneity concerns. This is a smaller issue for emigration to Argentina, since less up-front capital is needed to emigrate there; however, prior emigration to the U.S. could have provided the necessary liquidity for future departures. And, although education does not make migration cheaper *per* se, it does increase the expected return to emigration, especially in the U.S. or Spain.[25] Finally, I only observe migration and on-farm decisions for those families that both remained in the area and chose to send a migrant overseas. Some families may have handed management of their plot to another household, or exited farming completely. They are not accounted for in our sample.

Panel Methods

A retrospective panel data set is my main tool used to address endogeneity concerns. Identification of peach adoption comes from the variation in the timing and number of parcels on which households have adopted peaches. Other variables for which I have reliable retrospective data include the number of total parcels and maize parcels, the size of the family and its demographics, the number of water rights, and the location of the household's parcels, which is measured by the proximity to canals and roads. Although I lack data on the full historical household holdings of wealth, animals, and off-farm labor, the time-varying measures I use are exogenous to the conversion decision. In this area, families typically inhabit land acquired generations earlier. Water rights were either historically determined (attached to the land) or were created with the advent of the dam. Both of these markets are quite thin, and so the allotment was largely settled by the time peach growing took off. Transactions on water rights, in particular, are quite rare.

[25] Although many migrants work in unskilled professions, such as construction work, those who find employment as nannies or in clerical jobs often command a wage premium.

The panel dataset was constructed using retrospective data collected during the 2009–2010 growing season. Each survey respondent was asked to list household and family members along with each member's educational attainment and migration history. Data were collected on the year and destination of the first out-migration (if any) as well as the length of that trip and the current location of the member. Migrants who stayed in the foreign destination less than 6 years are counted as "short-term" migrants, while other are considered "long-term." Similarly, information on each parcel's size, date of acquisition, and proximity to roads and canals were used to create a historical dataset of the household's land holdings and parcel characteristics.[26]

Fixed Effects Model

The first model examines the effects of migration on peach conversion. The data encompass 92 households that were randomly drawn from the watershed. The use of lagged data helps address simultaneity; however there is still a concern that two or more variables are caused by unobserved variables, such as farming ability. For these reasons, the use of a fixed effects model is most appropriate because the household's reported characteristics are likely correlated with the unobserved household attributes (Wooldridge 2002). One drawback of the fixed effects model is that it does not allow for the inclusion of time-invariant characteristics of the household, such as its location or the age of the household head.

The model used is:

$$PeachConversions_{ht} = \alpha + \boldsymbol{X\beta} + \gamma_1 EmigArg_{h,t-6} + \gamma_2 EmigUS_{h,t-6} + \nu_h + \theta_t + \epsilon_{ht} \quad (1)$$

[26] Unfortunately, I do not observe deaths in the family nor sale of parcels that occurred before 2000. Therefore, the size of the family and land holdings increased monotonically during the retrospective period from 1970–2000.

where γ_1 and γ_2 are the main variables of interest; ν_h is a household fixed effect; θ_t are year fixed effects; and, the vector **X** includes the following time-varying household characteristics: the number of people in the family, the number of parcels and water rights held and the number of parcels that are adjacent to a road. This model regresses the number of parcels converted to peaches on a vector of (time-varying) household characteristics and emigration measures. The emigration variables are the lag of the total number of migrants to either Argentina or the United States six years before the date of observation. Six years is a reasonable timeframe because a household undergoes a multi-stage process which only begins with the departure of the migrant (or when the household began to save money to finance the departure). Then, the migrant must accumulate and remit or bring back monies in order to finance a peach conversion, which may take several more years. Once the parcel is chosen, the household must plan the conversion (leveling the parcel, planting the orchard, setting up irrigation ditches) as well as secure an alternate source of income to rely upon while the orchard is beginning to grow. This totals, on average, 4-5 years for migration and the accumulation of capital and an additional 1–2 years to plan and install the orchard. In section 5.4, I show that my results are robust to other lag structures.[27]

Equation (1) tests whether migration to Argentina or the U.S. shapes conversion to peaches. For Argentina, migrants can monitor their plots and if necessary return home in the case of a shock or to help with the harvest. They may also finance the investment intending peaches as an on-farm activity for themselves upon return. While migrants to the U.S. can relax liquidity constraints for the family remaining in the source community, they may not be interested in the

[27] I include specifications where the exogenous variables are lagged for more or less years as well as a model which includes lagged variables for both 3 and 6 years.

peach portfolio option as part of their future. γ_1 and γ_2 represent the effect of migration on future peach orchards. If relaxing liquidity constraints was a sufficient basis for peach conversion, we would expect to see a positive and significant value for γ_2; if, however, monitoring and return options are also a critical condition in peach conversion decisions, γ_1 could be significantly greater than zero while γ_2 might not be.

Portfolio Analysis

The panel regressions examine the temporal effect of migration on peach conversion, but in order to further explore how the departure date, destination and permanence of the migration affect current household portfolios, I use a cross-sectional approach. As I do not have past values of animal or household wealth, income, remittances or educational attainment, a panel model is not possible. So, to examine these portfolio choices, contemporary estimates of these measures are needed. Although these results are subject to the qualifications delineated above, they nevertheless offer an additional window into migration, peach conversion and other household portfolio choices.

Seemingly Unrelated Regression (SUR)

One potential issue of a running multiple cross-sectional OLS models is that they do not account for the comovement of the error terms. Since an explanatory variable which, for instance, causes increased education might also lead to decreased animal wealth, the error terms in those two equations may be correlated. To address this, I create a system of three equations whose dependent variables are peach parcels, animal wealth, and average family education, and solve them simultaneously. As opposed to peach conversion, the number of parcels indicates to what extent their current activities involve those crops. Animal wealth is the other main on-farm activity, which requires less specialized knowledge and a considerably smaller upfront investment. The biggest investment made in the next generation perhaps is in their education. This estimation permits the inclusion of variables which were not included in the fixed effects model, namely, the canal group that the household is a part of, and whether they lived in Arbieto, the major nearby town. In each of these regressions, I use exogenous variables on land and family characteristics from 1993, the year before the dam was constructed.

$$PeachParcels_h = \alpha + \boldsymbol{\beta_1}'\boldsymbol{X_{h,1}} + \boldsymbol{\beta'_2}\boldsymbol{X_{h,2}} + ShortMigArg_h + \delta_2 LongMigArg_h + \delta_3 ShortMigUS_h + \delta_4 LongMigUS_h + u_1 \tag{2a}$$

$$AnimalWealth_h = \alpha + \boldsymbol{\beta_1}'\boldsymbol{X_{h,1}} + \boldsymbol{\beta'_2}\boldsymbol{X_{h,2}} + \delta_5 MigrationArg_h + \delta_6 MigrationUS_h + u_2 \tag{2b}$$

$$Education_h = \alpha + \boldsymbol{\beta_1}'\boldsymbol{X_{h,1}} + \boldsymbol{\beta'_2}\boldsymbol{X_{h,2}} + \beta_3 EduHead_h + \beta_4 NumKids + +\delta_5 MigrationArg_h + \delta_6 MigrationUS_h + u_3 \tag{2c}$$

where $\boldsymbol{X_{h,1}}$ is a vector of household and land characteristics in 1993, including the number of parcels; the number of water rights; the number of parcels adjacent to a canal $\boldsymbol{X_{h,2}}$ is a vector of controls including two canal dummies and an indicator variable if the household is located in the major city. In Equation 2b the number of parcels adjacent to a canal are not included, as they do not directly affect the decision to raise animals. Equation 2c also includes the education level of the household head and the number of children, rather than family size. The SUR model assumes homoscedastic errors. To account for heteroskedasticity, I use bootstrapped standard errors. I repeat the estimation 500 times where each time a new random sample is drawn, with replacement, from the original observations. In these regressions $\gamma_1 - \gamma_6$ are the main variables of interest.

In the following three sections, I present estimations using other covariates. These constitute a more nuanced cross-sectional analysis of the factors influencing each of the activities households engage in.

Peach Parcels

The panel results test for a causal relation between migration and peach conversion. In the following cross-sectional analysis, I estimate the causes of the accumulation of peach parcels using measures of short-term and long-term migration, aggregated at the household level. I also include variable of household characteristics in 1993, directly before the construction of the dam in the mid-nineties.[28] The cross-sectional specifications follow:

$$PeachParcels_h = \alpha + \boldsymbol{X\beta} + \delta_1 ShortMigArg_h + \delta_2 LongMigArg_h + \delta_3 ShortMigUS_h + \delta_4 LongMigUS_h + \epsilon_h \quad (3)$$

where $\boldsymbol{X}$ includes household variables from 1993: the number of parcels, their proximity to the road and canal, the number of water rights, family size. In addition there are binary variables for two main canal groups, and if their residence is in the largest nearby town. As above, if monitoring and return are a big part of the story then $\delta_1 > 0$. Migrants residing in Argentina will be better able to manage an investment in peaches, and are more likely to plan to cultivate the orchards upon return. Alternatively, if it is just liquidity which is necessary then $\delta_4 > 0$.

[28] Between 1993 and 2001, the number of households with allocated water rights grew from 28 before the dam was built to 78 afterwards.

Wealth

To assess the factors determining animal and household wealth, I estimate the equation:

$$Wealth_h = \alpha + \beta_1 WaterRights_{h,1993} + \beta_2 Hectares_{h,1993} + \beta_3 TotalParcels_{h,2003} + \beta_4 ParcelNearRoad_{h,1993} + \delta_1 MigrationArg_h + \delta_2 MigrationUS_h + \epsilon \quad (5)$$

where $Wealth_h$ is the value of either the house or animal holdings. Two migration variables are used: one includes the number of all past migrants to Argentina, the other all migrants to the United States. One hypothesis is that Argentinian migration leads to increased animal holdings ($\delta_1 > 0$). This may be simply that migrants returning to the Valle Alto want productive assets in the form of livestock and other animals or because these migrants are less educated and the raising of animals is significantly negatively correlated with household educational attainment. A second conjecture is that any migration, but especially migration to the U.S., causes house values to increase. Since U.S. emigrants do not want to invest in productive assets that they cannot monitor and do not plan to return to, they instead will put money into physical capital, as savings or to improve the living standards of their family members in Bolivia.

Education

Lastly, I analyze the determinants of present individual and average family education levels. I use an equation of the form:

$$Education_h = \alpha + \mathbf{X}\boldsymbol{\beta} + \delta_1 MigrationArg80 + \delta_2 MigrationArg90_h + \delta_3 MigrationUS80_h + \delta_4 MigrationUS90_h + \epsilon \quad (5)$$

where the dependent variable is either the SAGE measure of educational attainment or the average number of years of education for a subset of household members.[29,30] The measures of migration include decade-destination pairs for the 1980s and 1990s. . The ***X*** vector includes the number of water rights and peach parcels in 1993 and 2003, education of the household head, and canal group and city indicator variables. I estimate this once with the household dataset and again using the individual-level dataset, which has a larger sample size. Regressions using decade-destination buckets are also estimated (not shown). The main hypothesis in regards to education is that long-term emigration to the U.S. will cause years of schooling increase $(\delta_3, \delta_4 > 0)$. For these migrants, increased educational opportunities are attractive both because they themselves are more highly educated and since they may wish to transform labor market opportunities for family members.

5 Results

This section presents the causal factors of peach adoption, house or animal investment, and education, finding that while these options may be complementary for some households, for other families they are substitutes. In the discussion, I explore how the empirical regularities present in these patterns improves our understanding of rural Bolivian households as they pursue a mix of on-farm investments and off-farm labor opportunities at home and abroad. It is

[29] The SAGE measure is defined as $SAGE = \frac{S}{A-E} * 100$, where S is the total number of years of school completed, A is the age of the child, and E is the age that children start school, which in this case is 6 years old. . A score of 100 means that a child is keeping up with the grade level expected for his or her age, and scores less than 100 mean that either the student has missed some school previously or is currently not participating. For our analysis, SAGE scores are useful measures because they highlight the long term educational attainment for older children who may still be in school or have graduated.

[30] The household head and their spouse, and any family members over the age of 25 or under the age of 15 were excluded from the calculation of average family education.

important to note that although many households not sending migrants are poor, some have considerable agricultural or off-farm income.

Peach Adoption

Since the late 1990s, the Valle Alto region has undergone a tremendous change in land use as the adoption of peaches became widespread. While maize production and other traditional crops have been—and are—profitable and maintain an important cultural value, the potential gain from peach growing greatly outstrips that of traditional crop production. Crops in maize rotation are well-understood and typically require limited capital inputs from year to year. Conversely, peach cultivation is riskier, but has a higher potential rate of return. Figure 5 shows the distribution of households' adoption of peaches, using the year that they converted the first parcel. Beginning in the late 1970s, but accelerating after 1990, lands growing traditional crops were leveled to make way for peach orchards. The adoption of peaches peaked in the mid-2000s and has declined since then, as yields have suffered and farmers became aware of the potential damage due to frosts. While peach cultivation is broadly prevalent among the households surveyed, there is no prototypical peach-growing household. Orchards were installed by households with varied migration profiles and all demographic types.

Here I report on results from testing Equation (1), whether U.S. or Argentine migration leads to peach adoption. Table 5 shows the main results: a panel data analysis of the determinants of peach adoption. The number of peach conversions each year (typically only one) is regressed on a number of household and plot-level characteristics. Households may convert parcels in more than one year. Because peach adoption did not take off until the mid-1990s, I restrict the sample to 1993 onward. This is the beginning of dam construction and the allocation of water rights. The retrospective panel allows for the tracking of parcel and water rights acquisition, certain family demographics, and emigration.[31] While some variables, such as water rights, may be codetermined, migration and other household variables are lagged six years, which approximates the amount of time from when an emigrant is abroad and the parcel is converted to peaches. As discussed above, this includes time to receive remittances or transfers and establish other sources of income during the initial years when the peach orchard does not bear fruit. Column (1) shows the most parsimonious specification. There is a positive and significant effect of lagged Argentinian migration on peach conversion. Households with fewer parcels and those closer to a canal are more likely to adopt peaches. Column (2) adds year fixed effects and an additional measure of past migration: the accumulated years of emigration to the U.S. These families are actually less likely to adopt peaches; rather, as explored below, emigration to the U.S. is positively associated with strong investments in human capital, not peaches or other agricultural investments. Column (3) adds lagged peach parcels, which discourage adoption. In each of the specifications the number of migrants in Argentina has a positive effect on peach parcel conversion. Finally, in Column (4) the number of maize parcels is regressed on the same exogenous variables for the longer period from 1970-2009. Here, a different picture emerges. Families with more parcels and those with fewer water rights hold more parcels in maize. Migration to the U.S. was also negatively associated with maize cultivation.

Consistent with the hypotheses developed above, households with no migrants or migrants in Argentina continued to grow maize. This is a region where migration is dynamic and

[31] Because of how data were collected, in the panel we observe births but not deaths, and the acquisition but not the sale of parcels before 2000.

shifting. Residents are becoming increasingly more likely to travel overseas, and, if current trends continue, there will be still fewer family members staying in the Valle Alto to cultivate crops (see Figure 4). In many cases, family members entrust their plots to siblings, parents or other relatives. For wealthier families, this may be partly because peaches, while labor intensive at certain times, are more capital intensive than the maize parcels they are replacing.

Seemingly Unrelated Regressions

This section reports on the main cross-sectional results, which are estimated using a seemingly unrelated regressions (SUR) model. I test for the effects of exogenous variables on the number of peach parcels, total animal wealth, and children's education. The first represents high-return on-farm activity, the second a low-return activity, and the third human capital investment which does not pay off in the short-term. I estimate equations 2a, 2b and 2c as described in section 4.2, using bootstrapped standard errors to control for heteroskedasticity.

In these equations, I use a snapshot of household and farm activity in 1993. SUR assumes exogeneity of the independent variables, and at this date 88% of peach parcels had yet to be converted or acquired. Current-day decisions on animals were not made until much later and at that time the majority of children in the sample had not yet finished schooling. This should allay concerns that the outcome variables are endogenous. The household variables observed in 1993 are: the number of parcels, the number of water rights, and the proximity of parcels to roads and canals. Demographic variables include family size and education of the household head. Also included are binary variables for two of the main canal associations and for those who live in Arbieto, the largest nearby town. Table 6 portrays the key SUR regression results.

The number of peach parcels owned by households is a result of conversion decisions undertaken in the decades prior to 2010. Since there were few abandoned peach orchards during this time, the number of peach panels observed at the time of the survey (the dependent variable), reflects the decision to convert. Column 1 shows the results. In this specification, each additional short-term migrant to Argentina increases the number of peach parcels by 0.26, which constitutes 24% of 1.1, the average number of peach parcels owned. Belonging to the Cardozo canal group also increased holdings, by 0.58 parcels.

Along with the installation of peach orchards, many families have significant animal wealth.[32] As described in section 3.4, all but 10 households raise some animals. Although any measures of wealth in these data are noisy it is evident that households with more schooling possess less animal wealth. This holds true whether measuring the educational level of the household head, household members, or the extended family. Column 2 regresses animal wealth on short-term and long-term migration as well as household and parcel characteristics observed in 1993. The results show the number migrants in the U.S. decreases the value of animals by US$280 but no other migration estimate has a statistically significant impact on these holdings.

Finally, the results in column 3 show that there is a strong effect of migrants in the U.S. on years of schooling. Each additional migrant adds 0.22 years to the *average* family education level. Additionally, the the education of the household head both have positive and statistically significant effects on schooling. Each year of education for the household head results in one-sixth of an additional year in school for children and other younger family members. The results presented here, combined with the panel results are consistent and non-contradictory. Short-term migration to Argentina increases peach adoption, while U.S. migration leads to more human

[32] Survey respondents listed the number of each type of animal raised in the study area. They reported prices at sale, which were used to estimate the animal wealth of each household—for both sold and retained. In cases where no price was listed, the average of other households' sale price was used.

capital accumulation. The next section investigates which other factors lead to changes in peach holdings, animal wealth, or schooling.

Additional Cross-sectional Results

In addition to the regressions in the previous section, I also use OLS to estimate the effects of other independent variables on peach adoption, wealth, and schooling, many of which were not feasible within the SUR model. This section describes each of these results.

Peach Adoption

The cross-sectional results presented in Table 7 help explain which emigrants, in particular, have increased household peach holdings. In these regressions, the number of peach parcels is regressed on measures of migration and household characteristics. For several of the explanatory factors, I use household-specific variables from 1993, the year preceding the building of the dam. Column (1) shows the determinants of peach adoption using location-specific short and long-term migration as well as two of the main canal groups. Column (2) uses the same variables, but adds in more canal associations as these associations may have a large effect on water availability. The results show that households with short-term migrants in Argentina most likely to grow peaches, while those with short-term emigrants in the U.S. have a smaller and less significant positive effect. Each short-term Argentinian migrant increases by one-fourth of a parcel the number of peach parcels under cultivation. Consistent with earlier results, households with long-term emigrants to the U.S. are less likely to adopt peaches (relative to other types of migration). The geographic controls show that those outside the Mamanaca canal group are more likely to plant peaches, as are those living in Arbieto, the main city. Taken together, Tables 5, 6, and 7 clearly substantiate the hypotheses tested by Equations (1) and (2a); it is Argentine migration—specifically short-term migration—which causes peach adoption. This lends credence to the notion that for many households, rather than simply lifting liquidity constraints, the ability of migrants to monitor their investments and the likelihood of return matters most for investment in peaches.

Investment in animals and houses

Table 8 shows further explanatory factors that lead to increased house values and the accumulation of animal wealth. The first column regresses house values on the number of emigrants to both Argentina and the U.S. as well as other explanatory variables, showing that households with migrants in either destination have increased home values. Each additional Argentinian migrant adds roughly $3,300 to the value of the house, and each U.S. migrant about $1,000 less.[33] Each additional peach parcel in 1993 decreases house value by $12,000. The second column regresses animal wealth values on migration and the same control variables. Here, as expected, emigration to the U.S. decreases animal wealth, although there is no significant effect from Argentinian migrants.

Education

Table 9 shows the determinants of family education, using as the dependent variable either the the schooling-for-age (SAGE) variable or the average years of schooling among family members aged 15-25 (those who were between 5 and 15 in 2000).[34] These variables are regressed on city

[33] The sample size is reduced because only 55 households were willing or able to give an estimate of the price of their house.

[34] Restricting the sample in this way excludes 8 households. Using an average of all family members' schooling yields near-identical results. I use decades rather than short- and long-term migration because of the truncated sample.

and canal-level control variables, the number of peach parcels and water rights, and migration decade and destination. The first two columns use the SAGE measure. Both show a positive and significant effect of having family members migrating to the U.S. during the 1990s. Column (1) uses, as the migration variable, the number of migrants who departed in the 1990s and 1980s, while Column (2) uses the number of migrants who were away during those decades. Column (3) finds a similar effect, while using average family education variable as the dependent variable. Families with U.S. emigrants have higher educational attainment, while no other types of emigration have a consistently significant effect. The presence of at least one family member in the United States during that decade adds 0.4 years to the *average* years of schooling for that family, increasing the SAGE estimate by 3 percentage points. In each case, the years of education of the household head has a significant, positive effect on family education.

These results offer compelling evidence in support of the hypothesis that overseas migration positively affects education. Migration to the U.S. has a major effect on the trajectory of children's education, even after controlling for the education of the household head and other household and agricultural characteristics. Conversely, as shown in Table 8, investment in on-farm capital for families with U.S. migrants is negative; the increase in human capital investment comes at the cost of off-farm activities. The household head results imply lasting effects. Across generations, each additional year of a household head's schooling adds an average of 0.3 years for each of his children. In turn, these educated children are more likely to emigrate to the U.S. The potential gains to education are lower for those staying in agriculture.

Robustness Checks

In this section I demonstrate that the main regression result, that sending a migrant to Argentina increases the likelihood of peach conversion, is robust to alternate assumptions and specifications. Section 5.1 demonstrated a significant effect of a migration episode on the uptake of peaches six years later. Each additional migrant increased the likelihood of peach adoption by 5%. Using the same specification and covariates as in Table 5, Column (2), Figure 4 shows the coefficient on the lagged migration term, varying the lag time between migration and peach conversion. As can be seen, the coefficient on this term is positive in each specification between a five and eight year lag, with negative values when the lag is considerably shorter or longer. This is consistent with the rationale presented: that households although typically cannot undertake a conversion soon after the migrant has departed, they may still lack the necessary liquidity or prefer to time the return for when the peaches are planted.[35]

Reverse Causality

To further address potential endogeneity, I test for reverse causality: that peach planting causes migration, not the other way around. In this regression, I specify the following model:

$$Peaches_{ht} = \alpha + \mathbf{X}\boldsymbol{\beta} + \gamma_1 EmigArg_{h,t+6} + \gamma_2 EmigUS_{h,t+6} + \gamma_3 EmigArg_{h,t+3} + \gamma_4 EmigUS_{h,t+3} + \nu_h + \epsilon_{ht}$$

where $Peaches_{ht}$ is the number of plots converting to peaches in a household. $\boldsymbol{X}$ contains the household and plot characteristics, the same control variables in the main results. Rather than the lagged emigration variables, I include future migration for both the U.S. and Argentina.

Table 10 shows the results. If peach conversion were causing migration, rather than the opposite, there would be positive coefficients on the future migration terms. These terms (shown

[35] The average duration for a returning migrant to Argentina who departed between 1980 and 2000 was 5.74 years.

in Column (1)) are close to zero and insignificant. Column (2) shows results excluding the three-year terms. In both specifications, the sign on the projected coefficient is either slightly negative or very close to zero. In a test of reverse causality (not shown), I restrict the sample to only peach conversions before 2000—before the explosion of migration to the United States. This reduces the sample size by 15%. The coefficient on lagged Argentine migration remains similar in sign and magnitude, but is not significant at the 5% level.[36] Table 11 includes three-year lagged variables in addition to those in six years. If there were varying short and long-term effects of migration, a double-lag structure would be preferred. Here, the addition of an earlier lagged year does not significantly change the estimate of the coefficients or improve the fit of the model.

Finally, in addition to the results discussed here, I also tested whether inclusion of migration to Spain would change the results. I replace U.S. migration with the number of migrants to Spain and the U.S. jointly, and the sign and significance level of the coefficients do not change.

6 Discussion

These results establish that, in the communities under study, there are large differences in observed household activities depending on the destination of migrating household members. A seemingly unrelated regression model estimated the determinants of current-day activities. Fixed effects panel methods were used to control for the endogeneity associated with the decision to migrate and choose crops and found that Argentinian migration did significantly spur peach adoption while US migration did not.

[36] In addition, I try truncating the sample at each year from 1997-2002 and find similar results for each year.

This study is relatively unique in that it features two main international destinations. Within the literature, international migration has been found to increase the uptake of new agricultural technologies (Mendola 2008) or farm productivity (Lucas 1987; Rozelle et al. 1999; Taylor and Lopez-Feldman 2010). Others studies have found international migration results in a switch into animals (Wouterse and Taylor 2008; Damon 2010). As discussed below, migration can have a positive effect on educational outcomes. The migration observed in this study notes effects in each of these categories.

In the Valle Alto, Bolivian families in the 1970s to early 1990s owned land but limited water rights. Traditional crop cultivation remained the dominant form of agriculture. During this time, over half of men and women who would become heads of household traveled abroad. By 1984, two-thirds of current or future household heads who would emigrate had left; by 1994, an equal proportion had returned. The agricultural developments of the mid-nineties in the region were shaped considerably by these migration flows. From 1994 to 2004, peach cultivation expanded from one-tenth to one-half of the 92 homes surveyed. Meanwhile, in the five years following 1993, two-thirds of households received their first water rights under the new irrigation system as the percentage of those with access to canal irrigation jumped from 24% to 90%.

Examination of the historical patterns of migration in the Valle Alto shows that households have followed two main accumulations paths. During the period from 1970–1994, the majority of emigration was returning migrants in Argentina. These migrants and their families invested in physical capital and developed agriculture, including peaches. This segment of the population forewent additional schooling to develop these farms, averaging less than six years of education. The influx of capital before peaches became prevalent allowed for these households to spearhead the development of orchards. The ability of families to monitor farm plots from Argentina—and to return home, if necessary or preferred—likely added to the desirability of planting orchards. Peach harvesting is more labor intensive at the time of harvest, and, given the relative proximity of Argentina, extended family members are often able to return and assist.

In contrast, families with emigrants living long-term in the U.S. exhibit different accumulation paths. They also invest in houses, but not in on-farm assets or technology. There is either a negative or insignificant effect of long-term U.S. emigration on peach adoption despite its larger potential for relaxing liquidity constraints. Monitoring is costly from abroad, and migrants established in the United States are less likely to plan to return. If they did, they may be less likely to draw on that kind of productive asset. Likewise, investments in animal ownership are found to be considerably lower in households with U.S. migrants (see Table 8).

This study also supports the literature establishing the benefits of certain types of migration in increasing human capital (Bansak and Chezum 2009; Calero et al. 2009). Long-term migrants in the U.S. have 10.4 years of education on average, nearly three years more than short-term migrants to Argentina, This continues to the next generation: children in households with at least one migrant in the U.S. added one year of schooling after controlling for other factors.

From these data, distinctive portfolios are associated with different migration destinations. Those in the U.S. remit to foster education, improve housing stock, and, in many cases, bring their family members abroad. Migrants to Argentina invest in animals, crops, and housing. It is not a matter of just relaxing liquidity constraints, but reflects the trajectory of migrants and what they anticipate for themselves and family members abroad. Parents who are able to emigrate to the U.S. change the educational trajectory of their offspring and future members of their family. In contrast, emigrants to Argentina may improve the agricultural productivity and animal wealth of the household, increasing household wealth and on-farm productivity.

Overall, these results from Argentina are in support of the New Economics of Labor Migration literature showing that remittances can alleviate liquidity and risk constraints and entice families to make and sustain more productive investments (Stark and Bloom 1985; Stark 1991). While this is not the case for peach conversion financed by migrants in the United States, I postulate that this may be due to the stronger appeal of other, now affordable investments. It could also be the case that the remittances are sufficient for families not to need productive investments (see (Mendola 2012) for a discussion). From this study, the effects of migration and remittances on the broader communities are not clear. In a recent study, Jones (2013) finds that in a different part of the Valle Alto, income inequality among migrant-sending households is lower than in non-migrant sending households.

Those interested in designing effective policy in this region should consider which impediments forestall community development. A sub-sample of maize-growing respondent households was asked what they considered to be constraints to peach adoption. The top three reasons for not planting peaches were inherent risk (80%), lack of access to water (78%), and insufficient available labor (77%). Capital or credit constraints (23%) and a lack of knowledge (17%) were also listed as barriers. Policies to foster new technologies and agricultural investments should be aware of the non-pecuniary needs of farmers.

In this analysis, I have been able to control certain exogenous variables which affect the timing of peach adoption. In the panel regressions, migration, household demographics and parcel characteristics were used as covariates in determining the conversion decision. However, this analysis put aside many spatial characteristics. By observation, it is clear that land use change does not happen randomly across the watershed. Rather, peach parcels tend to be clustered, nearer to canals, and predominantly in certain areas. Fortunately, I can control for some of these elements using information gleaned from overview photographs. The next chapter takes account of the geography and positioning of the parcels, using spatial statistics, such as neighbors' activities, to explain land use patterns.

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Table 1: Demographic Summary Statistics

Variable	N	Mean	Std. Dev.	Min	Max
HH Size	92	5.26	2.28	1	13
Family Size	92	5.96	2.25	1	13
Female Household Head	92	0.20	0.40	0	1
Age of Household Head	90	59.8	13.9	23	88
Education of Household Head	89	6.34	4.72	0	20
Maximum Educ. of HH	92	9.50	4.89	0	20
Maximum Educ. of Family	92	13.09	3.46	5	20
Migrant Abroad Now (%)	92	0.62	0.49	0	1
Number Active in Ag.	92	2.70	1.88	0	12

Note: Household size refers to all of the members living in the household at the time of the survey. Family size is all of these members plus children who are not living at home. Not all family members active in agriculture live in the household.

Table 2: Emigrant Characteristics

Destination	N	% Short-term Migrants*	Age at Departure	% Remitting (at any time)	Decade of Departure				
					1960s	1970s	1980s	1990s	2000s
Argentina	121	41.4	23.5	.305	13.7	16.2	25.6	21.4	23.1
United States	161	22.8	27.1	.708	2.0	2.6	12.4	28.1	54.9
Spain	21	50.0	22.3	.380	0.0	0.0	0.0	5.9	94.1
Total	303	32.3	25.5	.524	6.6	8.0	17.1	24.0	44.2

* Short-term migrants are those migrants who departed before 2005 and returned within 6 years. 74 migrants who departed in 2005 or after are excluded from this column.

Table 3: Educational Characteristics of Long-term vs. Short-term Emigrants

Destination	N*	Years of Schooling			Migration Duration (years)
		Migrant	Household Average	Family Average	
Long-term Emigrants (> 6 years)					
Argentina	58	7.55	6.44	8.36	18.07
United States	91	10.44	6.68	9.41	12.75
Spain	6	14.33	12.13	12.40	10.0
Short-term Emigrants (≤ 6 years)					
Argentina	41	6.20	6.05	8.56	2.48
United States	27	12.26	6.49	9.86	3.0
Spain	6	5.67	5.58	6.65	4.0
Non Emigrants	226	8.69	7.36	8.86	-

* Due to non-responses in some of the survey questions, the sample size of migrants may vary.

Table 4: Second Generation Emigration

Destination of Household head	Sample Size (children)	Avg. # Kids per Family	Percentage of children who emigrated to:			% of Children Staying Home
			Arg.	U.S.	Spain	
Argentina	166	3.68	16.87	40.96	5.42	36.75
United States	37	3.7	0	56.78	8.11	35.14
Spain	10	5	10	0	10	80
No emigration	106	3.06	41.51	18.87	3.77	35.85
Total	3 19	3.49	41.69	15.36	5.33	37.62

Table 5: Panel Estimation of Peach Conversion and Maize Parcels

VARIABLES	(1) Peach Conversion	(2) Peach Conversion	(3) Peach Conversion	(4) Maize Parcels
Year	0.00426			0.00195
	(0.00293)			(0.00764)
Total hectares (t - 6)	-0.000669			
	(0.0181)			
# of Parcels (t - 6)	-0.0969***	-0.0759**	-0.0629*	0.232
	(0.0318)	(0.0340)	(0.0353)	(0.157)
# of Water Rights (t - 6)	0.0124	0.00277	0.00625	-0.158***
	(0.0129)	(0.0138)	(0.0132)	(0.0426)
Adj. to Road (t - 6)	0.0122	-0.00945	-0.0130	-0.236
	(0.0404)	(0.0403)	(0.0381)	(0.153)
Adj. to Canal (t - 6)	0.0942**	0.0801**	0.0704*	-0.108
	(0.0370)	(0.0376)	(0.0382)	(0.161)
Family Size (t - 6)	-0.00495	-0.00695	-0.00382	0.0297
	(0.00925)	(0.00988)	(0.00979)	(0.0448)
# of Emig. Arg (t - 6)	0.0424*	0.0520**	0.0494*	0.179
	(0.0250)	(0.0257)	(0.0251)	(0.109)
# of Emig. USA (t - 6)	-0.00801	0.00486	0.00387	-0.113**
	(0.00676)	(0.00823)	(0.00813)	(0.0463)
Total Past Emig. USA (t - 6)		-0.00240	-0.00205	
		(0.00148)	(0.00136)	
# of Peach Parcels (t - 6)			-0.0452*	
			(0.0229)	
Constant	-8.419	-6.609	-7.549	-2.266
	(5.829)	(5.683)	(5.693)	(15.13)
Observations	1,183	1,183	1,183	1,923
R-squared	0.016	0.047	0.049	0.120
Number of households	87	87	87	87
Year FE	No	Yes	Yes	No
Restricted Years (1993–2010)	Yes	Yes	Yes	No

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Seemingly Unrelated Regression

VARIABLES	(1) Peach Parcels	(2) Animal Wealth (US$)	(3) Average Family Education
Number of parcels in 1993	-0.0110	-130.4	-0.801*
	(0.114)	(914.5)	(0.471)
Water rights in 1993	-0.0197	536.0	-0.0197
	(0.0874)	(584.8)	(0.365)
Parcels close to canal in 1993	0.0372	838.6	0.968
	(0.139)	(956.4)	(0.585)
Water rights: Mamanaca (bin)	-0.471	3,573	-0.582
	(0.377)	(2,596)	(1.566)
Water rights: Cardazozo (bin)	0.578**	-359.5	-3.750***
	(0.259)	(1,749)	(1.105)
Ciudad: Arbieto (bin)	0.301	-2,804*	2.003**
	(0.259)	(1,668)	(1.040)
Family Size in 1993	-0.0859**		
	(0.0459)		
Short-term Argentinian migrants (#)	0.264*		
	(0.135)		
Long-term Argentinian migrants (#)	0.166		
	(0.0890)		
Short-term U.S. migrants (#)	0.0847		
	(0.103)		
Long-term U.S. migrants (#)	-0.0216		
	(0.0637)		
Parcels close to road in 1993		941.8	
		(949.1)	
Past Argentinian migrants (#)		-220.0	-0.168
		(222.8)	(0.139)
Past U.S. migrants (#)		-280.4**	0.221**
		(169.1)	(0.105)
Education of hh head			0.144*
			(0.0811)
Constant	1.030***	6,117***	9.590***
	(0.265)	(1,314)	(0.980)
Observations	86	86	86
R-squared	0.254	0.153	0.204

Bootstrapped standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Cross-sectional peach adoption

VARIABLES	(1) Number of Peach Parcels	(2) Number of Peach Parcels
Number of parcels in 1993	-0.0397	-0.0467
	(0.147)	(0.144)
Water rights in 1993	-0.00436	-0.0163
	(0.108)	(0.107)
Parcels close to canal in 1993	0.124	0.146
	(0.189)	(0.183)
Family Size in 1993	-0.0906**	-0.0778*
	(0.0406)	(0.0403)
Short-term Argentinian migrants (#)	0.244*	0.270**
	(0.138)	(0.131)
Long-term Argentinian migrants (#)	0.149	0.157
	(0.0992)	(0.0952)
Short-term United States migrants (#)	0.135*	0.119*
	(0.0699)	(0.0711)
Long-term United States migrants (#)	-0.00987	-0.0203
	(0.0639)	(0.0636)
Ciudad: Arbieto (bin)	0.661***	0.467*
	(0.216)	(0.254)
Water rights: Gringo (bin)	-0.338	-0.311
	(0.234)	(0.309)
Water rights: Mamanaca (bin)	-0.804***	-0.781**
	(0.285)	(0.378)
Water rights: Prado (bin)		0.319
		(0.274)
Water rights: Cardazozo (bin)		0.277
		(0.367)
Water rights: Other suyos (bin)		-0.640**
		(0.314)
Constant	1.192***	1.130***
	(0.284)	(0.326)
Observations	91	91
R-squared	0.224	0.272

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Determinants of house value and animal wealth

VARIABLES	(1) House Value ($000)	(2) Animal Wealth ($000)
Parcels close to canal in 1993	-7,885	575.8
	(5,532)	(1,056)
Hectares in 1993	-1,578	-60.54
	(3,010)	(427.7)
Number of parcels in 1993	2,555	392.3
	(3,417)	(985.9)
Water rights in 1993	7,511	737.3
	(7,885)	(557.4)
Peach parcels in 1993	-12,015*	-1,089
	(6,786)	(1,019)
Ciudad: Arbieto (bin)	-6,193	-2,686*
	(11,506)	(1,356)
Water rights: Mamanaca (bin)	-21,878**	1,873
	(10,416)	(2,732)
Water rights: Cardazozo (bin)	-8,236	-848.3
	(10,714)	(1,643)
# of Arg. Emigrants	3,285**	-137.0
	(1,300)	(181.4)
# of U.S. Emigrants	2,322*	-219.0*
	(1,221)	(112.3)
Constant	20,220***	5,896***
	(6,287)	(1,109)
Observations	55	92
R-squared	0.281	0.147

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Determinants of education

VARIABLES	(1) SAGE measure of education[a]	(2) SAGE measure of education	(3) Average Family Education for those Aged 15-25[b]
Water rights in 1993	-0.261	-0.0785	0.480
	(3.187)	(3.248)	(0.595)
Water rights in 2003	-2.697	-2.547	-0.611
	(1.989)	(1.972)	(0.377)
Peach parcels in 1993	1.898	2.452	1.109
	(3.865)	(3.933)	(0.826)
Peach parcels in 2003	4.495	4.458	1.507
	(3.908)	(3.866)	(1.056)
Water rights: Mamanaca (bin)	7.899	7.801*	0.331
	(4.758)	(4.333)	(0.753)
Water rights: Cardazozo (bin)	-14.34*	-14.30*	-3.985**
	(8.051)	(7.851)	(1.445)
Ciudad: Arbieto (bin)	-1.167	-1.189	-0.201
	(4.885)	(4.552)	(1.136)
Education of hh head	0.786*	0.824*	0.326***
	(0.458)	(0.456)	(0.0675)
# US Emig depart in 80s	-0.402		
	(3.520)		
# US Emig depart in 90s	3.117**		
	(1.465)		
# Arg. Emig depart in 80s	-1.816		
	(3.670)		
# Arg. Emig depart in 90s	-0.294		
	(3.219)		
# of US emigrants in 80s		-3.337*	-0.521
		(1.699)	(0.357)
# of US emigrants in 90s		3.219**	0.403*
		(1.406)	(0.213)
# of Arg. emigrants in 80s		-1.561	-1.247*
		(2.565)	(0.726)
# of Arg. emigrants in 90s		-0.173	0.654
		(2.731)	(0.545)
Constant	93.00***	92.72***	11.33***
	(4.974)	(4.780)	(0.933)
Observations	48	48	40
R-squared	0.334	0.341	0.468

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[a] The SAGE measure captures the educational attainment of family members between the ages of 7 and 25 (inclusive) where the maximum number of years of education is 12
[b] Average family education is the average years of schooling for of all family members between the ages of 15 and 25 (inclusive)

Table 10: Reverse Causality Tests

VARIABLES	(1) Peach Conversion	(2) Peach Conversion
# Emig. USA (t+6)	-0.000277	-0.00681
	(0.00989)	(0.00965)
# Emig. Arg (t+6)	0.000246	0.00324
	(0.0148)	(0.0151)
# Emig. USA (t+3)	-0.0171	
	(0.0151)	
# Emig. Arg (t+3)	0.000587	
	(0.0169)	
Constant	-12.58	-10.43
	(11.37)	(10.68)
Control Variables	Yes	Yes
Observations	1,003	1,003
R-squared	0.035	0.033
Number of encuestaid	80	80

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Base regression with additional lagged year

VARIABLES	(1) Peach Conversion
# of Emig. Arg (t - 3)	-0.0271
	(0.0268)
# of Emig. USA (t - 3)	0.0126
	(0.0126)
# of Emig. Arg (t - 6)	0.0545**
	(0.0257)
# of Emig. USA (t - 6)	-0.0166
	(0.0111)
Constant	-4.731
	(5.819)
Control Variables	Yes
Observations	1,181
Number of households	87
R-squared	0.054

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 1: Map of the Valle Alto

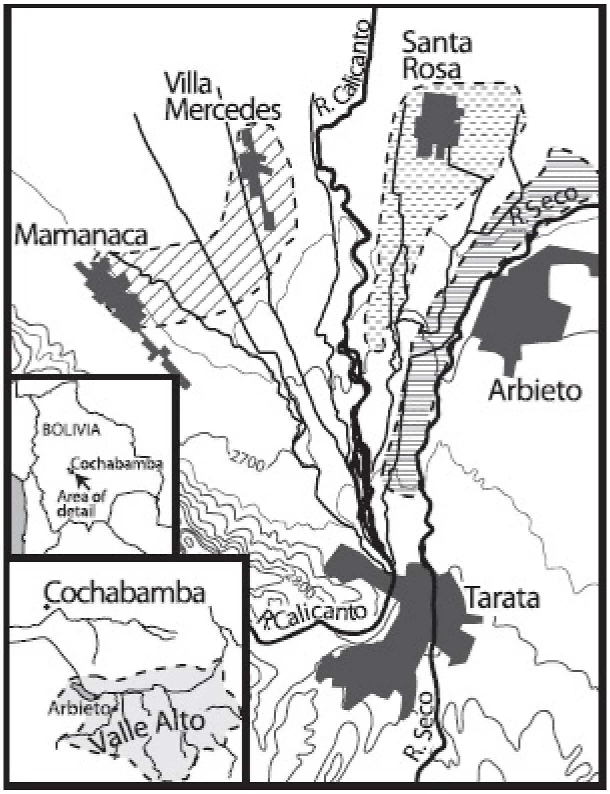


Figure 2: Migration and Peach Adoption

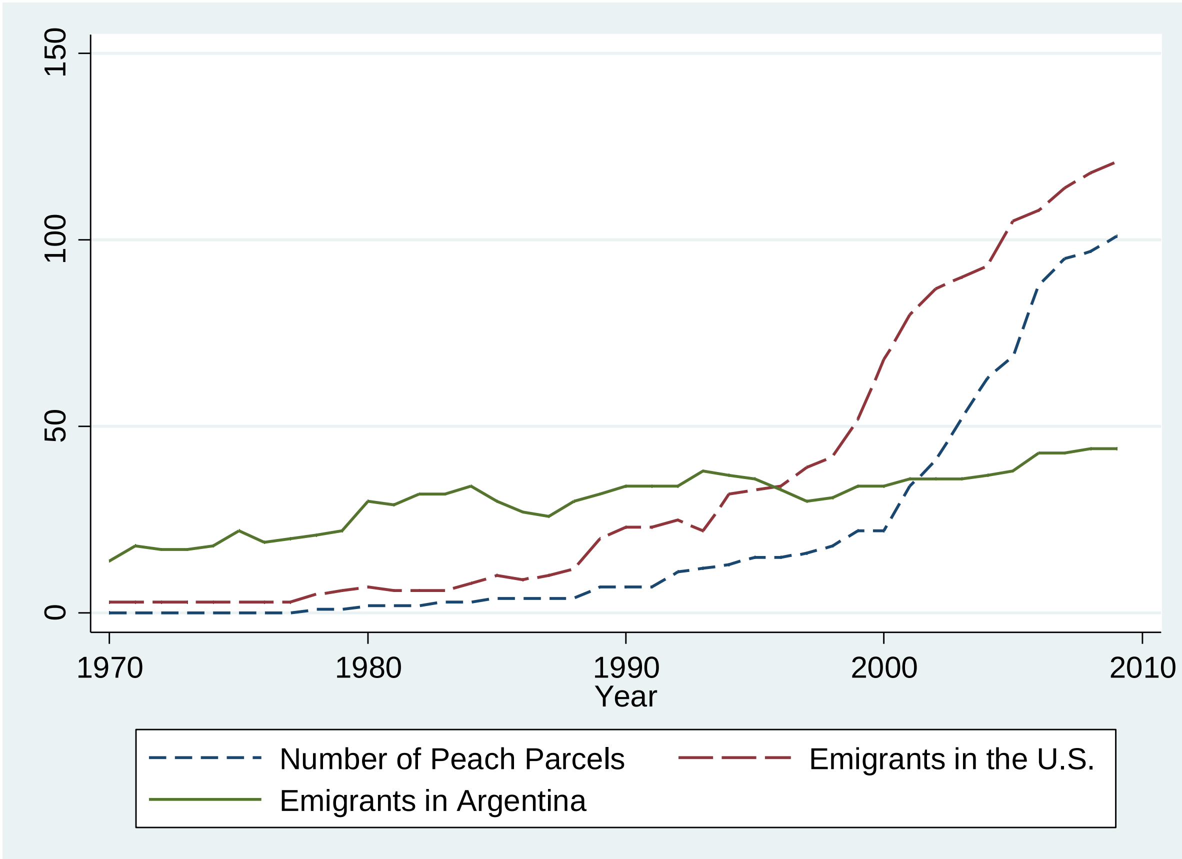


Figure 3: Potential migration and investment pathways

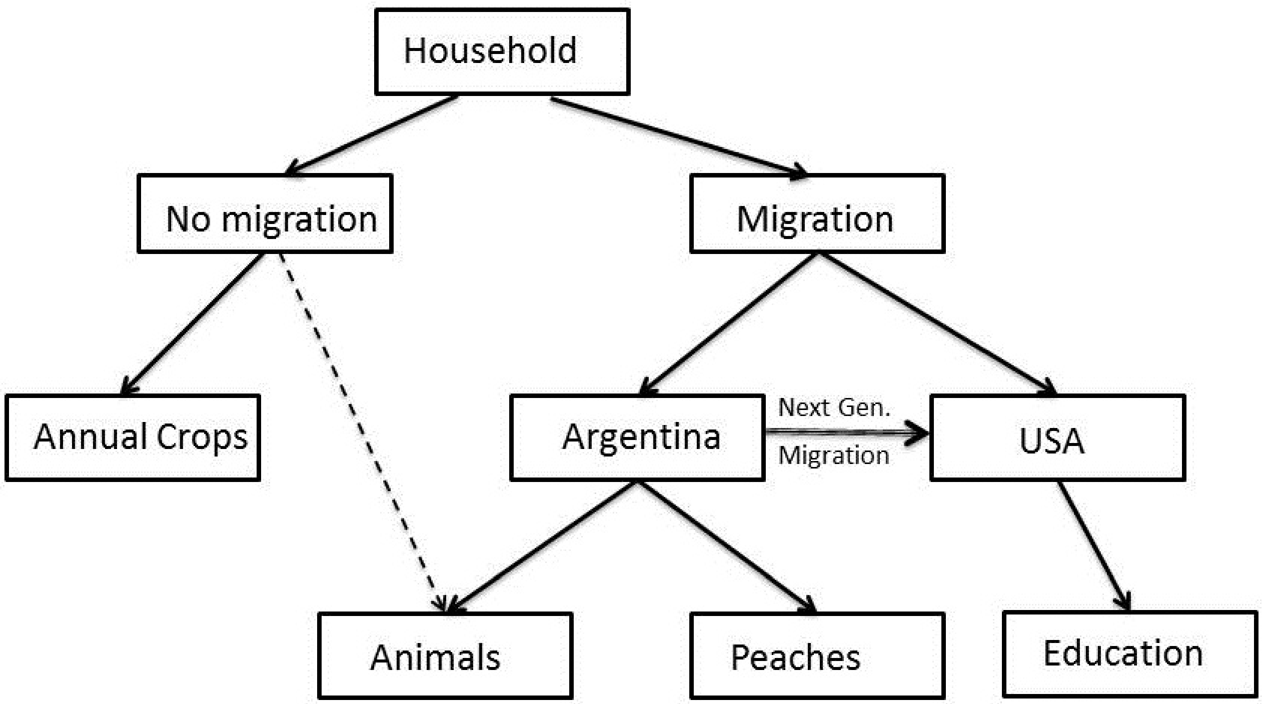


Figure 4: Migration Destinations, 1960 to 2009

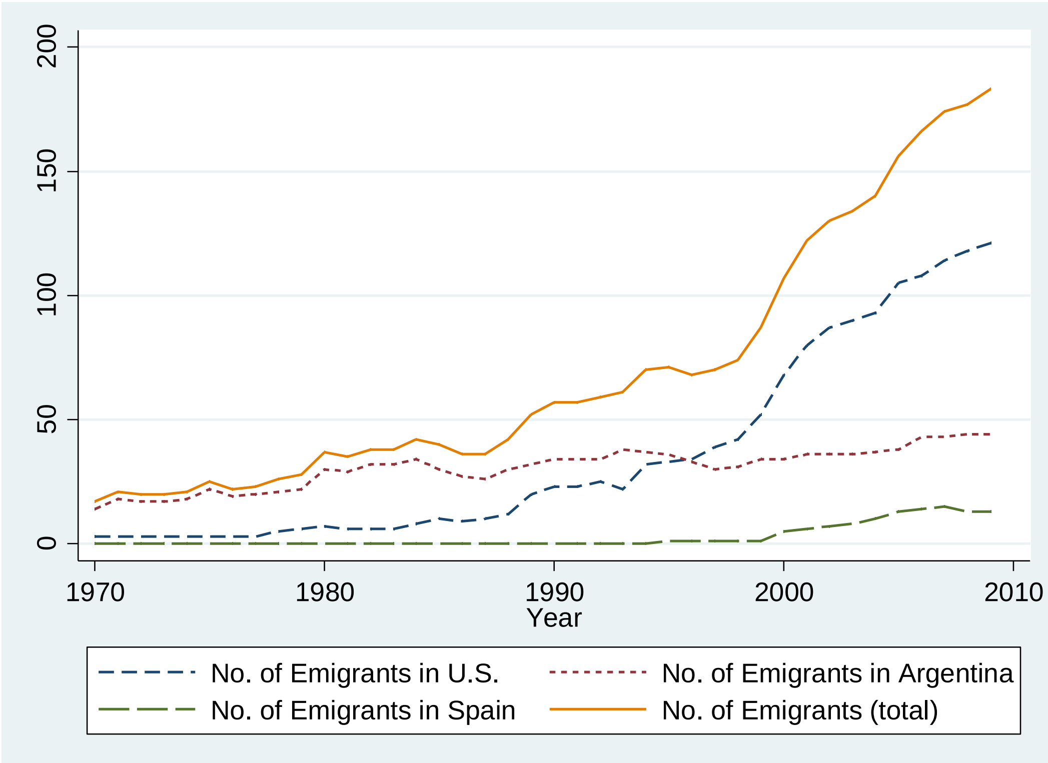


Figure 5: Histogram of First Peach Adoption

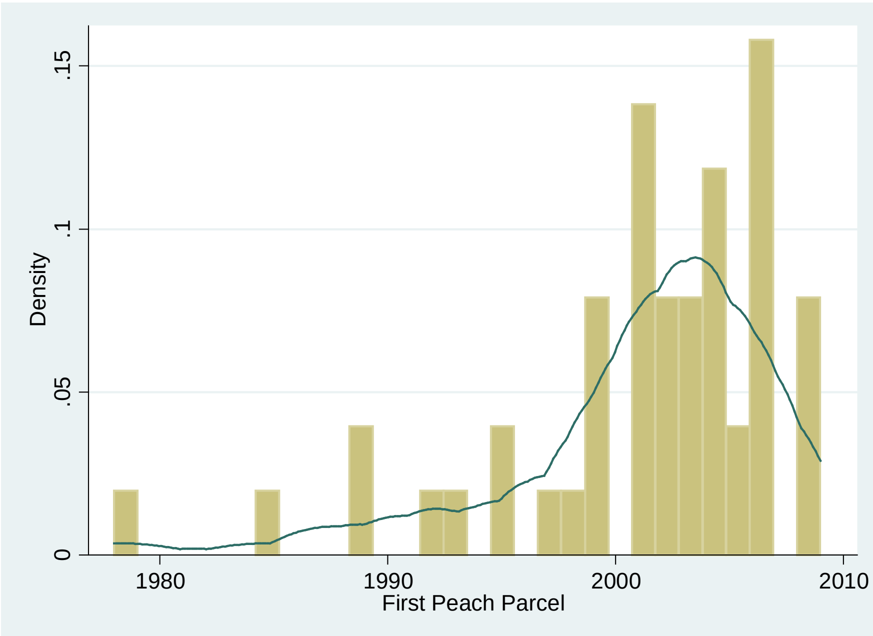
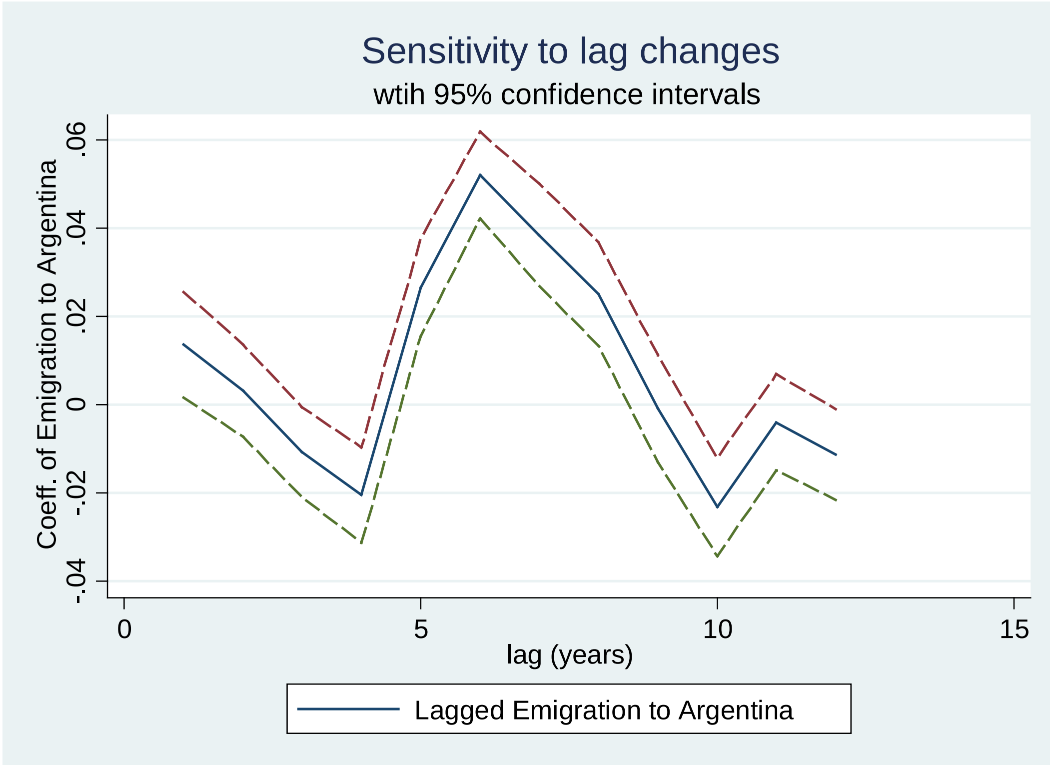


Figure 6: Sensitivity to Other Lag Values



A Spatial Analysis of Peach Adoption in the Valle Alto: Do Neighbors Pave the Way?

Daniel Prager, Amy Burnicki, and Brad Barham

1 Introduction

In the Valle Alto region of Bolivia, there has been a widespread and rapid conversion of farmland from traditional maize rotations to peach orchards. Peaches are a new and often much more lucrative crop, which had minimal uptake before 1990, yet for many Valle Alto households form the basis for a higher-yielding rural household portfolio. They are also a capital-intensive crop that require timely attention, and careful monitoring for weather shocks (mostly frosts) during the early Spring months and at harvest time. For a non-peach household, having neighbors who have converted land to peaches could make it easier to make that crop choice as well. For example, reciprocity in labor and monitoring of orchards could reduce transaction costs, while shared learning about this new crop could help to improve management practices and productivity. Pooled transactions can also help to reduce input and transport costs. Conversely, the congestion of many neighbors all drawing on the same limited irrigation source might cut in the other direction and discourage clustered adoption patterns.

This paper presents a spatial analysis of land use change in this region focusing on the clustering of peach production, building on conjectures raised in Lewis, Barham, and Zimmerer (2008) about factors that might shape agglomeration of land use choices. Using remotely-sensed data derived from overflight images, we investigate how the physical and locational characteristics of a given parcel affect changes in its land use between 2003 and 2008. While land use decisions are certainly a combination of parcel, household and community-level characteristics, one benefit of using only spatially-derived statistics in this context is that the data span the entire study area, while the available household survey data provide a much smaller random sample taken predominantly from the Western side of the watershed.[37] In the process, we develop a methodology that is broadly applicable in areas with satellite imagery even if on-the-ground data are not available. Later in this chapter, we also combine the remote sensing data with household data and offer preliminary results as to whether some of the key spatial results are sensitive to inclusion of these other variables.

In the previous chapter, we examined the decision to convert lands from maize rotation to peaches using a household portfolio model that features demographics, migration histories, and liquidity constraints. However, individual land use decisions are also governed by watershed-wide concerns, such as water availability, neighbors' decisions, and spatial patterns of land use change. There has been considerable work investigating domestic urban or agricultural decisions, for instance whether to convert an agricultural or undeveloped parcel into residential land, but fewer land use changes in developing countries using watershed-level data. Herein, we employ spatial econometric techniques to investigate the drivers of land use change patterns in the Laka Laka dam agricultural area in Valle Alto, Bolivia (see Figure 1 for a map of the canals and residential areas in the study area).

Remote sensing data from satellite images, taken in 2003 and 2008, allows for analysis of the decision to convert from cropped, fallow, or undeveloped land to peaches.[38] Over the course

[37] The household survey identified 140 geolocated parcels (3.3% of the total) which contain both household and parcel-level information. See section 2.

[38] In 2008, the image was taken during the harvest season and other crops such as wheat were identifiable; the

of those five years, the number of peach parcels grew by 50%, from 445 to 680 of a total of 4,281 parcels. While there was a limited amount of disinvestment in peaches, the number of new adopters was five times as large. These land use change patterns provide substantial variation within the watershed which allows us to test how different aspects of a given parcel, such as its size, location, and the land use of neighboring parcels affect the planting of peach trees over the ensuing five-year period.

The next section describes the study area and reviews relevant literature. Section 3 details the data collected, and uses spatial statistics to explore the presence and pattern of peach clusters. In the Section 4, we present a model of household decision-making and derive hypotheses about the causal factors of land use change. Section 5 introduces the econometric models. Lastly, Section 6 provides results and a conclusion.

2 Motivation and Background

Since the late 1970s, economists have studied the unique issues that arise when spatial correlation is present. Traditional regression models are unable to account for the common factors which affect observations that are spatially proximal to each other, and failure to account for spatial dependence leads to omitted variable bias if the neighborhood around an observation is part of the data-generating process. It can also fail to account for otherwise unobserved spatial heterogeneity, such as land slope or soil quality and negative or positive externalities, such as runoff and input pooling (LeSage and Pace 2009). Measurement error generated by the aggregation of spatially heterogeneous data is common and can produce spatial dependence. For

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2003 image was taken in the Spring cannot distinguish between various land crops.

instance, population data collected at the census rather than household level may conceal clustering of, for instance, low or high levels of education. Therefore, an analysis of the effect of education on an outcome variable may not be correctly specified. More generally, errors of this type are dependent on the scale of the data collection (Brady and Irwin 2011). This paper expands on previous work using remotely-sensed satellite data to analyze the factors contributing to land use change. We add to the literature by developing and testing a simple but effective way to measure neighbors' effects while accounting for the potential endogeneity from adjoining parcels that are owned by the same household (when household-level data are not available).

Spatial data typically derives from two main sources, tax-parcel data which is based on political or institutional boundaries, and remotely-sensed data from satellite imagery. Herein, we focus on satellite imagery as there were no available tax data for the study area.[39] Recently, remotely-sensed data has been used to address the drivers of land use change and other environmental outcomes. While analyzing deforestation in Mexico, Nelson and Hellerstein (1997) use a spatially-explicit multinomial logit model to show that less road access predicts less deforestation. Pfaff (1999) develops a model in which profitability of land use drives a household's land use choice and finds that more roads lead to more deforestation in Brazil. Robalino and Pfaff (2012) model the effects of neighbors on similar decisions in Costa Rica, finding positive effects of neighbors' deforestation on own-parcel deforestation. Other work incorporates household survey data, in addition to spatial data, to directly test the motivations behind land use change (Muller and Zeller 2002; Caviglia-Harris and Harris 2008).

There are several methods and techniques for analyzing discrete-choice land-use decisions which account for spatial dependence. McMillen (1992) developed the first spatial

[39] See Brady and Irwin (2011) for a comprehensive discussion of early efforts which use such imagery.

probit model which used an expectation-maximization algorithm. In iterative steps, the expectation procedure generates parameter estimates while the conditional maximization is performed based on the parameter estimates from the first step. This method is both computationally intensive and can produce biased confidence intervals (LeSage 1999). An increasingly common method is to use Baysian approaches such as Markov chain Monte Carlo (MCMC) methods to address these computational issues (Li 2013). An advantage of the Baysian approach is that it does not involve the inversion of the spatial weight matrix (**W**)**.**

Other efforts estimating spatial discrete-choice models have cut down on the computational requirements by using sampling methods. Carrion-Flores and Irwin (2004) discard the nearest spatial neighbors to decrease the number of observations. Alternatively, a large number of parameter draws using the Gibbs sampler can be used to produce valid measures of dispersion for all parameters in the model (LeSage 1999). To address inconsistent and inefficient estimators due to autocorrelation, Rashford et al. (2013) use other sampling methods in a bootstrapped estimating procedure. They consider the tradeoffs using high-resolution remotely-sensed data in the context of grassland conversion in the Great Plains. Other approaches use a generalized method of moments (GMM) estimator (Pinske and Slade 2010) or a multinomial probit model (e.g., Chakir and Parent (2009)). Calabrese and Elkink (2013) discuss the relative merit of these different approaches.

In this chapter, we use several approaches including the standard (non-spatial) probit model and a multinomial logit model. Rather than including a spatial weight matrix, these estimations incorporate a measure of the number (or area) of nearby peach parcels. This measure of the extent of peach uptake in the area surrounding a given parcel captures the effects of neighbor's choices on land use change in a similar (though not identical) way. The inclusion of a spatial weight matrix would not necessarily improve the efficiency of our estimations.[40]

Irrigation and water rights allocation

Understanding the adoption of new and better agricultural crops and techniques, such as more robust or higher-yielding varieties, is a longstanding and ongoing focus of the microeconomics literature (Feder, Just and Zilberman 1985; Foster and Rosenzweig 1995; Conley and Udry 2010). More recently, there has been an increase in the development of spatially explicit adoption estimators, and they are becoming common in many software programs.[41] As discussed above, these econometric estimators have been used to study the geographical elements of agricultural land use change (Towe et al. 2008). Understanding land use decisions within the watershed of a developing country matters for many reasons, including measuring the benefits of improved irrigation and uncovering potential externalities and distributional implications of spatial patterns of activity. All of these can be used to evaluate the benefits of a project and inform decisions about technical assistance (Lewis et al. 2008). In this study, recent changes provide a novel case to see who has benefitted from the location of their parcels, their neighbor's land use choices and improved water delivery infrastructure.

The installation of a dam was a primary reason for this study of the watershed encompassing the farming community in the Valle Alto of Bolivia. Within the watershed, there is a reservoir and extensive irrigation networks made possible by the creation of a dam built in

[40] We will directly test this in a future version of this paper, which will include probit estimations using both the neighbors' measure and a spatial weight matrix, and compare those results to the estimations contained herein.

[41] There are a variety of comprehensive packages and programs available, including MatLab, GeoDA, and STATA, among others. This analysis uses the Tools for Spatial Analysis developed by Maurizio Pisati at University of Milano Bicocca, Italy.

the early 1990s above the municipality of Tarata.[42] The watershed has six main and many subordinate canals which are organized through canal or sub-canal specific irrigator's associations. Most of the parcels in the area are part of the Laka Laka irrigation system. The system is based on a system of water rights (*acciones*) which are plot-specific and owned by a household. The irrigators association keeps tight control over the market, not permitting transactions except in specific circumstances. Of the households surveyed, 88% have access to this system of canals; others are irrigated through wells or rainwater management, generally providing more costly or very limited water access.

Water rights were allocated under a highly structured system during the 1990s. Those who had rights to water under the previous system received similar access under the new regime, though they were required to contribute manual labor during the construction of the system. Although water rights were available for purchase during that time, later the granting of new rights was not possible as there was not enough water to irrigate those who already had access to the system. To maintain water rights a household paid 2 Bs. ($0.30) per month to the irrigators association and was required to contribute several days of labor to the maintenance of the system. Those who had access to the canals system were granted the right to irrigate half of an *arrobada* (0.36 hectares) for each water right they possessed. Water was stored kept in the reservoir behind the dam, and dispersed several times during the growing seasons, depending on stored water capacity. For each dispersal (*lagrada*) enough water was released to irrigate each plot along the canal with rights for a fixed period of time, usually about 1–1.5 hours.

[42] This was made possible by a grant from the Canadian International Development Agency (CIDA). The dam first opened in the Spring of 1993.

The irrigator's association oversaw the flooding on each parcel in in order to make sure farmers did not take more than their allotment. Those who violated the rules of the system were subject to escalating fines, and, in rare cases, lost their water rights altogether. The reservoir, which was roughly 15 years old at the time of the study, had accumulated silt and mud sedimentation shrinking its capacity. This, in combination with climatic changes, sharply reduced the amount of water available for irrigation. The number of releases of water from the dam had fallen from eight at the time of the dam's construction to 3–4 in 2008-2009 and as low as 1–2 in the 2010 growing season. While the irrigator's association strove to give the same amount of water to all parcels along the canals, in practice those with parcels closer to the dam received more consistent allotments. The system included primary canals (over 4 km) which were lined with cement. A larger amount of secondary canals were dirt-only and thus inefficient for water transport. Due to the decrease in reservoir size, at the peak of the rainy season the dam overflowed, providing water when it was not needed and diminishing the amount in reserve. Maintenance could have solved this problem at a relatively low cost. However the irrigator's association lacked necessary funds, and there was a collective action problem among agents: no canal group wanted to finance improvements of the dam, unless the other sub-canal groups (*suyos*) contributed equally

Neighbors Interaction and Reciprocity

Learning, input pooling, and reciprocal arrangements with neighbors can diminish the cost of adopting a new agricultural technology (Conley and Udry 2010). In the Valle Alto region, data collected as part of the household survey provide insight into how neighbors interact. Among that sample, 69 of 92 agricultural households indicated that they had at least discussed their on-farm problems with other farmers and 39% learned a new technique or improved an older one jointly with another farmer.[43] Among all farmers, nearly one-third engaged in reciprocity for seeds, and one-fourth of the sample either exchanged labor or shared irrigation efforts.

Among those peach growing households who responded to the survey, a high percentage (71%) had learned something from a friend or neighbor in the last five years and 76% indicated that they had at least one reciprocal arrangement. To prevent theft, some farmers sleep in small huts, watching their neighbor's orchard in addition to their own or reciprocate in the transportation or sale of the harvest. Of these peach-growing households, 44% had such an arrangement. In table 1, we divide the sample by whether the date of earliest peach adoption occurred before or after 2003. While both groups had similar levels of reciprocity, a higher proportion of early adopters (82%) than late adopters (59%) engaged in learning in the previous year. Conversely, reciprocal arrangements for seed acquisition, frost prevention and the sale of peaches were 1.8 to 2.2 times more frequent for those late adopters. There was a substantial amount of neighbor cooperation and coordination for both peach and non-peach growers. New entrants benefitted especially from certain types of these arrangements and may be more likely to adopt given readily-available information and the potential of reciprocal arrangements. Those who either learned from or had reciprocal arrangements with their neighbors had markedly higher on-farm revenues from peaches.

3 Data and Neighbors Analysis

[43] As described in the previous chapter, the data were sampled randomly in and outside of peach clusters. Peaches-growing households were purposefully oversampled.

Our analysis combines information and imagery from a number of different sources to create an integrated GIS database. While satellite imagery was available in this area of Bolivia, there do not exist consistent state or municipal-level spatial data to augment the remotely-sensed data. Several sources of information are included in the GIS database. To ensure consistency of measures across source datasets and time, and due to the lack of household data, the parcel is used as the unit of analysis throughout.

Quickbird imagery was used for the remote sensing analysis. A satellite image from 2008 was used as the base. However, parts of the image were obscured because of flooding and clouds. This image was supplanted using a second image acquired in 2006.[44,45] The field boundaries were hand digitized using the 2006 image as the base map, due to flooding and clouds in the 2008 image. Classification was performed using the 2008 image as the base map, except where fields were obscured due to clouds or flooding. In those cases, land use labels were assigned based on the 2006 image. In cases where the 2008 image revealed a change in field structure, the field boundaries were updated using the 2008 image (~200 fields were adjusted). The land use labels assigned to each field consisted of agricultural classes (e.g., peaches, wheat, maize) and series of other land-use types (e.g., roadways, waterways, woody vegetation, mixed use, unclassified [due to extensive water damage in both years]).

For the 2003 data, a Quickbird image was also acquired.[46] The field boundaries previously digitized were updated to account for changing field structure. Because the image was

[44] These 2006 and 2008 Quickbird images were acquired on 4/11/2006 and 4/21/2008, respectively. The resolution is a 0.6m panchromatic band and 2.4 m multi-spectral band.

[45] Because of flooding and cloud cover, a small portion of the 2008 image was replaced using an image from 2006. However, the flooding did not take place in the upper and middle part of the watershed, where peach cultivation is most common.

[46] This image was acquired on 7/2/2003 and also has a 0.6m panchromatic band and a 2.4m multi-spectral band.

taken outside of the growing season when individual crops were not identifiable, a simplified land-use classification system was used. Manually identified agricultural classes consisted of either peach or other agriculture. The other land-use classes identifying waterways, roadways, mixed uses were maintained. A consistent basis for analysis between the two time periods required the use of a simplified land-use classification system. Both land-use maps were simplified to the following three classes: peach, other agriculture, and non-agricultural land. The parcel is the relevant unit of analysis as that is the scale at which most household agricultural decisions are made.

The GIS database also incorporates data from a large paper map that was copied and annotated during a field visit in the study area. The map covers the entire watershed but individual parcel boundaries in some cases were not discernable due to a loss in fidelity from photocopying. However, local farmers and community leaders identified which parcels were associated with canal groups in the Western part of the watershed. The image was scanned and the canals and the associated canal groupings were manually digitized creating two additional spatial layers—canals and canal groups. Roughly half of the parcels in the study area were associated with a particular canal group.

Changes in land use were determined by overlaying the 2003 and 2008 land-use classifications. Prior to the overlay procedure, all non-agricultural parcels were removed. Changes to the spatial structure of parcel boundaries over time prevented a direct assessment of land-use change for all parcels. Consequently, the GIS database was constructed using the 2008 parcel boundaries as the base topology.

Peach Neighbors

One of the main goals of this study is to identify the presence and evolution of spatially proximate neighbors within the watershed between 2003 and 2008. During this time, the large increase in peach parcels occurred unevenly throughout the region (Figure 2). In addition to the canal group that a parcel is associated with, neighbors can be a major influence on the land use decisions regarding a parcel. Possible economic explanations for this spatial correlation include the following: they can provide an observable example for others to follow, reduce information costs, facilitate pooling of inputs or labor reciprocity, and decrease the uncertainty around adoption of a new technology (Lewis et al. 2008; Conley and Udry 2010). As a final addition to the GIS database, parcel-level information obtained from household surveys was merged with the GIS data-layer information. This added information on the date of acquisition, actual peach adoption, and other household characteristics including retrospective historical data.

Identifying neighbors

Neighbors were defined using two different methodologies in this analysis—one based on adjacency and the other based on distance. First, a neighbor was any parcel which is contiguous with the "home" parcel, i.e. shared a border. Second, and our preferred definition, was any parcel whose land area was within 50 or 100 meters of the centroid of the home parcel. Any neighbor parcel growing peach was considered a "peach neighbor," which is a key explanatory variable. However, a major concern is that households may own two or more parcels which are neighbors as defined above, which would introduce endogeneity issues if used in statistical analysis. Within the survey data collected, roughly one-third of households had two or more parcels which were adjacent or within 50m of each other. Thus, if a household has already converted one parcel by 2003, the conversion of a second parcel may not be influenced by neighbors per se, but rather be an expansion of current peach land under cultivation. This would not be evidence of spatial correlation related to others' activities, and would confound the estimations.

To address this concern, we use a third definition of a neighbor, which combines the 50 and 100 meter cutoff points. This measure counts the number of 100m parcels which are *not* present in the 50m radius, and is referred to below as the "donut" definition. By hollowing out the immediate core, it should largely account for the problem of having multiple, contiguous parcels owned by the same parcel as neighbors of each other.

Figure 3 shows a histogram of peach neighbors for all parcels within the watershed for each land use pairing between 2003 and 2008 (e.g. Ag-Ag, Ag-Peach). The y-axis shows the percent of all parcels with that number of neighbors. By inspection it is clear that the peach parcels in 2003 have considerably more peach neighbors than those in other agriculture businesses. However, even among agricultural parcels, there is a different distribution for those agricultural parcels which converted to peaches by 2008. Over the watershed, the proportion of agricultural parcels with no peach neighbors declined substantially over the five years, from 42.8% of parcels in 2003 to 29.3% in 2008.

Establishing clustering

Both cross-tabular and statistical methods are used to establish spatial relationships and peach clustering within the Laka Laka watershed. As described above, each parcel was categorized by its land-use transition between 2003 and 2008. The number of parcels that transitioned to peach are highlighted in Table 2.[47] 13.7% of the parcels in the 2008 map were the result of either a

[47] In 2008, all parcels were classified either as “Ag” or “Peach.” In 2003, there were two additional categories “NA” (the parcel was not digitized in 2003) and “Multiple” (two or more parcels from 2003, of which all at least one parcel was in peaches and another in agriculture. To create measures that were consistent across the two years, all NA parcels were categorized as Ag and all “Multiple” parcels were classified as peach. This classification scheme

merging of two (or more) parcels or a splitting of two (or more) parcels in 2003.[48] In this area, the majority of non-peach parcels were growing maize and nearly all other non-peach parcels were in maize rotation. We typically refer to these parcels as “Ag” throughout.

Statistical evidence of clustering can be tested using the Moran's “I” statistic. To calculate this statistic, first we categorize all possible links between parcels and then categorize each join as either Ag-Ag (AA), Peach-Ag (PA) and so forth. Then the number of each join types are calculated where Peach-Peach is the join of interest. These are calculated within a particular area (the “join count” within a canal grouping). This is then compared with the counterfactual of having no spatial autocorrelation. The null hypothesis for the join count test was that the distribution of peach parcels followed a random pattern. The significance of the test statistic was assessed using a randomization approach. To test for significant clustering, we ran 999 simulations, where the total number of peach and agriculture parcels remained constant but the assignment of Peach or Ag to each parcel was randomly assigned (LeSage and Pace 2009). Join count statistics were calculated for the entire watershed and for each canal grouping.

The join count statistic was calculated to determine whether peach parcels clustered in space. The calculation first required the specification of neighboring parcels and queen adjacency was used in this analysis. The statistic enumerates all possible link, or “joins,” between neighboring parcels and then categorizes each join according to the possible join types

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was used because the key decision is the peach conversion. For this and all further analysis, 2008 parcels were used as the unit of analysis.

[48] Within the entire watershed, 428 parcels (10%) were the result of a switch and 204 parcels were formed from a merging of two or more parcels in 2003. As a merge may be endogenous to the land use choice or an artifact of the remote sensing algorithm, this measure is not used in most of the regression results below. Additionally, the water rights associated with these parcels cannot easily be merged.

Ag-Ag (AA), Peach-Ag (PA), Ag-Peach (AP), or Peach-Peach (PP). The join of interest for this analysis was PP. The observed number of PP joins (O_{PP}) were compared to the number expected (E_{PP}) if land-use classes were randomly assigned to each parcel according to the following test statistic:

$$Z = \frac{O_{PP} - E_{PP}}{\sigma_{PP}}$$

Table 3 shows the number of parcels and peach parcels in individual canals between 2003 and 2008. There was growth in every watershed except for the Medio Pareto canal in the north part of the study area. The "Join Count" columns show the observed number of connected parcels. The final columns show the associated p-values for this test in 2003 and 2008. As can be seen, there is evidence of peach clustering (in 2008) in every canal group except for Sahonero. Although it does not into account for other factors, this descriptive approach suggests that the clustering of peach parcels in 2008 has been affected by the 2003 spatial distribution. The establishment of clustering within the study area indicates that having neighbors in an early period may play a causal role in peaches observed today. Table 4 shows physical canal characteristics for the same canals.

Diagnostics

Before detailing the models used in the econometric analysis, we first check for the existence of unaccounted-for spatial dependence using an ordinary least squares (OLS) specification. To do so, we estimate the OLS equation, then perform spatial diagnostic tests using the error terms. These models use as a baseline the regression:

$$y = \rho W y + XB + u$$
$$u = \psi W_u u + \epsilon \quad (1)$$
$$\epsilon \sim N(0, \sigma^2 I)$$

The specification tests whether ρ and ψ are equal to zero in the null hypothesis in which case Equation (1) reduces to OLS. The top of Table 5 shows the most parsimonious specification using a restricted sample.[49] The dependent variable in this estimation is *AgToPeach*, a binary measure restricted to non-peach parcels in 2003, which is equal to one if that Ag parcel was converted to peaches between 2003 and 2008 and zero otherwise. *AgToPeach* is regressed on an X matrix that includes the parcel's distance to the canal, the distance to the dam, its area, and whether or not it is the result of a merge of two or more parcels in 2003, as identified by satellite imagery. The top rows of Table 5 present the Moran's "I" test of spatial autocorrelation (described above), showing strong evidence of its presence. The two Lagrange multiplier (LM) tests indicate whether the spatial lag or the spatial error model is best suited to account for the spatial autocorrelation. These tests use non-robust Lagrange multiplier tests developed by Anselin and Hudak (1992), and robust versions of the same tests developed later by Anselin et al. (1996). The LM tests compare the OLS model to both spatial models. In this case, since the test statistic is significant for both the spatial error and spatial lag models, the robust Lagrange multiplier test indicates that the spatial lag is most appropriate since it has the higher test statistic.

The second panel of the table runs the same regression but adds in a measure of the number of neighbors within 100m of the parcel. Because the neighbors' measure accounts for part of the spatial relationship, its inclusion provides improved fit similar to using a spatially-

[49] Starting from 4281 parcels, this discards the parcels that had already converted to peaches, leaving 3815 parcels.

explicit model. However, as in the first equation, it shows that there are gains from using the spatial lag model, which is described in more detail below.

4 Model and Hypotheses

Next, we posit a household choice model of land conversion to peaches. The conversion decision is decided within the context of a multiyear investment. Families may want to adopt a wait-and-see approach. Deciding to postpone conversion until next year maintains an option value which is potentially valuable in itself (Dixit and Pindyck 1994). Depending on their risk profile, households may choose to convert earlier to increase the net present value of their land or wait until there is more information regarding the likely outcome of a peach decision. Schatzki (2003) examines the role of these real options in the context of the irreversible decision to convert agricultural land to forest in the state of Georgia, and finds that irreversibility postpones conversion. Also in the United States, Towe et al. (2008) employ a hazard model and find that both the presence of preservation programs and an increase in the variance of returns also delays conversion from farmland to other uses.

The model described here considers the household's conversion choice as a multi-period decision where in any given period the household opts to maximize the stream of net benefits from that point forward. For this analysis, we modify a model put forth by Carrion-Flores and Irwin (2004), who estimate the determinants of residential land conversion in a suburban county in Ohio. Our model differs from theirs in that they are able to draw on a much richer dataset, and therefore have considerable information about relevant household characteristics. In the Bolivian context, all of our data is derived from satellite imagery, and does not contain information on the households which own the individual land plots.

Additionally, there may be other binding constraints such as access to the necessary capital, land and water rights, and reliable labor, which would diminish or negate potential profits from a conversion. The household's problem is:

$$Max_{t^*}\left\{NB_i = \sum_{t=0}^{t^*} A\left(\pi_i^A, t\right)\beta^t - N\left(x_i, p_{i,}, n_i, t^*\right)\delta^{t^*} + \sum_{t^*+1}^{T}\left\{\left(R(p_i, t) - C(p_i, t)\right)\delta^t\right\}\right\}$$
$$\pi_i^A = rs_i \qquad (2)$$

where $t^* \in [0, T]$ is the time period in which the household may choose to convert, π is profits on an unconverted land of size s_i, r is the rate of return to that land, and δ is a discount factor. $A(\cdot)$ is present value net returns to keeping land in traditional crops. The total cost of conversion $N(\cdot)$ is determined both by parcel **($\boldsymbol{p_i}$)** and household ($\boldsymbol{x_i}$) characteristics as well as the number of peach neighbors n_i. If $t^* > T$ then no conversion takes place and $N(\cdot)$ equals zero. Finally $R(\cdot)$ and $C(\cdot)$ are respectively the total revenues and costs associated with conversion to cash crops.

Therefore, the likelihood that a household will convert their land is:

$$Prob[Y(i, t^*) = R(\boldsymbol{x_i}, t^*) - C(\boldsymbol{x_i}, t^*) - rs_i - N(\boldsymbol{x_i}, \boldsymbol{p_i}, n_i, t^*) \geq 0] \qquad (3)$$

That is, the household will convert in a given period, if the net revenue from peaches is greater than their yield from the maize rotation. This yields the following equation to be estimated:

$$Prob[Y(i, t^*) = \boldsymbol{\phi}(i, t^*)'\boldsymbol{\beta} + \epsilon(i, t^*) \geq 0] \qquad (4)$$

where $\boldsymbol{\phi}(i, t^*) = (\boldsymbol{x_i}, \boldsymbol{p_i}, n_i, r, t^*)$ and $\epsilon \sim (0, \sigma_i^2)$. Hypotheses are based on the βs which correspond to individual components of $\boldsymbol{\phi}(i, t^*)$. Because we only have data for $\boldsymbol{p_i}$ and n_i, interpreting the coefficients on these variables assumes that the r and $\boldsymbol{x_i}$ are not changing throughout the watershed. It is perhaps reasonable to assert that the interest rate is similar for most households, but the individual household characteristics certainly vary considerably, as shown in the last chapter. If the household characteristics vary, the equations may suffer from omitted variable bias; however our assumption is that they do not vary *systematically* throughout the watershed. Analysis of available household data shows that variables such as the number of family members and migrants (which influence household portfolio decisions) are not significantly correlated with their location in the watershed. If true, this assumption should attenuate the effects of omitted variable bias on the spatial outcome estimates.[50]

Hypotheses

Parcel characteristics and the number of neighbors should affect the likelihood of converting a given parcel to peaches in the following ways:

1. $n_i > 0$. Households whose neighbors have nearby peach parcels will more easily learn from and establish reciprocal relationships with the owners of these parcels. Therefore, the number of peach neighbors in 2003, or the nearby extent of peaches, should have a positive effect on the likelihood of a given parcel converting between 2003 and 2008.

    1a. $n_i^2 < 0$. If it is the case the number or area of peach parcels drawing from a particular irrigation canal will eventually diminish available water, then past a

[50] One exception is that the parcels closer to the dam are owned by more educated heads of household. Though not a focus of this paper, more educated household heads are slightly more likely to own peach parcels, however, they do not appear to have higher revenues in these parcels, relative to less-educated household heads.

certain point the number of peach parcels could decrease the likelihood of adoption by a congestion effect. Also, there are diminishing returns to neighbors for the purposes of inputs coordination and reciprocity.

2. *DistCanal* < 0. Peaches require regular water dispersals to grow, and this should be more easily accessible near the canal.

3. *DistDam* < 0. According to the canal association rules, a parcel close to the dam gets the first right of access to each dispersal. However, canal association leaders maintained that all parcels received the same amount of water. In addition, richer household may own parcels closer to the top of the watershed, and may be more likely to grow peaches. We conjecture that distance is likely to matter despite the 'equity' rules identified by canal leaders.

4. *Area* > 0. If there are economies of scale in the conversion process or in managing a peach farm in this region, and they are more substantive than in maize cropping, then bigger plots would be more likely to convert to peaches.

5. *Canal Groups* have a mixed effect. To account for canal-specific factors, such as water availability or quality, we include fixed-effects for each identified canal. The sign on each individual canal will vary with how conducive the water allocation is to growing peaches.

5 Econometric Models

In order to test these hypotheses we estimate three types of econometric models. First, we use limited dependent variable models to estimate the land use change decisions of residents of the Valle Alto. Next, we use a spatially explicit specification—the spatial lag model—which incorporates a spatial weight matrix. Lastly we present results from the subset of parcels with household information. In each of these, the main variable of interest is $PeachNeighbors_{03}$, which is the "donut" estimator described in section 3. As control variables, dummy variables for each $CanalGroup$ are included. Our challenge in this estimation is to properly identify the effects of neighbors on a particular parcel-holder's adoption behavior. There are many conduits through which a change in behavior can happen. Neighbors may induce an endogenous social effect, whereby the parcel owner changes their behavior. However, both parcels may be responding to the same outside exogenous forces or may be identical in their characteristics, and therefore make similar decisions (Manski 1993). This paper does not attempt to distinguish these effects; rather, it establishes that neighboring parcels do, indeed, shape a parcel owner's actions.

<u>Multinomial Logit Model</u>

In the most inclusive specification, we estimate the effects of parcel characteristics on the four land use categories. The multinomial model is appropriate when the regressors do not change over the alternative specifications. In this case, parcel-level explanatory which are available do not change according to land use type, leading to the following model:

$$\left\{ LandUseCat_p = \begin{matrix} Ag. \rightarrow Ag. \\ Ag. \rightarrow \ Peach \\ Peach \rightarrow Peach \\ Peach \rightarrow Ag \end{matrix} \right\} = \alpha + \beta_1 PeachNeighbors_{p,03} + \beta_2 Merge_{p,03} + \beta_3 DistCanal_p + \beta_4 DistDam_p + \beta_5 Area_p + \beta_6 CanalGroup + \epsilon_p. \tag{5}$$

where $LandUseCat_p$ is a categorical variable for each Ag-Peach combination. Definitions for each variable are listed in Table 6.

<u>Probit Model</u>

A simpler version of the above restricts the analysis to only those parcels in agriculture in 2004 that is the parcels which have the potential to convert to peaches. This decreases the sample by 466 parcels or about 11% of total observations. The model used is:

$$\left\{Conversion_p = \begin{matrix} Ag. \rightarrow Ag & = 0 \\ Ag. \rightarrow Peach & = 1 \end{matrix}\right\} = \alpha + \beta_1 PeachNeighbors_{p,03} + \beta_2 Merge_p + \beta_3 DistCanal_p + \beta_4 DistDam_p + \beta_5 Area_p + \beta_6 CanalGroup + \epsilon. \quad (6)$$

Spatial Lag Model

One drawback of the above models is that they may not sufficiently account for spatial autocorrelation. Although the analyses in section 3 show that the *PeachNeighbors* variable may capture some of the spatial dependence in the land-use variable. There are several reasons why this spatial dependency may persist. First, the boundaries that were used to collect the data and the boundaries used in the underlying spatial process may generate an error term that is spatially autocorrelated. Second, the parcel-level data used in the analysis may have omitted necessary characteristics, such as soil quality. To correct for spatial autocorrelation, a spatial weight matrix is included as part of the following "spatial lag" equation.[51]

$$\begin{gathered} y = \rho W y + X\beta + \epsilon \\ y = (I - \rho W)^{-1} X\beta + (I - \rho W)^{-1}\epsilon \\ \epsilon \sim N(0, \sigma^2 I_n) \end{gathered} \quad (7)$$

[51] The spatial weight matrix is constructed by first creating a symmetric matrix where each row (and column) represents an individual parcel and the cell in *row we* and *column j* contains the distance between parcel we and parcel j (the diagonals are zero). Typically a cutoff point is used to delimit a maximum distance where one parcel may affect another. A cutoff 150m was used, and pairs of parcels with distances less than that contain a 1 and the rest are zeroes.

If $\rho = 0$, then adding the weight matrix doesn't add any additional explanatory power and OLS is sufficient. [52] Using that model, we estimate the following equation:

$$PeachConversion_p = \alpha + \beta_1 PeachNeighbors_{p,03} + \beta_2 Merge_p + \beta_3 DistCanal_p + \beta_4 DistDam_p + \beta_5 Area_p + \epsilon. \quad (8)$$

6 Results

The econometric results show broad consistency of the role of neighbors in peach adoption. In this section, we first present results from standard limited dependent variable regressions. These models do not use the spatial weight matrix employed below but rather use several of the neighbor variables to capture spatial dependency within the watershed. As described above, there are four possible land use categories combining peaches and agriculture for any given parcel (Ag-Ag, Ag-Peach, Peach-Ag, Peach-Peach).[53] This categorical variable is *LandUseCat.*

Table 7 shows the results from a multinomial logit regression using the Ag-Ag category as the baseline. Two regressions are shown, the first includes all three categorical variables in addition to Ag-Ag. The second omits the Peach-Ag category. Each regresses *LandUseCat* on the size and locational characteristics of the parcel and its canal association. The main independent variable of interest, the "donut" neighbors measure, is positive and significant at the 1% level for Ag-Peach in both regressions, indicating that having more peach neighbors within this band increased the propensity of a parcel to be converted. However, relative to the baseline case (Ag-Ag), having peach neighbors were not a causal factor for those parcels abandoning peach orchards (Peach-Ag). This result is robust to using the alternate peach neighbor variables.

[52] Revisions of this paper will use the spatial probit model, as explained at the end of section 5.

[53] Peach-Ag parcels constitute 1.5% of the sample and are excluded in most of the regressions below.

The results also confirm that proximity to the dam located above the watershed increased the likelihood that an individual Ag parcel converted to peaches. Relative to the baseline, Ag-Peach parcels were likely to be a greater distance from the dam, suggesting that being closer to the dam also affected adoption timing. Peaches were more evenly spaced along the canal prior to 2003 than during the ensuing 5 years. In fact, the average Ag-Peach parcel was 2.9km from the dam, while the corresponding Peach-Peach parcel was 3.6km away, or 27% farther. Another robust result is that, having a larger area also increased the likelihood of peach growing, although in the entire watershed Peach-Peach parcels were larger than any other category. Although the mechanism is not clear, it may be that, as hypothesized, wealthier families have both larger parcels and are more likely to grow peaches, or that there are efficiencies of scale in peach production. The land parcels most likely to convert are those in the Cardozo, Gringos and Sahonero canals. The former two comprise the West side of the watershed, in between the central and the Western-most edge of the growing area.

In table 8, we omit both the Peach-Peach and Peach-Ag categories and use the resultant binary variable (whether an agricultural parcel converts) as the dependent variable. This specification eliminates several hundred observations, but it is a clean measure of the decision to convert an agricultural parcel to peaches across the two time periods. The first two columns model the probability of conversion using the number of nearby neighbors (in the donut) as key explanatory variables, using the area and the distance to the dam and nearest canal as covariates. Column 1 includes canal fixed effects while column 2 does not. The last two columns show the same analysis, using the peach area inside the donut and its square rather than the number of peach neighbors. We find a significant, positive, and diminishing effect of neighbors and area in each case, except column 3 lacks significance. Similar to table 6, proximity to the dam was also both positive and significant.

Marginal Effects and Turning Point

Table 8A shows the marginal effects of each of these variables. Having an additional neighbor either within the band between 50m and 100m increases likelihood of conversion by 3% to 4%. On average, parcels had 1.4 peach neighbors within a 100m radius. The coefficients of the *PeachNeighbor* and *PeachNeighbor^2* variables in the first column indicate a concave function with a turning point at 4.28 neighbors. This implies that of the 3815 agricultural parcels, 196 have neighbors which have a diminishing marginal effect on the propensity to convert.

Figure 3A illustrates the marginal effect of an additional peach neighbor on conversion using the parameter values from column 1. The average marginal effect in this specification is 3.2%, but rises to nearly 5% at its maximum. The observation that this effect has concavity, and that the concavity occurs within the sample range of possible conversion, shows that the 5% of parcels with the most neighbors may be limited by congestion. In addition, we run a semi-parametric analysis using the following equation:

$$LandUse = DistCanal_p + DistDam_p + Area_p + Canal_c + z(neighbors)$$

where no functional form is assumed for $z(\cdot)$. As can be seen in figure 4B, there is a similar concave relationship between neighbors and the likelihood to adopt, with the turning point also occurring around 4 neighbors.

In table 9, the results of the spatial lag model (equation 7) are displayed. Under this specification, the addition of a peach neighbor increases the likelihood of conversion by 1.9% (or

4.5% if the quadratic term is included). The estimation of ρ, which is significant at the 10% level indicates that inclusion of the spatial weight matrix improved the fit of the model. Among other independent variables, the distance to the dam is the only factor which maintains statistical significance in this specification.

In this model, we use both a spatial lag and "neighbors" variable. The spatial lag captures the "lagged" effect of a neighbor's conversion decision. That is, the extent to which conversion decisions are related to the same decisions of those parcels within close proximity to the observed parcel. The "neighbors" variable, rather, captures the effect of *past* conversion decisions on a given parcels likelihood to convert in the present. The existence of a spatial lag is determined by the existence of ρ, which shows the extent to which the vector of observation y is explained by the average of neighboring observations' values (irrespective of prior choices). A significant coefficient on n_i indicates that the prior choices of non-adjacent neighbors matters as well.

The previous chapter modeled the determinants of peach conversion using household-level survey data. Due to the cost of data collection, the sample is much smaller and accurate geospatial information was gathered for only 123 parcels. Of these, 93 parcels were in maize rotation in 2003. For these parcels, we possess household information including demographic information, land and water holdings, investments and past migration histories. As a final exercise, we run the probit and multinomial logit regressions shown in equations 4 and 5. One question this data can address for the limited sample is whether the coefficients identified above remain significant with inclusion of household information. In table 9, the results are displayed. Column 1 shows the probit results. The multinomial logit land use categories Ag-Peach and

Peach-Peach are shown in columns 2 and 3, using the Ag-Ag category as the baseline. In each of these, the data indicate that the number of peach neighbors remains a causal factor in peach adoption.[54]

Conclusion

This paper has demonstrated that within the Valle Alto watershed there is a clear, causal relationship between baseline land use choices of adjoining parcels and the likelihood of a parcel in maize rotation converting to peaches. This correspondence is present across a variety of models, specifications, and with the inclusion of a number of covariates. We have also shown that the inclusion of spatial weight matrix improves the fit of the model, but that the *PeachNeighbors* variable actually captures much of the spatial autocorrelation present in the data. One potential pitfall is that the neighbor variable may include one or more parcels owned by the same household as the observed parcel. To address this, we use a "donut" definition of neighbors which decreases the likelihood of same-household parcels being included. Most previous studies use either exogenous neighborhood definitions, self-reporting from households or a K nearest neighbor (KNN) approach (Irwin and Geogheganb 2001). Many of these also use a household, rather than a parcel, as the unit of analysis. Therefore, they do not address the potential endogeneity of multiple parcels being owned by a single household. The approach used here also has applicability in areas where land ownership records are not available. Based on our estimation, it appears that past 4 or 5 neighbors, the positive effect of neighbors adoption on the conversion decision starts to diminish and turns negative after 8 neighbors. Further work is

[54] Please note that this is a preliminary result. There exist many questions on causality and endoegenity that are not addressed here. For instance, the households which already owned a peach parcel prior to 2003 are not accounted for.

needed to investigate why this is so. Better data on the consistent availability of irrigation water could test whether this is due to a finite local water supply and hence congestion effects.

Lastly, we match the satellite imagery with household survey data in order to test whether the results hold in the presence of household-level data. While the main neighbors finding is robust to their inclusion, future versions of this paper will incorporate household-level data not included here with more careful attention to endogeneity concerns than offered in this initial approach. For instance, this analysis does not take into account whether a given parcel was the first household parcel converted to peaches (in which case, liquidity constraints had been binding) or a second or third parcel (in which case the timing of conversion might be more of a tactical household development decision).

Overall, the results of this chapter suggest that when introducing a desirable, expensive technology, spatially diverse targeting could increase the spread of the technology throughout a given area, especially if large clusters are less advantageous than smaller ones. In an agricultural context, embedded economic incentives may be sufficient to induce technology adoption in certain parts of a watershed (e.g., closer to the dam), but not in others. Increasing the equitability of access to irrigation or other spatially uneven binding constraints could further facilitate rapid diffusion.

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Table 1: Learning and Reciprocity

	Early Adopters (<2003)			Late Adopters (>=2003)			
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	
Learning: Discuss Problems							
Reciprocation: Preparation	23	0.39	0.5	22	0.18	0.39	**
Reciprocation: Seeds	23	0.26	0.45	22	0.45	0.51	**
Reciprocation: Irrigation	23	0.39	0.5	22	0.27	0.46	
Reciprocation: Frosts	23	0.26	0.45	22	0.45	0.51	*
Reciprocation: Sale	23	0.17	0.39	22	0.41	0.5	**
Reciprocation: Any	23	0.74	0.45	22	0.77	0.43	

Table 2: Land use figures

Land Use 2003–2008	N	Area	Distance to Canal	Distance to Dam
Ag—Ag	3526	2385	254	3457
Ag—Peach	280	2617	129	2900
Peach—Peach	400	2946	123	3564
Peach—Ag	65	2446	161	3786
Total	4281	2454	232	3435

Table 3: Clustering by Canal

Canal Group	Parcels	Peach Parcels 2003	Peach Parcels 2008	Joint Count 2003	Joint Count 2008	P-values (2003)	P-values (2008)
Cape Llania	313	14	22	4	9	0.022	0.001
Cardozo	292	60	99	35	78	0.001	0.001
Gringos	172	22	37	8	33	0.035	0.001
Ladera	169	3	27	2	15	0.001	0.001
Mamanaca	294	8	12	2	4	0.025	0.01
Medio Parieto	138	2	2	1	1	0.016	0.0105
Prado	532	76	111	46	67	0.001	0.001
Sahonero	84	3	11	1	3	0.067	0.2775
Total	2354	240	404	135	270	0.001	0.001

Table 4: Physical Characteristics of the Parcel

	N	Distance to Canal (m)	Distance to Dam (m)	Area (m2)
Cape Llania	323	130	3163	2518
Cardozo	293	67	1867	2865
Gringo A	59	44	2687	2527
Gringo B	97	42	3170	2521
Gringo C	187	67	4194	2197
Gringos	171	56	2362	2621
Ladera	182	118	1296	3056
Mamanaca	313	159	3107	2754
Medio Parieto	131	61	3103	2330
Prado	551	96	3000	2692
Sahonero	86	71	3390	2193
Total	2393	96	2834	2633

Table 5: Diagnostic tests for spatial dependence in OLS regression

AgToPeach = DistCanal + DistDam + Area + Merge

	Statistic	p-value
Moran's I	2.008	0.045
Spatial Error		
Lagrange multiplier	3.801	0.051
Robust Lagrange multiplier	2.950	0.086
Spatial Lag		
Lagrange multiplier	4.771	0.029
Robust Lagrange multiplier	3.921	0.048

AgToPeach = Neighbors100m + DistCanal + DistDam + Area + Merge

	Statistic	p-value
Moran's we	2.043	0.041
Spatial Error		
Lagrange multiplier	3.938	0.047
Robust Lagrange multiplier	2.641	0.104
Spatial Lag		
Lagrange multiplier	4.867	0.027
Robust Lagrange multiplier	3.571	0.059

**Using a row-standardized weight matrix

Table 6: Variable Definitions

LandUseCat is a categorical variable which takes one of four values based on land use in 2003 and 2008. The values are: Ag-Ag=0, Ag-Peach=1, Peach-Peach=2, Peach-Ag=4.

AgToPeach is a binary variable for non-peach parcels in 2003. The variable is equal to 1 if the parcel converted to peaches by 2008.

PeachNeighbors_50m is a count variable equal to the number of peach parcels within 50m of the centroid of a given parcel.

PeachNeighbors_100m is a count variable equal to the number of peach parcels within 100m of the centroid of a given parcel.

PeachNeighbors50_100 is a count variable equal to the number of peach parcels between 50m and 100m of the parcel. It is calculated by subtracting *PeachNeighbors_50m* from *PeachNeighbors_100m.*

Canal is the canal associated with a particular parcel. There are 11 identified canals in the data, which comprise roughly half of the total parcels.

Split is a binary variable indicating whether the 2008 parcel was the result of the splitting of a 2003 parcel. The variable is equal to 1 if the parcel boundaries resulted from a split.

Merge is a binary variable of the opposite—i.e. whether the 2008 parcel was the resulting of merging together to 2003 parcels; The variable is equal to 1 if boundaries resulted from a merge of two or more parcels.

DistCanal is the straight-line distance to the nearest canal, in meters.

DistDam is the straight-line distance to the dam, in meters.

Table 7: Multinomial Logit

	4 Categories			3 Categories	
	(1)	(2)	(3)	(4)	(5)
VARIABLES	Ag-Peach	Peach-Peach	Peach-Ag	Ag-Peach	Peach-Peach
Peach Neighbors 50m to 100m (03)	0.142***	0.320***	0.120	0.142***	0.319***
	(0.0474)	(0.0446)	(0.104)	(0.0474)	(0.0446)
Merged (in 2008)	-0.0239	0.233	1.741***	-0.0474	0.179
	(0.371)	(0.307)	(0.584)	(0.371)	(0.308)
Distance to Canal (m)	-0.00152	-0.00277*	0.00108	-0.00147	-0.00265*
	(0.00125)	(0.00144)	(0.00216)	(0.00125)	(0.00143)
Distance to Dam (m)	-0.000557***	0.000154	0.000336	-0.000559***	0.000149
	(0.000119)	(0.000118)	(0.000329)	(0.000119)	(0.000118)
Land Area (sq. meters)	7.06e-05*	0.000198***	-1.86e-05	7.20e-05*	0.000199***
	(3.87e-05)	(3.65e-05)	(0.000134)	(3.89e-05)	(3.68e-05)
CANALS					
Cardozo	0.932**	1.606***	-14.59***	0.933**	1.605***
	(0.404)	(0.366)	(0.656)	(0.404)	(0.368)
Gringo A	-0.995	-0.222	-15.05***	-0.990	-0.215
	(1.069)	(0.642)	(0.575)	(1.069)	(0.643)
Gringo B	0.716	-0.186	0.420	0.735	-0.160
	(0.547)	(0.617)	(0.900)	(0.549)	(0.620)
Gringo C	2.054***	1.015**	0.155	2.060***	1.025**
	(0.450)	(0.410)	(0.759)	(0.450)	(0.412)
Gringos	1.236***	1.068***	-14.58***	1.240***	1.071***
	(0.398)	(0.398)	(0.618)	(0.398)	(0.400)
Ladera	0.544	-0.115	-14.43***	0.542	-0.127
	(0.425)	(0.567)	(0.695)	(0.425)	(0.566)
Mamanaca	-0.377	-0.622	-0.0991	-0.379	-0.632
	(0.517)	(0.500)	(0.658)	(0.517)	(0.500)
Medío Pareto	-14.66***	-0.901	-15.12***	-14.01***	-0.901
	(0.356)	(0.784)	(0.531)	(0.356)	(0.784)
Prado	0.892**	0.814**	0.676	0.895**	0.812**
	(0.363)	(0.342)	(0.534)	(0.363)	(0.343)
Sahonero	1.309***	-0.207	-15.08***	1.315***	-0.201
	(0.505)	(0.618)	(0.537)	(0.506)	(0.619)
Constant	-1.854***	-4.191***	-5.550***	-1.857***	-4.186***
	(0.485)	(0.503)	(1.215)	(0.486)	(0.507)
Observations	2,393	2,393	2,393	2,364	2,364

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
NOTE: Base category is Ag-Ag.

Table 8: Probit Results

VARIABLES	(1) Number of Neighbors	(2) Number of Neighbors	(3) Area of Neighbors	(4) Area of Neighbors
Peach neighbors 50m to 100m (2003)	0.0323***	0.0420***		
	(0.0106)	(0.00685)		
Peach neighbors 50m to 100m^2 (2003)	-0.00376*	-0.00487***		
	(0.00206)	(0.00128)		
Peach Area 50m to 100m (1000 m^2)			0.0133	0.0282***
			(0.0114)	(0.00717)
Peach neighbors 50m to 100m^2 (1000 m^2)			0.000426	-0.00163
			(0.00225)	(0.00137)
Distance to Canal (m)	-0.1000	-0.0284	-0.123	-0.0377*
	(0.0900)	(0.0222)	(0.0913)	(0.0223)
Distance to Dam (m)	-0.0438***	-0.0287***	-0.0431***	-0.0263***
	(0.00950)	(0.00444)	(0.00913)	(0.00429)
Land Area (sq. meters)	4.496	2.546	4.604	2.830
	(3.063)	(2.240)	(3.016)	(2.204)
Canal Fixed Effects	Yes	No	Yes	No
Observations	2,019	3,816	2,019	3,816

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8A: Marginal Effects of Probit Model

` VARIABLES	(1) Number of Neighbors	(2) Number of Neighbors	(3) Area of Neighbors	(4) Area of Neighbors
Peach neighbors 50m to 100m (2003)	0.0323***	0.0420***		
	(0.0106)	(0.00685)		
Peach neighbors 50m to 100m^2 (2003)	-0.00376*	-0.00487***		
	(0.00206)	(0.00128)		
Peach Area 50m to 100m (1000 m^2)			0.0133	0.0282***
			(0.0114)	(0.00717)
Peach neighbors 50m to 100m^2 (1000 m^2)			0.000426	-0.00163
			(0.00225)	(0.00137)
Distance to Canal (km)	-0.1000	-0.0284	-0.123	-0.0377*
	(0.0900)	(0.0222)	(0.0913)	(0.0223)
Distance to Dam (km)	-0.0438***	-0.0287***	-0.0431***	-0.0263***
	(0.00950)	(0.00444)	(0.00913)	(0.00429)
Land Area (sq. meters)	4.496	2.546	4.604	2.830
	(3.063)	(2.240)	(3.016)	(2.204)
Canal Fixed Effects	Yes	No	Yes	No
Observations	2,019	3,816	2,019	3,816

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Spatial Lag Model

VARIABLES	(1) Converts from Agriculture (2003) to Peach (2008)
Peach Neighbors between 50m and 100m	0.0189***
	(0.00280)
Distance to Canal (m)	8.33e-06
	(1.63e-05)
Distance to Dam (m)	-3.50e-05***
	(4.78e-06)
Land Area (sq. meters)	3.23e-06
	(2.44e-06)
Rho	0.0779*
	(0.0438)
Constant	0.157***
	(0.0167)
Observations	3,815

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Probit and Multinomial Logit regressions including household variables

	Probit	Multinomial logit	
VARIABLES	Ag to Peach	Ag-Peach	Peach-Peach
PeachNeigh03_50m_100m	0.198**	0.266*	0.387***
	(0.0895)	(0.161)	(0.135)
Distance to Canal (m)	-0.000956	-0.00150	-0.0147**
	(0.00260)	(0.00455)	(0.00739)
Distance to Dam (m)	-1.86e-05	7.94e-05	0.000899**
	(0.000294)	(0.000482)	(0.000431)
Land Area (sq. meters)	0.000217**	0.000238**	0.000476***
	(9.00e-05)	(0.000112)	(0.000135)
# of migrants in Arg. in 2000	-0.258	-0.349	-0.976**
	(0.207)	(0.333)	(0.454)
# of migrants in U.S. in 2000	0.0715	0.136	0.155
	(0.143)	(0.215)	(0.248)
Water rights: Gringo (bin)	0.248	0.0237	-0.332
	(0.408)	(0.694)	(0.680)
Water rights: Prado (bin)	1.200*	1.555	2.415**
	(0.618)	(1.144)	(0.978)
Ciudad: Arbieto (bin)	1.122**	1.707**	1.921***
	(0.483)	(0.689)	(0.713)
# of parcels owned in 2000	-0.142	-0.115	-0.0655
	(0.149)	(0.229)	(0.271)
Education of HH Head	0.0466	0.0835	0.138**
	(0.0344)	(0.0576)	(0.0595)
Constant	-2.581**	-4.004**	-6.586***
	(1.122)	(1.693)	(1.824)
Observations	93	123	123

Figure 1: Valle Alto Watershed

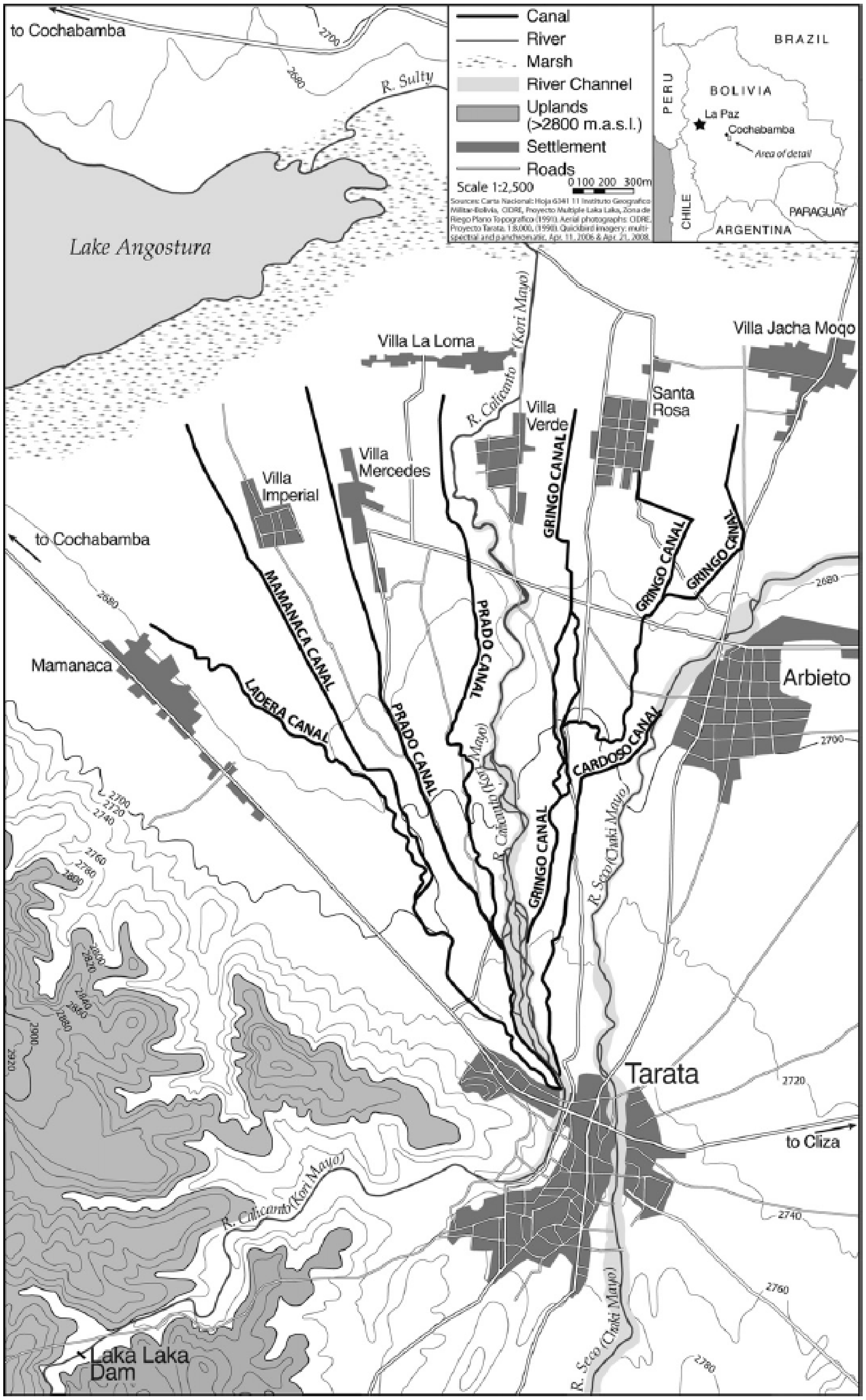


Figure 2: Land Use Change between 2003 and 2008

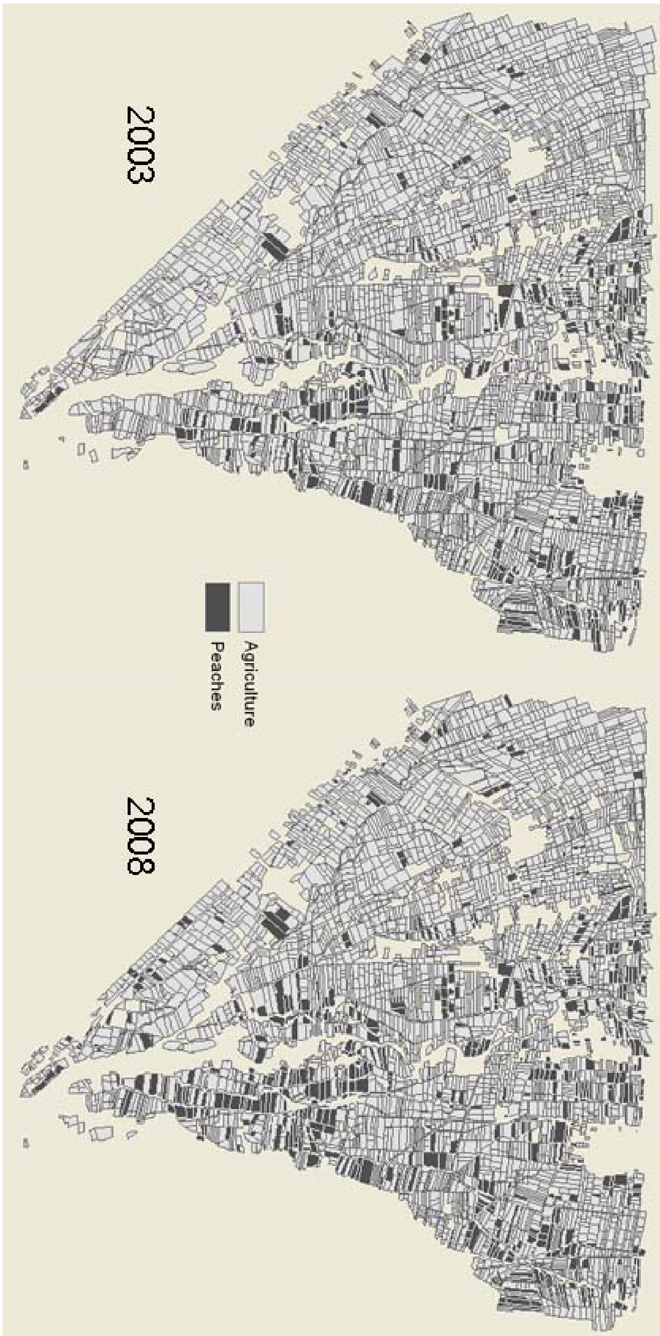


Figure 3: Peach Neighbors in 2003

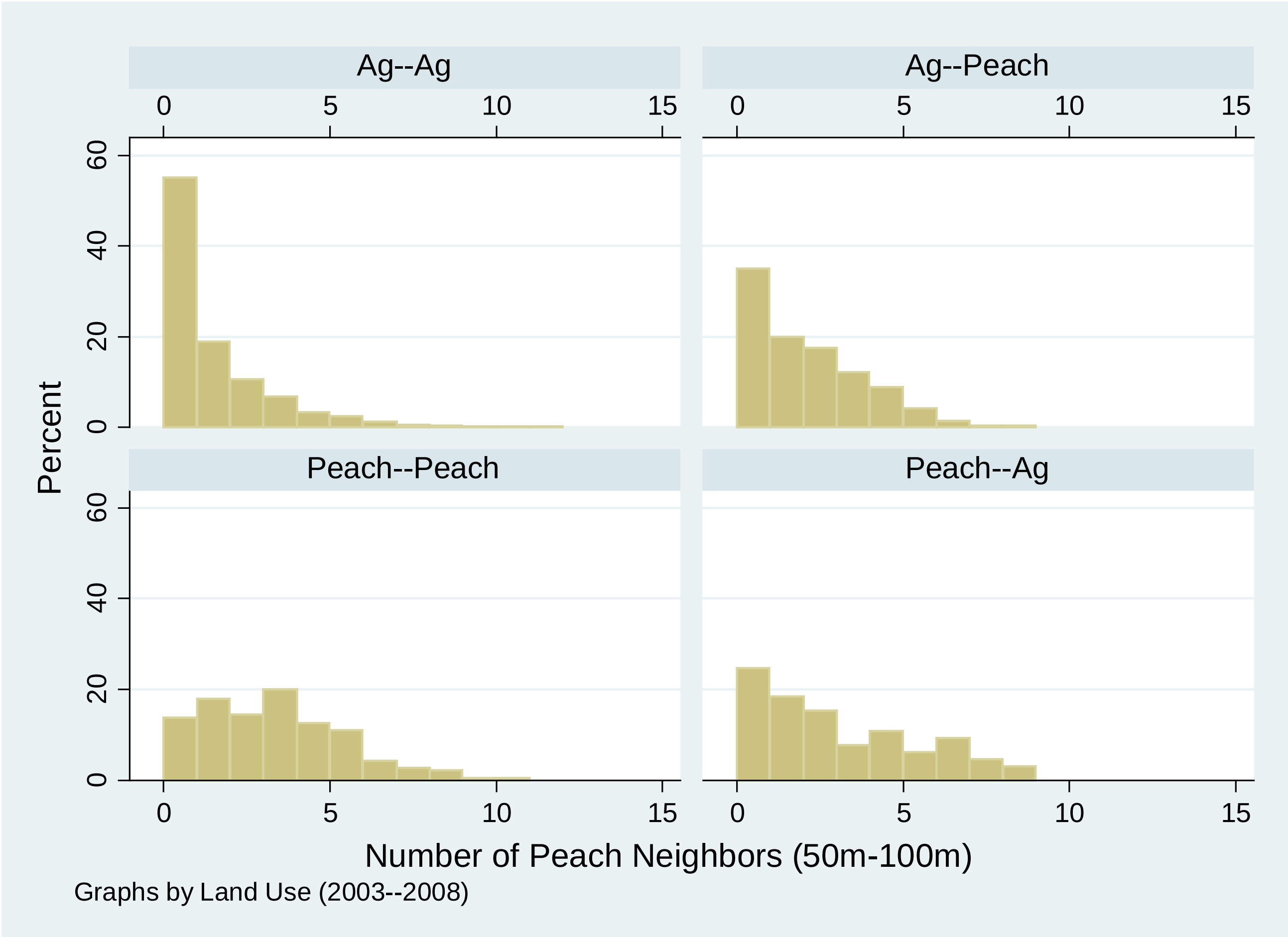
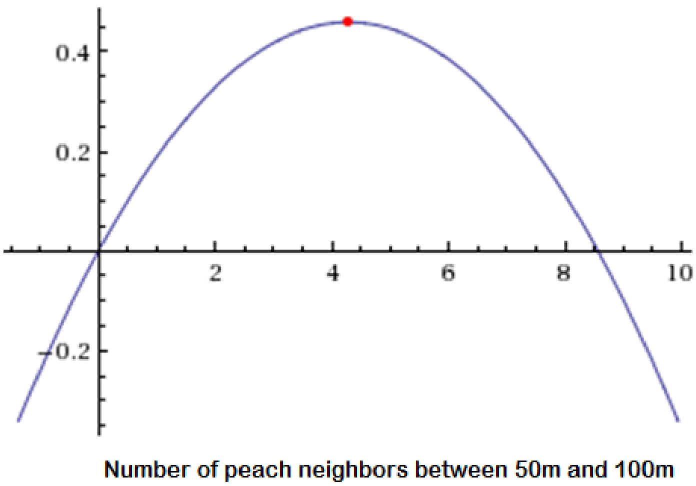
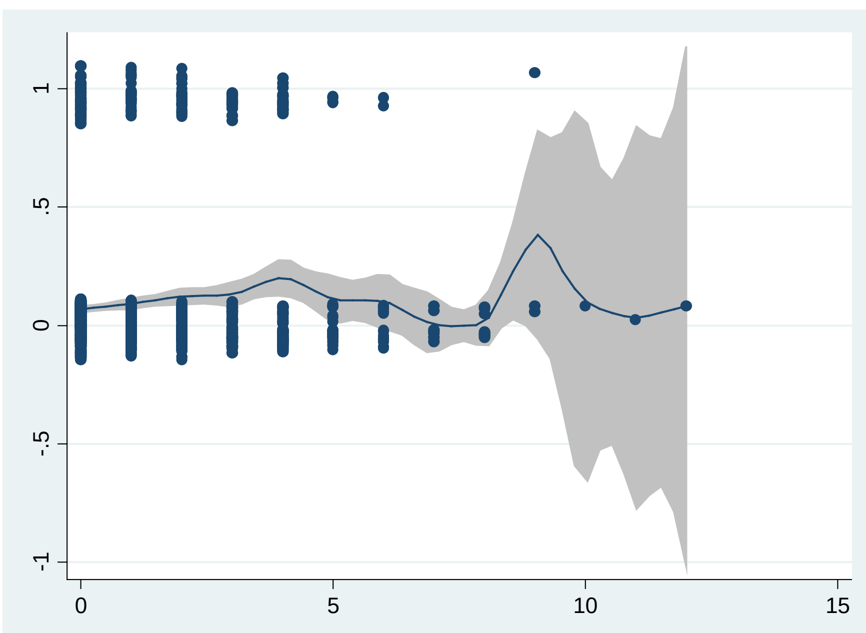


Figure 4: Turning point of peach neighbors

Panel A



Panel B



Making Time for Science

Bradford L. Barham, Jeremy D. Foltz, Daniel L. Prager

1 Introduction

Understanding the inputs and constraints that allow university researchers to make the most of their time and capacities is a critical question for those seeking to enhance academic productivity and the prospects for scientific discovery and technological change (Bellas and Toutkushian, 1999; Rouser and Tabata, 2010). Over the past four decades, the expectations of and demands on university faculty at top tier research universities around the world have evolved with the opening of new frontiers of science, the rapid diffusion and advancement of information technologies, and institutional changes occurring in relation to public funding for universities, research commercialization, contracting, compliance, and grant applications, approval processes, and administration (Stephan, 2012). This article investigates the evolution of faculty research time since the late 1970s by examining overall changes in time allocation along with trends in other key inputs to research and research production.

The empirical analysis exploits data collected in four random-sample surveys of agricultural and life scientists at 52 U.S. Land Grant universities in the years spanning 1979-2005. Among a critical subset of U.S. research faculty these data allow for a consistent, comparative assessment of the factors influencing the time that faculty at leading public universities have for doing science and the implications of those findings for overall research performance. In academic circles, time is often seen as a major ‘currency of the realm’, along with research support, because time provides scientists the opportunity to be creative and advance their inquiries and careers. Despite the recent explosion of academic investigation of university research performance (Levin and Stephan, 1991; Lee and Bozeman, 2005), little information exists on the dynamic evolution of time that faculty actually have for doing science. This article attempts to fill that gap and sharpen scholarly and policy discussion on an issue of critical importance to faculty and the vitality of scientific inquiry.

Our methods for analyzing the repeated cross-sectional data are straightforward and extend the analysis that Harter, Becker, and Watts (2011) do for economists surveyed in 1995, 2000, and 2005. Cross-tabulations and pooled, university-level fixed-effect econometric models are deployed to identify trends and potential drivers in time faculty have for science. The time trend analysis includes attention to incentives in the form of tenure norms and salary increases. The next two sections set the context for the empirical analysis by providing a selective review of recent academic work on university research performance centered around the 'time for science' issue and introducing the reader to the four waves of survey data. The empirical analysis starts with basic time trend comparisons and then moves through a set of descriptive statistics and econometric models that carefully dissect the faculty research time trends. Further examination of the evolution of other key research inputs and outputs provides a fuller portrayal of what time for science changes might mean for faculty research performance.

The primary empirical finding is a significant and broadly experienced secular decline in research time, on the order of 10 hours per week over the 30 year span covered by the data. An even broader decline is evident in the last two waves of the survey when we introduce the concept of active research time to distinguish pre and post-grant research administration efforts from the actual pursuit of research. Perhaps not surprisingly, the other major significant trend is a commensurate increase in faculty time spent on the combination of general administrative activities and specific pre- and post-grant research administration responsibilities. In comparison to these significant changes in research and administrative time allocations, time spent on teaching has remained constant, and time spent on extension has increased. Very little variation in the declining time for science result is associated with age, rank, gender, or other faculty characteristics, other than some differences across fields. On the incentive side, we find evidence that faculty with administrative appointments are being rewarded at levels greater than or equal to those with high-level research performance.

Comparisons of time trends for research with the evolution of other key inputs reveal that time is the only input whose levels have fallen significantly over the past 25 years. Other key research inputs show relatively minor variations year-to-year and no significant changes over the time span. Likewise, research output, as measured by refereed articles and a broader measure that includes other publications (e.g., books), has stayed relatively steady across the same time span. Using non-parametric methods we explore the relationship between faculty time and research output, and find evidence that the decline in time for science is associated with significant foregone research productivity. In the discussion section, we synthesize the empirical findings and reflect on their implications for faculty and policymakers concerned with advancing scientific inquiry.

2 Selective Literature Review

A long-standing literature has uncovered a number of trends in the university academic research enterprise over the last 50 years that hold implications for scientific inquiry (see de Solla Price (1965) and Stephan (2012) for summaries). Broadly that literature has identified the following important trends: an increase in the “burden of knowledge” which makes innovative research more difficult (e.g., Jones, 2009), an increase in academic patenting since the Bayh-Dole act of 1980 (e.g., Henderson, Jaffe & Trachtenberg, 1998; Azoulay, Ding and Stuart, 2009), an increase in scientific collaboration and co-authorship (e.g., Jones, Wuchty and Uzzi, 2008; Lee and Bozeman, 2005), an increase in the use and length of post-doctoral positions (Stephan and Ma, 2005), an increase in competitive grant applications (Auranen and Nieminen, 2010), and an increase in the use of "soft money" for funding research positions (Stephan, 2012). As far as we are aware, to date none of these studies have incorporated explicit measures of a key input in research, faculty time.

Time for research is of course widely recognized as a crucial determinant of academic research production, the quality of research, and scientist job satisfaction. A growing literature, especially concerned with the economics of higher-education and science, has begun to analyze time allocation of university faculty, mostly in regards to tradeoffs between teaching and research outcomes. Harter, Becker, and Watts (2011) and Bentley and Kyvik (2013) are recent examples, and they also include literature reviews that highlight several themes: the importance of university-level emphasis and disciplinary norms on incentives for tenure and promotion; individual factors and preferences that may shape choices of faculty in allocating time between research and teaching; the implications of time allocation on research productivity; and, the potential for life-cycle changes in both time allocation and productivity outcomes associated with incentives, preferences, and family conditions for faculty. From this list, it is clear that the factors shaping faculty time allocation are potentially complex, because any explanation could include a variety of extrinsic and intrinsic factors that can vary over time, institutions, individuals, and dynamically over their life-cycle.

Interestingly, so far none of this research on faculty time explicitly examines the role of administrative responsibilities, either in the lifecycle of faculty or in a dynamic manner as universities evolve and potentially change their allocation of tasks assigned to faculty. Moreover, in the empirical literature, it is rare to find repeated cross-sectional data that allow for a dynamic picture of the evolution of time allocation for a representative cohort of faculty (Harter, Becker, and Watts, (2011); Labond and Tollison, (2003) are two examples from the economics profession), and likewise none of these studies include administrative time allocation in their empirical analysis. They focus instead almost entirely on the research-teaching time division (some include service as a residual but largely undifferentiated category). Some cross-sectional data are available on research time dedicated to administration and suggest that a substantial amount of faculty time goes to that activity. For example, Rockwell (2009) and Kean (2006) report on the results of recent surveys of U.S. scientists, which show that scientists spend 42% of their research time on pre-grant (22%) and post-grant (20%) administrative tasks. Other work, such as Rabinow's (1997) and Kenney's (1986) studies of biotechnology, also suggests a 30–40% allocation of research time to administration or administrative tasks.

None of these studies can assess how much the allocation of faculty effort to research, teaching, and administration has changed over time. One can surmise from the increase in competition for grants (Auranen and Nieminen, 2010), increases in multi-disciplinary, multi-country, and multi-institutional collaborations (Jones, Wuchty and Uzzi, 2008), and the loss of administrative help (Brown et al., 2010) that the amount of time scientists spend on administration and coordination tasks related to research has grown, and in all likelihood that the time spent on actual research has declined in the last couple of decades. While recent research shows that the shift in research funding from an institution-based to grant-based system has resulted in increased research output in the long run (Auranen and Nieminen, 2010), such a shift in funding sources may also come at a cost in terms of faculty research time.

3 Data

The data analyzed in this paper come from four random sample, representative surveys of agricultural and life scientists on the faculty of 1862 Land Grant universities. Surveys were conducted in 1979, 1989, 1995 and 2005 (see Busch and Lacy (1983) for a description of the 1979 survey; Buttel (2001) for a description of the 1989 and 1995 surveys; and, Goldberger et al. (2005) for a description of the 2005 survey). The researchers drew sample frames for the cross-sectional surveys randomly from available lists of faculty in colleges of agricultural and life sciences at all of the 1862 Land Grant universities in the country; for the first three from a USDA printed directory and in 2005 from the web sites of each university and member departments. Appendix tables A1 and A2 provide a list of universities and departments included in the survey.

The first three surveys were mailed to respondents with the last one conducted electronically over the internet with email and paper mail reminders. The later rounds of surveys repeated questions from previous surveys in order to provide comparisons over time and similar content across years.[1] Response rates ranged from a high of 76% in the 1979 survey to a low of 57% and 58% in 1995 and 2005, respectively. Sample sizes varied, but in the econometric analysis reported on below we use the following number of observations for each year: 1979, n=589; 1989, n=679; 1995, n=305; 2005, n=640. The 2005 survey respondents showed no significant differences in demographics from non-respondents using demographic information that could be

[1] Electronic versions of the actual survey instruments are available from the authors upon request.

gleaned from the web about non-respondents. We are not aware of any non-response bias tests on the earlier surveys and are unable to test for such.

Questions in these surveys document research inputs and outputs as well as demographics and disciplinary status of the individual respondent. On the research output side, respondents provided the number of journal publications they had produced over the previous 5 years as well as a range of other types of research outputs (such as: Ph.D. and Masters students graduated, books and book chapters, extension publications, and in 2005 patents and invention disclosures). On the research input side, faculty provided their average annual research budget for their lab or shop for the previous five years, as well as the number of graduate students, post-docs, and technicians who worked for them in the past year.[2] In the section on time allocation, faculty supplied their formal appointments, the total number of hours they worked, and how they divided their time in a typical week during the year between research, administration, extension and outreach, and instruction.[3] For the years 1995 and 2005, respondents further divided their research time between that spent actually on the research process, on grant preparation, and on other administrative activities.

4 Analysis of Trends in Faculty Time for Science

In this section, we present time trends of faculty researchers' time allocation observed in our sample. Table 1 provides a comparison of faculty research time measures from the four surveys

[2] Prices were adjusted for inflation using the Huffman and Evenson Agricultural Research Price Index (see Huffman and Evanson 2006, p. 105). It is based on the costs of total real private and public agricultural research expenditures. The authors of the index provided expanded data for the years up to 2005 for this research project.

[3] In the 1979 survey, respondents were only asked for their actual time allocation.

spanning 30 years of research activity (1975–2005). The regression analysis presented below expands on and deepens the empirical discussion, and serves to corroborate the baseline trends described here.

Table 1 shows that there has been a secular and statistically significant decrease in the proportion of faculty time allocated to research, from 59% in 1979, to 47% in 2005. In contrast to research time, the time allocated to teaching has remained relatively constant near 30%, while there has been a steady increase in extension time commitments in agricultural and life sciences colleges and, as further discussed below a significant increase in administrative time demands.[4] Among both the "top-ten" and "non-top ten" universities the percentage of time allocated to research decreased sharply between 1979 and 2005.[5] However, among the lower ranked universities, the drop was greater, falling 13 as compared to 10.3 percentage points in the higher ranked ones. The relative decrease in research time from both 1989–2005 and 1995–2005 is significantly larger for non-top ten universities than it is for the top ten.[6]

This aggregate measure of the drop in research time potentially belies the total amount of time allocated to "actual research work" as opposed to "grant preparation and administration." More detailed data on time allocations from the 1995 and 2005 surveys show major shifts in time

[4] The average time spent on extension work has increased due to two trends, a small shift in the proportion of faculty with extension appointments and a larger shift in the proportion of time committed to extension appointments. Specifically, the percent of faculty with an extension appointment dipped from 22% in 1979 to 15% in 1989 and then rose to 21% and 28% in 1995 and 2005, respectively. Meanwhile, the average appointment for each faculty rose from 25% in 1979 to 41-45% in the following years.

[5] For the years 1979 to 1995, top-ten status was determined by ranking land grant universities based on three criteria: (1) total State Agricultural Experiment Station research expenditures in 1992, (2) the number of doctorates granted in "agricultural sciences" in 1995, and (3) the number of doctorates granted in "biosciences" in 1995. An overall index was calculated by equally weighting these three items for each land-grant university. For 2005, top-ten status was determined by ranking land grant universities based on the Faculty Scholarly Productivity Index of top performing individual programs.

[6] The relative fall between 1989 and 2005 is significant at the 5% level while the change from 1995 to 2005 is greater for non-top ten universities at the 10% level.

dedicated to non-research activities within the time allocated to research (similar data are not available for earlier years). Table 1 shows the rising proportion of research time spent on grant preparation and administration relative to actual research work between 1995 and 2005. The rise in these grant preparation and administrative research tasks has led to a major decrease in time conducting active research, falling by more than a fourth over ten years, from 36.8% in 1995 to 27.1% in 2005. Coupled with the increase in non-research administration, over ten years the average fraction of time spent on administrative activities jumped from 20.6% in 1995 to 29.3% in 2005. The numbers in Table 1 from 2005 are also very similar to the estimates reported by Rockwell (2009) and Kean (2006) that 42% of research time was spent on administration. But the important difference our data provide is to show how much this has changed in the previous decade, with a statistically significant 50% increase from 28% of research time spent on administration to 42% within the research domain and overall from 20% to about 30% of faculty time spent on administration.

Time Trends by Subgroups

In Table 2, the allocation of time for research is cross-tabulated with professor status, size of laboratory, gender and discipline. A quick perusal shows that the decline in time for research is prevalent across almost all cohorts of the agricultural science professoriate. First, the declining trend in the allocation of time to research is evident in professors of all ranks with associate professors having the largest drop in their allocation of time to research. This finding is troubling from a research productivity perspective, because it is potentially the associate professor stage when researchers both mature and diverge in their research paths toward higher or lower productivity. If the growing administrative time demands on associate professors are the strongest, then that could bode poorly for research output in the long run. It is worth noting that even assistant professors who have the strongest incentives to pursue research, and generally the least administrative burden at least at the department level, have also experienced a large and statistically significant drop in research time.

When the sample is divided by the size of faculty member's laboratory (above and below the median funding levels), one sees that the decline in research time allocation occurs for both large and small labs in about equal amounts. While professors with large labs spend more time on research in all periods (and within each discipline), faculty in both cases have experienced about a 10% decline in the amount of time devoted to research. A similar decline in time for research is evident across male and female professors in agricultural and life science colleges.

When we divide the sample by disciplines in the last rows of Table 2, again we see the same secular decline in research time across several of them. The strongest decline happens in food sciences where the drop from 62% of faculty time being in research to 40% represents a 36% decline in hours allocated to research. Animal and Plant sciences show large and statistically significant declines in research hours of, respectively, 21% and 23% less time being spent on research. Environmental science has a non-significant decline between 1979 and 2005, but this may be due to the fact that the field already had a low percent of time spent on research (46%) in 1979. One striking result is that researchers who spend more time on basic science have been largely shielded from the decline in research time. In 1979, researchers spending over 40% of their time on basic research and other faculty spent nearly identical proportions of their time on research activities. In 1989, those focused on basic research spent 4 percentage points more time conducting research; this gap grew to 10 points in 1995 and 13 points in 2005. This trend can also be seen in the catch-all category of "all other disciplines," which includes biochemistry and other basic biological sciences housed in agricultural colleges. Among these faculty, there were no major changes in time allocation. They start in 1979 at a high level of 52% and basically maintain that high level with 51%, in 2005. This difference across the basic and applied sciences may reflect a premium being placed within these colleges on sustaining time for research in the fields where federal grants (such as NIH and NSF) are both large and highly competitive.

Incentives for Research and Administration

This widespread reduction in time devoted to research in agricultural science raises the question as to whether it is due to a change in incentives for faculty. This is a non-trivial question to answer, because incentives for faculty are multi-fold and diffuse. We explore two key incentives here: 1) efforts or output that increase the probability of getting tenure, and 2) efforts or output that might increase salary or other forms of compensation. If the returns to high quality research output in either of these changed over time, then one can at least postulate a behavioral incentive for less time being spent on research and more on administration. Note that while tenure rules only apply to assistant professors, it is often the case that universities have similar rules and metrics for promotion to full professor as well as for other rewards for faculty.

Figure 1 shows the evolution over time of what faculty reported with respect to the importance of various outputs and efforts on their ability to get tenure. These rankings are on a scale of 1 to 5 with 5 being most important.[7] What is most striking about the figure is that, while there is some variation year to year in the importance of various factors, the relative ranking

[7] In 2005, respondents were asked to rank the importance on a scale from -2 (strong negative influence on tenure or promotion) to +2 (strong positive). These responses were rescaled to make a comparison to previous years.

across years has not changed at all. The number of journal articles is always most important, followed in order by grants and contracts, high quality articles, teaching evaluations, government consulting, and private consulting. There has been a narrowing of the relative importance of "many articles" as compared to "grants and contracts" which is consistent with the push for more external research funding among agricultural science faculty. Together these two have declined relative to high quality articles. Since all three of these top three metrics of tenure and promotion are related to research time, however, they show no evidence that the incentives that faculty face for promotion are part of the reason why administrative time is increasing and research time is declining.

A second potential changing incentive is the ability to earn higher wages. Since we only have salary data for 2005, we cannot assess how incentives might have changed since 1979. Nonetheless, the results in Table 3 are suggestive in their comparison of the differences of average annual salaries in 2005 by different jobs and outputs. First, if one divides the sample at the 75th percentile of time doing research, 35 hours, we find no significant difference in salaries between those who spend more time doing research and those who spend less time. In contrast, we do find significant salary differences between those who produce more than the 75th percentile of the number of journal articles, 14, and those who produce fewer. That difference is worth about $10,000 or more than 11% of the average salary. As we have noted above, the key big increase in time allocation at the expense of research has been administrative time. In the final rows we divide the sample by whether a faculty member has a formal administrative assignment, which shows a significant difference in salary of about $16,000, almost 18% of the average salary. This is suggestive of strong incentives for faculty to take on formal administrative positions as a way to increase salaries, and these incentives may be more lucrative than more time spent on research.

5 Research Time Trends Regressions

As mentioned earlier, a small literature has investigated the determinants of faculty time allocations to research and teaching as a function of faculty and university characteristics. Following recent work by Harter, Becker and Watts (2011) we specify a regression of faculty time allocation as a function of year of survey, faculty characteristics, university characteristics, and faculty disciplines. The key dependent variable of interest is the percent of time devoted to research. We are especially interested in the year variable and whether, after controlling for faculty and university characteristics, the estimates reflect the same secular trends that our figures and cross-tabs have shown in which the percent of time devoted to research has declined in each subsequent survey year since 1979.

Our regression approach is a fixed-effect estimation of the following equation:

$$y_{ij} = \alpha + \gamma T + \beta X_{ij} + \eta_j + \varepsilon_{ij}, \quad (1)$$

where y_{ij} is the percent of time spent on research by faculty member i at university j, α is a constant, T is a vector of dummy variables for the survey years 1979, 1989 and 1995, and X_{ij} is a vector of characteristics of the faculty member. The error term has two components: a university fixed effect, η_j and the standard error term ε_{ij}, which we assume is heteroskedastic at the university level. To account for that heteroskedasticity, we use standard errors clustered at the university level for our analysis.

In terms of the elements of the vector X, which determine time allocation, we follow the literature in having individual faculty, discipline and university level controls. At the individual faculty level we use the years since PhD and its square as a measure of experience, dummy variables for assistant and associate professors to account for the effects of rank, gender to account for differences between men and women in research time allocation (as found for example by Harter, Becker and Watts (2011)), and the percentage of their work that they consider "basic research." We also include interactions between the "basic research" variable and the time dummy variables to capture what might be a change in research time for different types of faculty. At the university level we measure the prestige of the institution as a dummy variable for whether the university has a top-ten ranking in agricultural sciences; other university differences are captured in the university fixed-effect dummies. Finally, we include discipline level dummy variables to control for differences across fields. It is worth noting that these regressions, while useful for identifying the time trend and establishing correlations, are not structural and so are not to be taken as causal of research time allocations. Tables A3 and A4 show the definitions of the variables and summary statistics for all variables included in these regressions. Table A5 shows the correlations of the key variables used in the regression, while table A6 shows the changes in the sample composition over time.

Since the above discussion has also identified increases in administrative time as one of the major reasons for the decrease in research time, we also estimate a model of the determinants of administrative time. In this case we expect to see a rising estimate in the time trend variable for the amount of administrative time, and that administrative time is higher among older faculty (more years since PhD), full professors, and faculty who do less basic research. We would also potentially expect to see lower administrative burdens for faculty who do more basic research, although this effect might have lessened over time.

Table 4 shows the regression results of estimating equation (1) with two different dependent variables, research percentage and administration percentage. The first two columns show the baseline regression while the next two show the extended regression in which we test whether there has been a change over time in the importance of basic research percentage in faculty allocations of time to research and/or administration. In the first research percentage regression, very strong effects of the different time periods persist even after controlling for other faculty and university characteristics. Specifically, faculty research time percentages in 2005 are estimated to be statistically significantly lower by 12% than they were in 1979, 8% lower than in 1989, and 4% lower than in 1995. We do not find that age measured by years since PhD affects research time percentage, although assistant professors do spend significantly more time (6%) on research than other ranks. Faculty at top-ten agricultural colleges spend 4% more time on research, and the more basic research a faculty does the larger is the percent of his/her time spent on research. Disciplinary controls, which also account for any shifts there might be in the sample composition, show many of the same effects as the cross-tabs with plant scientists spending the most time in research and environmental scientists the least.[8]

The extended regressions, which test for changes over time in how faculty who do more basic research are affected by changes in university norms, demonstrates some additional

[8] As a robustness check, we re-ran these regressions excluding faculty with extension appointments since it might be that the decrease in research time was due to increases in extension appointments and extension appointments are specific to Land Grant Universities. The results hold when excluding faculty with an extension appointment although the magnitude of the yearly effects is reduced and the coefficient on 1995 loses significance. This confirms the validity of our framing as well as suggesting that these results on the decrease in research time and increases in administrative time are not driven by changes in the evolution of extension appointments.

evidence on the evolution of research and administrative activities. As in the baseline regression, faculty with a greater basic research orientation report spending significantly more time on research than applied researchers but not significantly higher time spent on formal administrative tasks. The time interaction terms offer two additional insights. First, compared with 1979, having a basic research orientation in 2005 leads to only a slight increase in faculty research time above the average. Put differently, the major decline in research time experienced by faculty between 1979 and 2005 is slightly less for those with a basic research orientation. The second insight is that compared to time available in 1995, faculty in 2005 with a basic science orientation experience had about 15% more research time available to them than those with an applied science orientation. This estimate suggests that the major administrative shift in recent years has been higher among more applied research scientists in the Land Grant institutions investigated in this study.

In the regression on administrative time percentages, we find a less statistically significant but relatively large trend effect in time allocation. Faculty in 2005 spent 4% more time on administrative tasks than did faculty in 1979 and 1995, while the 1989 coefficient in the same direction is not statistically significant. Given that administrative time in 1979 was 4.6% of faculty time, these estimates represent about a doubling in the average amount of time faculty spent on administration after controlling for other factors. The other factors that significantly impact administrative time are: age and rank, with older faculty and full professors spending the most time on administration; and prestige of the institution, with higher prestige institution faculty having lower administrative burdens. Note also that the size of the faculty lab also matters to administrative burdens in a negative way. Those with annual lab funding greater than $100,000 allocate, on average 8.1% of their time on administration versus 6.8 % of time allocated to administration for those faculty with lab funding of under $100,000. This difference is due to the higher percentage of faculty in large labs holding administrative positions (21%) as compared to those operating small labs (14%).[9]

The regressions overall demonstrate that the 20% decline in research time since 1979 and a doubling of average administrative time is robust to inclusion of controls for faculty, university and discipline effects. These findings raise the obvious question of what factors help to explain such a switch in faculty activities away from research and toward formal administrative work. One reason, as suggested above, could be the changing incentives in universities for salary increases, where formal administrative duties are frequently rewarded more heavily than research. Another could be the overall expansion of administrative activities within universities, which has trickled down to faculty in the form of increased "opportunities" for administration. A third might be the devolution of daily administrative tasks, such as budget preparation, travel forms, and other computer-based reporting activities that previously were completed by staff with input and pre-submission review by faculty. It is worth noting, however, that the major trends identified in the literature affecting faculty researchers (increased commercialization, collaboration, competition for grants, and burdens of knowledge) affect the time and effectiveness of research and would tend to reduce incentives to take on formal administrative tasks.[10]

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[9] Note that we are unable to include laboratory size in the regressions, since the amount of money received in grants is likely endogenous to the amount of time that faculty spend on research.

[10] It is possible that the growing burden of knowledge and increased competition for grants, by making the research treadmill more difficult, do increase the incentives for faculty to "drop-out" and take on more administrative duties. Our result that faculty with large labs are more likely to take on formal administrative appointments would be consistent with such a conjecture, although large lab faculty's demonstrated competence managing money and personnel is likely a better explanation.

6 Trends in Research Outputs and Inputs

In Table 5, we report on research outputs and the use of inputs other than faculty time in research labs for respondents to our surveys. We use two measures of research production, refereed journal articles and a composite measure of output, which includes books, edited books, and book chapters (but not patents). As shown in Table 5, after a statistically significant jump from 1979–1989, research article output has remained remarkably consistent at about 13 articles per faculty per five-year period, varying by a non-significant 0.5 articles after 1989. The composite output results show an identical trend, rising significantly from 1979-1989 then staying constant from 1989 to 2005.

Previous literature on faculty research outputs suggests that productivity may be differentially affected by technology in top-tier versus lower tier universities (Agrawal and Goldfarb, 2008; Ding et al., 2009) and it may also be the case that top universities have stronger incentives for research output. We split the sample into “top-ten” and “non-top ten” universities, using national rankings of departmental research output.[11] Among top-ten universities, journal article production fluctuated between 14.2 and 15.8 articles throughout the sample, while for non-top ten schools, 1979 output was significantly below the levels of 1989, 1995, and 2005. These results are consistent with a line of literature that argues for the positive effects of the expansion of information technology, especially internet access and reduced communication costs, on the research productivity of faculty at lower and middle tier research universities (Ding et al., 2009). A disaggregation of faculty output by research areas shows that although various disciplines (e.g., environmental and food sciences) produce at different overall levels, again in

[11] See section 4 for a full description of how this measure was constructed.

most cases there is a non-statistically significant jump in output from 1979 to 1989 and then little substantial variation in output within any discipline from 1989–2005. This suggests that the phenomena shown in the aggregated data are robust to differences in scientific disciplines.

The bottom of Table 5 offers trends in the key inputs into faculty research: graduate students, post-docs, and technicians who work in labs and research budgets to fund those labs. Over the same thirty-year period, inputs into research aside from faculty time have fluctuated year-to-year, but in net have remained fairly constant. Graduate students per researcher averaged around 2.6, with a high of 2.8 in 1995 and a low of 2.39 in 2005. The biggest change has been an increase in post-doctoral researchers, which more than doubled from 0.21 per lab to 0.45 per lab from 1979–1989 and then, continued a small non-significant increase after 1989. Meanwhile the number of technicians in labs dropped from 1.43 in 1979 to around 1.2 in the following years. These two changes suggest a replacement of permanent technicians hired on salary to the use of more transitory grant-funded post-doctoral researchers. Real research budgets varied slightly, but for the most part not statistically significantly. They did dip 20% between 1979 and 1995, but nearly returned to 1979 levels in 2005 in constant dollar terms.

7 Research Percentage and Journal Output

Up to this point we have demonstrated a secular decline in time devoted to research, some of its causes, as well as a flat production of the most common university outputs, teaching time and journal articles. In order to delve a bit further into the relationship between declining research time and journal article outputs, we estimate non-parametric (local polynomial smoothing) regressions between research time and journal articles across the different years of the data. While journal articles are a crude measure of total faculty output, a large literature on the returns to agricultural research - see Huffman and Evenson (2006) for an overview - shows very high public returns in terms of increased agricultural production from research conducted in colleges of agriculture (20–30% internal rates of return), measured either in articles or funding depending on the study. Thus, changes in the relative production of journal articles have potentially wide ranging implications for technological change and economic growth in the broader economy.

Figure 2 shows the non-linear relationship between research percentage and journal article output in each of the four years of our data based on estimates generated with a local polynomial smoother. Rather than specifying a functional form, local polynomial regression involves fitting the response to a polynomial of the regressor (research percentage) using locally weighted least squares. Although these graphs do not control for other factors, the main trends are still evident. First, it is clear journal article output for those allocating 50% of their time to research has risen, jumping from roughly 10 articles per 5 years in 1979 to roughly 14 articles in 2005. In fact there has been an increase in the slope (marginal returns to time) across the time periods. This is clearest when comparing 1979 with 2005, where the confidence intervals are the tightest: the slope of the earlier curve is visibly flatter than in the latter, which shows a monotonically positive slope.

Such a large slope shows a correlation of research time with journal article output, suggesting that the decrease in research time has an effect on this important university metric.[12]

[12] Research productivity increases could also occur because it requires less effort for individuals to get more articles published. Expansion of lower quality journals or co-authored articles are examples of possible mechanisms for lower required effort. While we cannot evaluate these measurement issues directly, there are important countervailing trends. On the one hand, the number of published authors in life science journals has increased dramatically (over 11 million citations in PubMed/MEDLINE between 2000 and 2004 compared to just 3 million between 1975 and 1979). Accordingly, leading journals (e.g., Science and Nature) report declining acceptance rates for submitted articles over the past several decades. And, while Jones, Wuchty and Uzzi (2008) report a substantial increase in the size of teams and the co-authorship of articles in PubMed/MEDLINE, recent literature (Lee and Bozeman, 2005; Bikard and Murray, 2011) also suggests broadly that greater collaboration actually reduces the quantity of output while increasing the quality. Since we have measured only quantity of output for individual

Looking at the difference between a 25% research time effort and a 75% effort, one sees in 2005 a more than doubling of research production. If we consider the effects of a drop in research percentage equivalent to what we see in the data of 59% to 47%, we can see that across all years that would reduce journal article production substantially. Considering the 2005 graph, in particular, one can see that increasing the research percentage on average to 1979 levels would increase journal article production on the order of 2 articles per every 5 years, or by about 15%. This shift, when summed across all university faculty in the agricultural sciences, could represent a substantial effect on research output and potentially on the productivity of agriculture and life science activities in the broader economy.

8 Discussion

With the help of a consistent set of surveys of agricultural and life scientists at 52 Land Grant universities in the United States, this article provides a thorough analysis of the evolution of faculty time allocation over more than a twenty-five year time span (1979-2005). The evidence is striking. Time for science has decreased significantly. A conservative measure, which simply delineates time spent on research from time spent on administration, teaching, extension, and other service reveals about a 20% relative decline from 59% of faculty time in 1979 to 47% in 2005.[13] This decline has been widely experienced across the professoriate at all levels and ranks, top and lower ranked public universities, gender, and so on. The one exception appears to be

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faculty, recent increases in collaboration, which would be expected to increase quality while reducing quantity, could provide a downward bias in our results if we are not appropriately controlling for scientist network size.

[13] This same trend holds true when excluding any faculty with an extension appointment.

across fields, in that the ‘all other category’, which included more basic biological researchers, held steady at around 52% of time dedicated to research.

A closer look at the last ten years of the data, which permit a further division of research time between active research and research administration activities associated with pre-award and post-award duties suggests that the time allocation story might be even less favorable for scientific inquiry. In particular, it revealed another 10% decline in overall time spent on active research, and overall about 40% of the faculty’s research time being spent on administering research efforts rather than ‘doing science’. Put differently, in 2005, an adjusted measure of time for active research is about 27%, compared to perhaps 50% in 1979, if one were to project back to 1979 the administrative loads within research experienced in 1995. This accounting would suggest that the increase in formal administrative time and increased research administration together have produced almost a 50% decline in the time that faculty have for doing science over the previous quarter century. [14]

These trends in faculty time allocation are striking and raise some critical questions that need deeper inquiry than can be offered here. One set of questions relate to the factors driving this secular change in time for science. How much of it is based on the ‘structure’ of federal research, which still provides about 75% of the funds received by the respondents to these surveys? There could be multiple drivers within the federal research structure—increased compliance demands, the rise of multi-institution, multi-disciplinary large grant initiatives, the highly competitive nature of peer-reviewed grant applications, and the digitalization of pre and post-grant reporting. How much of it is based on internal changes in university organization

[14] One limitation of our analysis is that we do not have consistent measures of the actual hours of time doing research across years. These data are, however, available (though not comparable) for 1995 and 2005. In those years the correlation between the percentage of a faculty’s time and the actual time doing research is 0.8 in 1995 and 0.9 in 2005, which suggests that the trends reported here are robust to measurements of actual time.

associated with reductions in support staff and devolution of daily administrative tasks to faculty? Are declines in regular merit-based salary exercises, associated with declining public financing of universities, encouraging faculty to be entrepreneurial or managerial in their behaviors in order to augment salaries? Our data offer some preliminary evidence in support of the first and third questions raised here, but they do not offer definitive answers to these questions that all seem likely to be in play in helping to explain the dramatic decline in faculty research time over the past three decades.

One possible but counter-intuitive explanation would be a shift in faculty preference for administrative work over research activity. This explanation seems unlikely given what the 2005 survey respondents reported as their idealized reward system for salary increases and promotions. By a significant margin, the most important items were research related, such as publication of high-quality research articles followed next by teaching related outcomes. Correspondingly, faculty did not value highly actions related to administration or even those whose primary motivation were monetary (consulting or patenting/licensing activities). This evidence suggests that the cause of the time shift away from science is extrinsic and not intrinsic. That conclusion is at least a valuable take-off point for further research and policy discussion on what is causing and what might be done about the decline in time for science.

A second set of critical questions related to the decline in faculty time for research is whether it matters beyond perhaps their own sense of satisfaction about their work. While the empirical analysis presented above does not delve deeply into that issue, it does provide a basis for concern. First, faculty time for science is the only major input to research that declined significantly over the same time span. Despite some fluctuations, research support in the form of graduate students held steady. The number of post-doctoral researchers rose, perhaps in part as a substitute for the decline in permanent lab staff and faculty time. Research budgets held steady in real terms (and indeed they increased substantially in 2005 from a low in 1995), at the same time that faculty administrative time demands increased substantially (in and out of the lab). Thus, faculty at US Land Grant universities are being asked to manage similar size and scale labs now with less time than they had before.

The full range of implications of this potential increase in time pressure is not explored above, but what is shown is that the total research output of faculty (measured by published refereed articles or broader counts including chapters and books) have held steady after growing in the first ten years of the data. Steady output set against declining faculty time for science translates into a higher research productivity measure of articles per faculty time unit, and this is reflected in our non-parametric estimation of a 20% loss of research production associated with the faculty loss in research time over the time span. Of course, these output measures are 'naïve' in terms of not being quality-adjusted, or set against possible changes in the extent of collaboration (and hence partial versus full authorship). They are only indicative measures of robust faculty research performance in the face of declining time to do science.

In summary, our empirical analysis reveals clear evidence that faculty faced increasing demands on their time for a range of administrative tasks, some associated with research and others not. At the same time, they produced more research articles with similar levels of other inputs. Combined, these results are suggestive of foregone opportunities for science and societal advances associated with declining research time. Further inquiry into these phenomena may well reveal sub-optimal choices being made at the level of universities and societies with regards to how US land grant university faculty are being asked to spend their time at work. It seems likely that the explanations will be manifold, ranging from university level devolution of basic administrative activities via computerization to the increased demands of federal grant preparation and administration associated with more competition and compliance to the search by faculty for new ways to increase their earnings in what has been a long era of fiscal constraint for most of their universities. But, if time is one of the major currencies of the realm for pursuing science and keeping faculty invested in their work, then it seems likely that this issue needs to be assessed in order to search for paths that would free up more time for faculty to do actual research. At the least, most faculty members would be likely to respond enthusiastically to that type of social objective, especially if increased research time were to come at the margin of administrative duties.

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Table 1: Time Trends

		Sample Year			
		1979	1989	1995	2005
Actual Time Spent	Research (%)	59 [c,d]	58 [c,d]	51.4 [a,b,d]	46.9 [a,b,c]
	Teaching (%)	30.1 [b]	25.3 [a,c,d]	31.1 [b]	29.2 [b]
	Admin (%)	4.6 [b,d]	8 [a]	6.3 [d]	9.8 [a,c]
	Extension Appt. (%)	5.3 [b,c,d]	7.3 [a,d]	8.6 [a,d]	12.9 [a,b,c]
Research (%)	Top-ten schools	58.3[c,d]	55.4[c,d]	49.3 [a,b]	48.0 [a,b]
	Not Top-ten	59.3 [c,d]	59.6 [c,d]	52.3 [a,b,d]	46.3 [a,b,c]
Research Time	Grant Preparation (%)	-	-	13.8 [d]	20.7 [c]
	Administration (%)	-	-	14.1 [d]	21.3 [c]
	Doing Research (%)	-	-	71.6 [d]	58.0 [c]
Adjusted Actual Research Time (%)		-	-	36.8 [d]	27.1 [c]

a=statistically different (at the 5% level) from 1979, b=from 1989, c=from 1995, d=from 2005

Table 2: Research Time Allocation Trends by Subgroup

		1979	1989	1995	2005
Rank	Assistant Prof.	62.6 [c,d]	62.5 [c,d]	51.9 [a,b]	55 [a,b]
	Associate Prof.	59.3 [d]	56 [d]	54.4 [d]	42.6 [a,b,c]
	Full Prof.	58 [c,d]	57.2 [c,d]	50 [b,d]	45.7 [a,b,c]
Lab Size	Small Lab	50.5 [c,d]	53.8 [c,d]	45.7 [a,b]	41.7 [a,b]
	Large Lab	64.9 [c,d]	61.8 [c,d]	57.5 [a,b]	54.2 [a,b]
Gender	Male	59.1 [c, d]	58.2 [a, c, d]	51.4 [a,b,d]	46.9 [a,b,c]
	Female	57.7 [d]	54.5 [d]	49.2	46.4 [a,b]
Disciplines	Ani. Science (%)	56.3 [d]	54.8 [d]	49.9	44.6 [a,b]
	Plant Science (%)	64.5 [c,d]	62 [c,d]	54.2 [a,b]	49.9 [a,b]
	Env. Science (%)	46.5	42.4 [c]	50.3 [b,d]	41.4 [c]
	Food Science (%)	62 [b,c,d]	50.6 [a,d]	49.1 [a]	39.9 [a,b]
	All Other†	51.7 [b]	58.1 [a,c,d]	49 [b]	50.5 [b]

a=statistically different (at the 5% level) from 1979, b=from 1989, c=from 1995, d=from 2005
†Includes biochemistry, basic sciences, and engineering in Agricultural Sciences departments.

Table 3: Salary Differences in 2005

		Annual Salary	
Research Time*	Low Research Time	$88,296	
	High Research Time	$90,369	
Administrative Appointment	No Formal Admin. Appointment	$86,092	
	Formal Admin. Appointment	$101,767	**
Research Output`	Low Research Output	$85,111	
	High Research Output	$95,143	**

* High research time is more than 35 hours / week spent doing research

† High research output is journal article production greater than 14 articles in the last 5 years

** Significantly different from the other category at p<0.05

Table 4: Time Trend Regressions

VARIABLES	(1) Research Pct.	(2) Admin Pct.	(3) Research Pct.	(4) Admin Pct.
Year 1979	11.91***	-4.796***	19.09***	-3.957**
	(1.310)	(0.968)	(2.597)	(1.619)
Year 1989	8.032***	-0.739	15.02***	-2.837*
	(1.335)	(1.044)	(2.348)	(1.665)
Year 1995	4.611***	-4.111***	8.647***	-5.082**
	(1.607)	(1.378)	(2.126)	(1.966)
Years Since PhD	-0.122	0.451***	-0.117	0.432***
	(0.192)	(0.118)	(0.196)	(0.118)
Years Since PhD^2	4.962	-12.22***	4.194	-11.88***
	(4.047)	(3.041)	(4.113)	(3.027)
Assistant professor	6.614***	-6.835***	6.113***	-7.063***
	(1.660)	(1.052)	(1.708)	(1.064)
Associate professor	1.073	-5.101***	0.748	-5.163***
	(1.380)	(0.802)	(1.382)	(0.791)
Gender (Male=1, Female=0)	2.982*	-0.496	2.962*	-0.512
	(1.559)	(1.201)	(1.504)	(1.188)
Basic research (%)	0.137***	-0.00609	0.249***	-0.0179
	(0.0177)	(0.0104)	(0.0281)	(0.0251)
Basic Research (%) * 1979			-0.197***	-0.0290
			(0.0559)	(0.0338)
Basic Research (%) * 1989			-0.168***	0.0472
			(0.0429)	(0.0306)
Basic Research (%) * 1995			-0.104**	0.0238
			(0.0417)	(0.0279)
High prestige institution	4.358**	-4.478***	4.787**	-4.483***
	(1.901)	(1.100)	(2.105)	(1.051)
Disc: Animal Sciences	0.864	-4.718***	0.981	-4.695***
	(1.750)	(1.077)	(1.741)	(1.078)
Disc: Plant Sciences	7.925***	-3.871***	7.900***	-3.809***
	(1.631)	(0.890)	(1.610)	(0.892)
Disc: Env. Sciences	-3.251**	3.337**	-2.641*	3.339**
	(1.587)	(1.263)	(1.510)	(1.293)
Disc: Food Sciences	0.559	-1.695	1.251	-1.702
	(2.564)	(1.749)	(2.589)	(1.763)
Constant	57.55***	5.092**	50.65***	4.452
	(3.479)	(2.406)	(3.914)	(2.878)
Observations	2,296	2,296	2,296	2,296
R-squared	0.168	0.108	0.180	0.111
University FE	Yes	Yes	Yes	Yes

University-clustered standard errors in parentheses
Social sciences not included
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Research Outputs and Non-time Inputs

		Sample Year			
		1979	1989	1995	2005
Journal Articles	Full Sample	12.04 [b]	13.34 [a]	12.86	13.05
	Top-ten schools	14.38	15.84	14.20	14.87
	Not Top-ten	10.92 [d]	11.94	12.30	12.32 [a]
	Animal Science	14.11	13.57	14.49	12.37
	Plant Science	11.53	12.74	11.89	13.57
	Env. Science	8.87	12.02	11.42	10.99
	Food Science	17.40	16.61	18.17	15.61
	All Other Disciplines†	10.8 [b]	14.64 [a]	13.48	12.83
Output**	Full Sample	13.55 [b,c,d]	15.39 [a]	15.33 [a]	15.21 [a]
	Top-ten schools	16.23	18.48	17.36	17.17
	Not Top-ten	12.26 [c,d]	13.65	14.48 [a]	14.42 [a]
Inputs	Grad students	2.63 [d]	2.54	2.8 [d]	2.39 [a,c]
	Post docs	0.21 [b,c,d]	0.45 [a]	0.47 [a]	0.49 [a]
	Technicians	1.43 [b,d]	1.16 [a]	1.23	1.1 [a]
	Research Budget ($1000)	174 [c]	154	137 [a]	166

a=statistically different (at the 5% level) from 1979, b=from 1989, c=from 1995, d=from 2005
†Includes biochemistry, basic sciences, and engineering in Agricultural Sciences departments.

Figure 1: Reasons for Tenure and Promotion

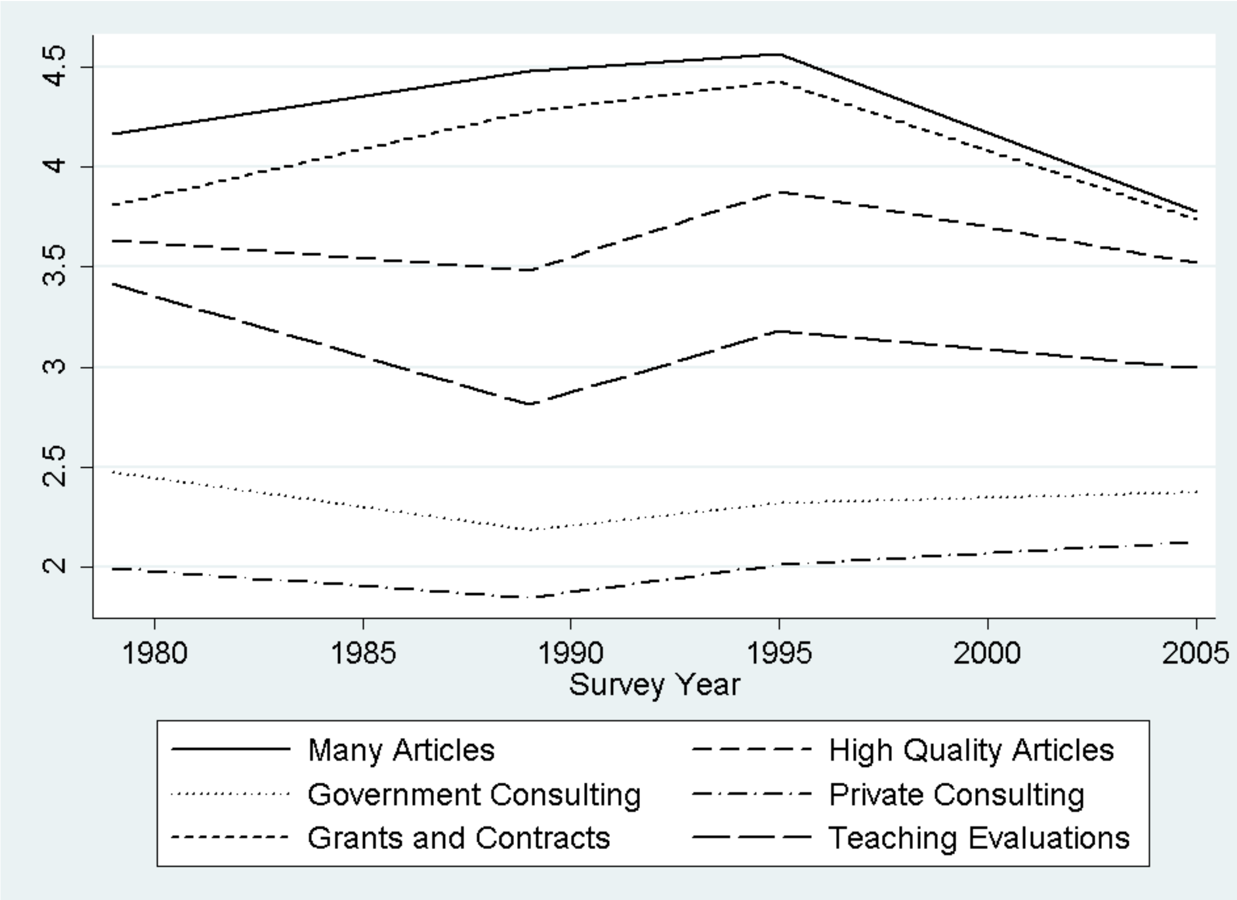
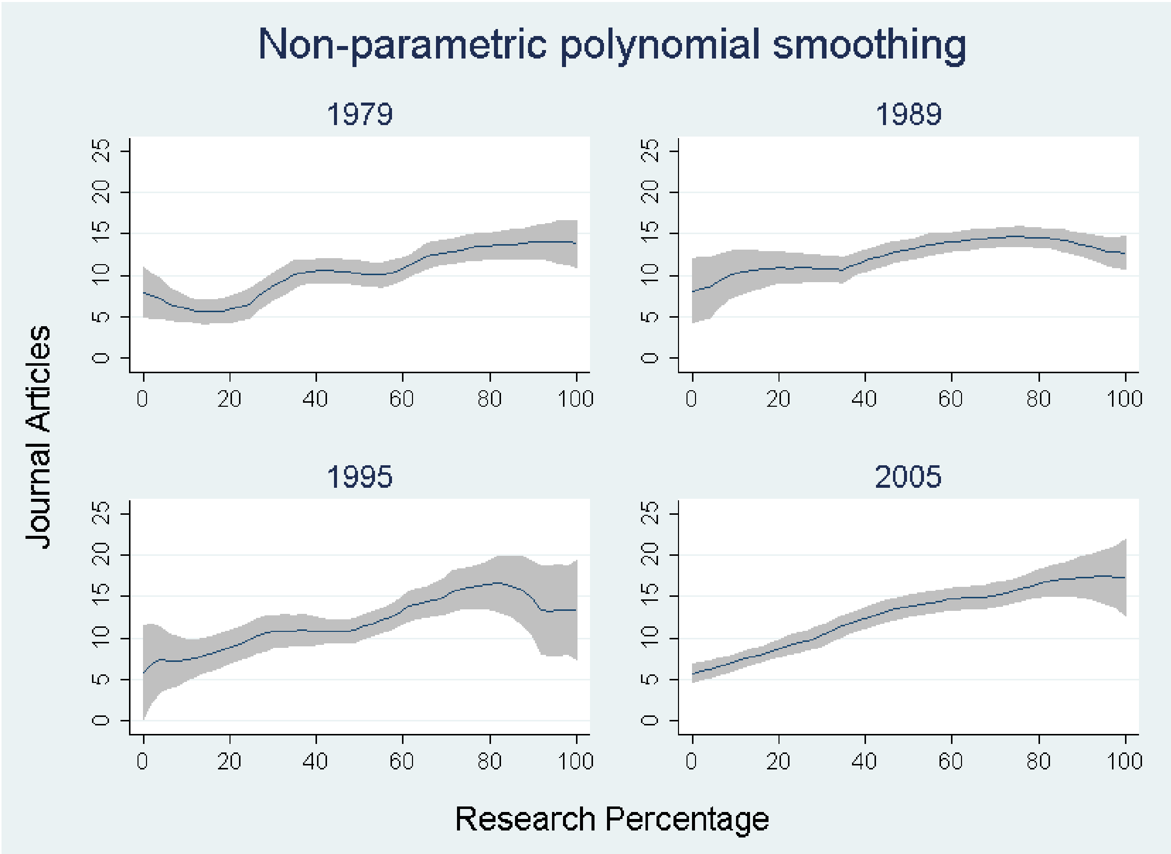


Figure 2: Bivariate Non-parametric Analysis by Year



Appendix Tables

Table A1: Listing of Universities Included in the Sample

University	
Auburn	U. North Carolina
Clemson	U. North Dakota
Colorado State	U. Rhode Island
Cornell	U. South Dakota
Iowa State	U. Tennessee
Kansas State	U. Vermont
Louisiana State	U. West Virginia
Michigan State	U. Wyoming
Mississippi State	UC-Berkeley
Montana State	UC-Davis
New Mexico State	UC-Riverside
Ohio State	Utah State
Oklahoma State	UW-Madison
Oregon State	Virginia Polytechnic
Penn. State	Washington State
Purdue	
Rutgers	
Texas A&M	
U. Alaska	
U. New Hampshire	
U. Arizona	
U. Arkansas	
U. Connecticut	
U. Delaware	
U. Florida	
U. Georgia	
U. Hawaii	
U. Idaho	
U. Illinois	
U. Kentucky	
U. Maine	
U. Maryland	
U. Massachusetts	
U. Minnesota	
U. Missouri	
U. Nebraska	
U. Nevada	

Table A2: List of Departments included in sample (all years)

Discipline / Departments	Frequency	Percent
Animal Sciences		
Animal sciences, dairy sciences, meat and poultry sciences	428	14.45
Biochemistry		
Biochemistry, biology, cell biology, genetics, microbiology, physiology	167	10.54
Engineering		
Agricultural engineering, biological engineering, biosystems, environmental engineering	123	4.15
Environmental Sciences		
Atmospheric science, environmental science, ecology, fisheries, hydrology, natural resources	327	11.04
Food Sciences		
Food chemistry, food engineering, food sciences, nutrition	216	7.29
Plant Sciences		
Agronomy, biometry, biostatistics, crop sciences, entomology, geography, plant pathology, soil sciences	1, 247	42.11
Social Sciences*		
Agricultural economics, agricultural education, rural sociology	308	10.40
Total	2, 653	100

*Note: The social sciences were not surveyed in 1989. Therefore, only analysis restricted to 1995 and 2005 includes this discipline.

Table A3: Variable Construction

Variable	Description
Research (%)	The percent of actual time allocated to research (other options were: teaching; administration; extension and outreach; other)
Doing Research (%)	The percent of time allocated to research less time spent on administration and time spent on grant preparation
Years since PhD	The number of years since a faculty member completed his/her PhD
Gender	Binary variable equal to 1 if the faculty is male
Basic Research (%)	The percent of time allocated to basic research (other options were: applied research, development research)
High Prestige Institution	Binary variable equal to 1 if the institution was considered one of the top ten agricultural sciences research universities. See footnote 5 on page **Error! Bookmark not defined.** for more details.
Animal Sci.. (Disc.)	Binary variable equal to 1 if faculty is a member of a animal sciences department
Plant Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of a plant sciences department
Env. Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of an environmental sciences department
Food Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of a food sciences department

Table A4: Regression Variable Summary Statistics

	N	Mean	Std. Dev.	Minimum	Maximum
Research Pct.	2473	53.92	24.18	0	100
Admin Pct.	2473	7.48	16.71	0	100
Basic Research (%)	2607	39.80	33.36	0	100
Years Since PhD	2598	17.84	9.74	0	56
Five-year Budget ($100,000)	2610	1.60	9.20	0	336.4
Gender	2679	0.90	0.30	0	1
Asst. Prof (%)	2687	0.18	0.38	0	1
Assoc. Prof (%)	2687	0.27	0.44	0	1
Top-10 University	2686	0.32	0.47	0	1
Animal Sciences (%)	2687	0.16	0.37	0	1
Plant Sciences (%)	2687	0.46	0.50	0	1
Env. Sciences (%)	2687	0.12	0.33	0	1
Food Sciences (%)	2687	0.08	0.27	0	1

Table A5: Correlation Table

	Research Pct	Admin Pct	Extension Appt.	Years Since PhD	Assistant Prof.	Assoc. Prof	Gender	Basic Research (*%)	Top ten school
Research Pct	1								
Admin Pct	-0.4113*	1							
Extension Appt.	-0.3887*	-0.047*	1						
Years Since PhD	-0.0539*	0.1267*	-0.0638*	1					
Assistant Prof.	0.0826*	-0.1259*	0.0112	-0.5308*	1				
Assoc. Prof	-0.027	-0.0799*	0.0453*	-0.2912*	-0.286*	1			
Gender	0.0686*	-0.0255	0.0045	0.1510*	-0.1635*	-0.0500*	1		
Basic Research (*%)	0.1928*	0.0183	-0.3133*	0.0093	0.0670*	-0.0456*	-0.0643*	1	
Top ten school	-0.0182	0.0367	0.0229	0.0292	-0.033	-0.0235	-0.0551*	0.0993*	1

Table A6: Sample Composition

		1979	1989	1995	2005
Demographic	Assistant Prof. (%)	13.6 [b,d]	20.2 [a,c]	13.7 [b,d]	20.7 [a,c]
	Associate Prof. (%)	27.4	27.1	25.8	26.9
	Full Prof. (%)	58.7 [b,d]	52.4 [a,c]	60.5 [b,d]	52.3 [a,c]
	Years since PhD	16.7 [c,d]	16.6 [c,d]	18.8 [a,b]	19.7 [a,b]
	Female (%)	5.0 [b,c,d]	7.6 [a,d]	8.3 [a,d]	19.1 [a,b,c]
Disciplines	Animal Science (%)	14.2 [b,d]	20.6 [a,c]	10.8 [b]	10.2 [a]
	Plant Science (%)	41.7 [b,c,d]	54 [a,c,d]	34.5 [a,b]	33.6 [a,b]
	Env. Science (%)	8.6 [c,d]	6.9 [c,d]	15.4 [a,b]	14.4 [a,b]
	Food Science (%)	6.6 [d]	6.8 [d]	4.3 [d]	9.3 [a,b,c]

a=statistically different (at the 5% level) from 1979, b=from 1989, c=from 1995, d=from 2005

Making Time for Agricultural and Life Science Research: Technical Change and Productivity Gains

Daniel Prager, Brad Barham, Jeremy Foltz

1 Introduction

Studies of research at US Land Grant institutions celebrate a long and storied history of scientific discovery, public good creation, and high social returns (see e.g., Alston et al., 2010; Fuglie and Heisey, 2007 for overviews). In one recent example of that literature, Huffman and Evenson (2006) show the rate of return to public resources invested in agricultural research is between 49-62%. While changes in the last two decades have increased the importance of privately captured research patenting and commercially propagated research (see e.g., Foltz et al., 2007; Just and Huffman, 2009), the primary mechanism for the dissemination of knowledge for US Land Grant universities has been and continues to be publicly available research publications: journal articles, books, research reports. The continued production of these public research outputs is a key metric of a successful agricultural (and scientific) research system. How efficiently Land Grant universities produce these research outputs and how research productivity may have changed over time is an important question for understanding the future of agricultural and life science research in the US.

This article investigates the evolution of US agricultural and life science faculty research performance in producing journal articles spanning three decades, 1975-2005. The primary focus is on how changes in time allocation and other key inputs to research shape faculty and university research productivity. We exploit data collected from agricultural and life scientists at U.S. Land Grant universities in four random-sample surveys, which also included a longitudinal sub-sample for the last two periods. Our empirical analysis takes advantage of both the repeated cross-sections and the panel to demonstrate the robustness of the following main result: US agricultural and life science faculty have become more productive, across various measures of research output, while their time for research has contracted significantly. The net effect is a steady level of public research output over most of the time period despite less time for science.

The combination of repeated, cross-sectional and panel data in this study permit the construction of comparable measures of the factors influencing research performance among a critical subset of U.S. research faculty and create the opportunity to study the evolution of individual faculty experiences over time as well. The empirical analysis tracks dynamic population level changes in research inputs and outputs as well as addressing endogeneity and other specification issues that arise in efforts to identify the factors shaping individual research productivity outcomes. What distinguishes this study from previous empirical examinations of faculty research performance is the opportunity to incorporate ‘time for science’ measures explicitly into the analysis in a consistent manner over a significant time span. Only Harter et al. (2011) have done something similar for academic economists, with more of an emphasis on the allocation of time across research and teaching activities than on the evolution of research productivity outcomes and how they relate to a broader suite of time measures.

This study identifies three broad empirical regularities. First, measured in articles (and broader research outputs) per unit of time, faculty productivity has grown significantly from the 1970s to the early 2000s, especially in the non-top ten Land Grant research institutions. These findings on research productivity dynamics are consistent with the Agrawal and Goldfarb (2008) study of the impacts of the expansion of the internet and computational opportunities on US faculty research performance in middle-tier research institutions. A second is that while most other key research inputs have stayed relatively constant (with some minor fluctuations), computational resources have increased and faculty ‘time for science’ has declined significantly over time across almost all cohorts (Barham et al. 2014). The main explanation for this decline in time for science has been a commensurate expansion in the proportion of time faculty spend on administrative duties, both general ones and those related to pre and post-grant responsibilities. Teaching time has not varied across the study period. The third finding is that while these productivity and time trends vary some by fields of study and by type of university, they are secular, widespread trends, which points to the potential value of broader policy consideration of whether faculty time allocation outcomes are in optimal alignment with respect to opportunity costs.

The remainder of this article is organized as follows. The second section is a selective review of the recent literature on faculty research performance that highlights key contextual, empirical, and methodological issues. Next is a summary of the data available for the analysis and its main features that shape and constrain the empirical analysis. The fourth section describes our empirical approach to studying faculty research performance, including the primary count-data regression specifications used to exploit the panel and pooled cross-sectional data sources. The fifth section presents the results, and the final section concludes with a reflection on the scientific and policy implications of the principal findings.

2 Faculty Research Productivity in the Literature

Both at the individual and university level, technical change over the last four decades has been a major factor in shaping the nature and rapidity of the publication of journal articles by university researchers. Especially since the late 1980s, advances in computers and software have provided ever expanding, ready-access computing capacity and data analysis at low-cost (Moore, 1975). Research professors throughout the U.S. (and the world) have today easily available data processing, information management, and communication options that were unimaginable in the early 1980s and still in their relative infancy in the early to mid-1990s. An array of related and complementary life science research tools (e.g., the gene gun; genetic sequencing, image resonance technologies; nano-sensory devices) have combined to create the potential for significant growth in the quantity (and quality) of scientific output by university faculty in life-science related fields. This opportunity has in turn motivated large public and private investments in life science research facilities and initiatives across the country and around the world (Owen-Smith et al., 2002; De Vol and Bedroussian, 2006). At the same time, agricultural researchers have experienced a major shift in their funding environment with the decline of formula funds and the substitution and expansion of major competitive federal grant opportunities (Just and Huffman, 2009).

Initial empirical evidence from the rest of the economy had at first suggested that productivity improvements associated with computers were lower than expected and took considerable time to achieve. Two leading studies in the 1990s, including one by a team of scientists at the National Research Council, described a “productivity paradox” of widespread diffusion of computers associated with little growth of productivity (Harris, 1994; Landeaur, 1995). One potential explanation of the productivity paradox was time shifting in which computerization merely shifted worker tasks without making them more productive (Landeaur, 1995). More recently, longer-term studies have found convincing evidence in the US economy of a significant productivity gain due to computers and other technologies (Jorgenson et al., 2003; Jorgenson et al., 2008, Bloom et al. 2012), but debate continues over the degree to which computers and other new technologies affect productivity of service sector work (Licht and Moch, 1999). Relatively little empirical work has investigated such productivity questions at the individual worker level; most micro-economic productivity studies instead analyze sector or firm-level data to study returns to capital invested in computers.

Despite its potential importance, the literature has not explicitly investigated the effect of actual research time as an input to faculty productivity. Time considerations are implicitly built into the analysis of tradeoffs or synergies across research activities (e.g., Foltz et al., 2007), or types of research, but overall research time measures typically have not been included in previous studies. The unique feature of our dataset is that it directly measures the proportions of faculty time allocated to research, teaching, administration, and outreach. Other research has found that endowment shocks, such as stock market declines and public funding cuts, can lead universities to trim administrative support staff throughout campus (Brown et al., 2010), which could increase the administrative duties of faculty. But, as far as we are aware, prior to this paper, actual impacts of these changes in time available to faculty have not been explicitly captured in analyses of university research productivity.

The academic literature of the past two decades, on the other hand, is replete with aggregate level research investigating the many influences and incentives affecting academic scientists' productivity (see e.g., Foltz et al., 2011; Stephan, 2012). Foltz et al. (2011) for example show rising productivity in scientific research production across all universities in the US using aggregated data from 1989–1998, that takes into account quality and a multi-output production process. They further demonstrate that Land Grant universities slipped further away from the productivity frontier than private universities in the 1990s but had the highest rates of technical change, an effect that was stronger in small Land Grants than large ones.

Within agricultural colleges there have been two major and somewhat divergent changes in the incentives scientist receive from different funding types. One is an increase in incentives for faculty to compete for grants increasingly from NSF, NIH and private sources rather than USDA (e.g., Huffman and Evenson, 2006; Alston et al., 2010). The other is an increase in commercial opportunities through patenting, licensing and explicit commercial funding, which may have reduced the amount of time devoted to public science, or might be synergistic with such a process (e.g.,Sampat, 2006; Foltz et al., 2007; Thursby et al., 2009).

Rather than focusing primarily on whether funding incentives are changing the output mix (and in effect diminishing time) devoted to open science research production, our work explicitly examines faculty time allocation and how it affects the research output of individual university faculty over a 30-year period from 1975 to 2005. If funding incentives were in fact changing the output mix it would imply lower productivity for publicly available research outputs such as journal articles per unit of input, in particular labor inputs. Our work described below also analyzes the potential effects on journal article production of changes in incentives between different types of faculty efforts: teaching, grant getting and research quality.

3 Data and Selected Key Descriptive Statistics

The data analyzed in this work come from four random sample, representative surveys of agricultural and life scientists on the faculty of 1862 Land Grant universities. Surveys were conducted in 1979, 1989, 1995 and 2005.[1] The researchers drew sample frames for the cross-sectional surveys randomly from available lists of faculty in colleges of agricultural and life sciences at all of the 1862 Land Grant universities in the country; for the first three from a USDA printed directory and in 2005 from the web sites of each university and member departments. Appendix tables 1 and 2 provide a list of universities and departments included in the survey.

In addition to the cross-sectional data, a panel of respondents from 1995 was re-surveyed in 2005. The panel is based on a representative sample of professors from 1989 who were re-surveyed in 1995.[2] In 2005, each active member of the 1995 panel was contacted and asked to participate in the latter survey. We use a consistent balanced panel of 147 faculty who responded in both years.[3]

The first three surveys (1979, 1989, and 1995) were mailed to respondents with the last one (2005) conducted using a web-based interface with email and paper mail reminders. The later rounds of surveys repeated questions from previous surveys in order to provide comparisons over time and similar content across years.[4] Response rates ranged from a high of 76% in the 1979 survey to a low of 57% and 58% in 1995 and 2005, respectively. Sample sizes

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[1] See Busch and Lacy (1983) for a description of the 1979 survey; Buttel (2001) for a description of the 1989 and 1995 surveys; and, Goldberger et al. (2005) for a description of the 2005 survey.

[2] Although the panel data collection began with the 1989 survey, we lack identifying information for that year and cannot include it in our analysis. Additional respondents were added from a random draw in 1995 to replenish the panel, maintain a similar age structure, and replace those who had exited academia.

[3] There were a total of 259 faculty who responded to the panel survey in both 1995 and 2005. We discarded pairs of observations for respondents who did not record their 5-year budget, their allocation of research time, journal articles produced, or years since PhD. In order to maintain as many as possible of the remaining observations, the following assumptions were made: (1) faculty who only reported post-docs or graduate students from one of the years were assumed to have the same number for the other year; (2) it was assumed that there was no extension appointment if that value was missing. Finally, to make results consistent with the cross sectional analysis, we include only data from the same disciplines used in that analysis. This left a fully balanced panel of 147 individuals. The key results presented in this paper are un-changed by expanding the sample to the full 259 faculty observations available.

[4] Electronic versions of the survey instruments are available from the authors upon request.

varied, but in the cross-section econometric analysis reported on below we use the following number of observations for each year: 1979, n=553; 1989, n=777; 1995, n=275; 2005, n=647. None of the panel data are included in the cross-section data. The 2005 survey respondents showed no significant differences in demographics from non-respondents using demographic information that could be gleaned from c.v.'s and other information available on the web about non-respondents. We are not aware of any non-response bias tests on the earlier surveys and are unable to test for such.[5]

Questions in these surveys document research inputs and outputs as well as the demographics and the disciplinary focus of the individual respondent. On the research output side, respondents provided the number of journal publications they had produced over the previous 5 years as well as a range of other types of research outputs (such as: Ph.D. and Masters students graduated, book chapters, extension publications, and in the 2005 data, patents and invention disclosures). For our measures of research productivity, we compare the number of published scientific articles with no adjustments for quality along with a composite measure of published output.[6] A robustness check described below using the 2005 data shows that adjusting for the relative number of citations to an article does not significantly change the key coefficients of interest.

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[5] Faculty responses came from a range of departments including physical and biological sciences, engineering, biochemistry, and social science. However, the only disciplines that were present in all four of the surveys include animal science, environmental science, food science, and plant science. We therefore exclude engineering, biochemistry, and social sciences faculty from the analysis below. An analysis that includes those fields yields the same key results as presented in this paper, but is not presented due to concerns about biases from year-to-year sample inconsistency. Results are available from the authors upon request.

[6] We also omit patent production, which would only add to the research productivity estimates given recent growth in patenting activity especially in the life sciences (Foltz et al., 2007; Azoulay et al., 2009; and Chavas et al., 2011). Our data do show that faculty in the 2005 survey with the intent to patent are 12% more productive than faculty who do not intend to patent. These results are available from the authors upon request.

On the research input side, faculty provided their average annual research budget for their lab or shop for the previous five years, as well as the number of graduate students, post-docs, and technicians who worked for them in the past year. Data for research budgets were converted into constant 2000 dollars using the Huffman-Evenson Agricultural Research Price Index.[7] In the section on time allocation, faculty supplied their formal appointments and how they actually divided their time in a typical week during the year between research, administration, extension and outreach, and instruction. For the years 1995 and 2005, respondents further divided their research time between that spent on grant preparation, research-related administrative activities, and actively doing research. Combined, these output and input measures, with both repeated cross-section and panel samples, provide a unique opportunity for focusing on the evolution of research productivity and time for science, while controlling for other key inputs.

We should, however, note some limitations of the data that shape our econometric modeling strategy and variations in specification. First, we only have consistent measures of the percentage of time allocated to research, rather than the actual hours spent. If the hours that faculty work each week has changed substantially over time, this could bias the results. Second, to account for the natural spikes in research output and budgets, data for these measures were collected for the five years before the survey, while in contrast our measures of time and other key input data are from the previous year. We do not believe this biases the results significantly since most of these variables are fairly consistent over a period of five years.[8] Finally, in our main results, our analysis is subject to the standard critique that the intrinsic ability of the

[7] The Huffman and Evenson Agricultural Research Price Index (see Huffman and Evanson 2006, p. 105) is based on the costs of total real private and public agricultural research expenditures. The authors of the index provided expanded data for the years up to 2005 for this research project.

[8] In 2005, the only year for which we have both measures, the correlation between the lab budget for the last year and the average of the budget for the last 5 years is 0.77.

researcher is unobservable. The 1995–2005 panel data, however, allow us to control for individual faculty-level unobservables, such as innate ability and variation in how they answer survey questions, through fixed effect estimation methods. As demonstrated below, the main results are consistent across the repeated cross-section analysis and the panel fixed-effect estimates.

Key descriptive statistics

The panels in table 1 show variable means for the cross-sectional data for both inputs and outputs of the research production process. The time allocation measures in panel A show the percentage of actual time faculty reported spending on the following activities: research, teaching, extension, and administration. The first thing to note is that panel A documents a large, secular decrease in the proportion of time available for research across all years from 60% in 1979 to 47% in 2005. This holds true across elite and non-elite universities, by tenure status and discipline, and among men and women. Furthermore the proportion of time dedicated to "pure" research, rather than grant preparation or other administration, has decreased substantially from 38% in 1995 to 27% in 2005.[9] Conversely, administration and extension activities were the primary activities where faculty time shares increased substantively. While the increase in administrative time is due to increases in both the intensive (more time) and extensive (more faculty) margins, the growth in extension time is almost entirely due to increases in the percentage of extension appointments for those who had extension appointments. Teaching time efforts are not significantly different from year to year, remaining effectively constant.

[9] Research time changes are statistically significant across almost all subgroups. See Barham et al. (2014) for a detailed disaggregation and discussion of these trends.

Panel A also demonstrates trends in the other key inputs into faculty research: graduate students, post-docs, and technicians who work in labs and research budgets to fund those labs. Over the same thirty-year period, inputs into research aside from faculty time have fluctuated, but in net have remained fairly constant. Graduate students per researcher averaged around 2.6, with a high of 2.85 in 1995 and a low of 2.38 in 2005. The biggest change has been an increase in post-doctoral researchers, which more than doubled from 0.17 per lab to 0.38 per lab from 1979–1989 and then, continued a small non-significant increase after 1989. Real research budgets varied slightly, but for the most part not statistically significantly. They did dip 24% between 1979 and 1995, but nearly returned to 1979 levels in 2005 in constant dollar terms.

Despite relatively constant research dollars overall, the data show large changes in funding sources for agricultural and life scientists between 1989, 1995 and 2005 (the 1979 survey contains information on funding amounts, but not sources). Between 1989 and 2005, the proportion of research monies from formula funds was cut in half (40.3% to 20.9%), while competitive research funding more than doubled (12.6% to 30.7%) even while the real value of research funding has stayed mostly constant. At the same time, across all disciplines, federal funding rose only moderately from 61% in 1989 to 67% in 1995 and 2005.[10] This trend is widespread: the rise in competitive funding and decrease in formula funding affects every disciplinary field without exception. In some fields the increase has been even more dramatic, for example in the food science field competitive funding soared from 9% of total funding in 1989 to 36% in 2005.

[10] An exception is social sciences, where federal funding decreased from 81.4% to 72.2% between 1995 and 2005. However, since we do not have data for 1989, this discipline is not included in the regressions.

Trends in research outputs are displayed in panel B. Research article output has remained remarkably consistent at 12–13 articles per faculty per five-year period, varying by a non-significant amount from year to year. The composite output measure,[11] which includes articles, books, book chapters, and edited books, shows a nearly identical trend, rising slightly from 1979-1989 then staying constant from 1989 to 2005. Among top-ten universities, as shown in panel B, journal article production fluctuated between 14.2 and 15.6 articles throughout the sample, while for non-top ten schools journal article production was consistently 25–30% lower than at top ten schools.[12] Though not shown, after 1979 average journal article production varies little within assistant, associate or full professors categories. Taken at face value, such stagnant output production in a period of substantial technological change in life sciences technologies would be consistent with a productivity paradox, if not for the decrease in time for science.

Finally, Panel C shows the composition of the sample for each survey year by demographic elements and research disciplines. Each year, associate professors comprise just over one-fourth of the sample. However, due to random sampling variation, the proportion of assistant and full professors varies by up to seven percentage points from year to year. Over the three decades in which the survey was conducted, the sample aged 2.5 years, became markedly more female, and reflects a steady increase in the average percentage of time dedicated to extension activities.

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[11] The output variable is calculated as: output = 1*(journal articles) + 3*(books) + 0.75*(book chapters) + 0.5*(edited books)

[12] For the years 1979 to 1995, top ten status was determined by ranking land grant universities based on three criteria: (1) total State Agricultural Experiment Station research expenditures in 1992, (2) the number of doctorates granted in "agricultural sciences" in 1995, and (3) the number of doctorates granted in "biosciences" in 1995. An overall index calculated by equally weighting these three items for each land-grant university. For 2005, top ten status was determined by ranking land grant universities based on the Faculty Scholarly Productivity Index of top performing individual programs.

4 Framework and Econometric Model

The combination of steady research output and decreasing time for science suggests a sharp rise in research productivity; however, to so conclude, one must also account for potential changes in other inputs such as levels of funding, post-docs, and graduate assistants. There are several key inputs to the production of university scientific research: faculty members contribute their own time, delegate tasks to graduate students and post-docs, and need sufficient funding to carry out research. Land Grant university faculty output is multifaceted, producing public research (journal articles, books, abstracts, etc.), private research (consultancies, patents, etc.), teaching output (trained undergraduate and graduate students), and extension/outreach. We focus on the production of a single output, public research, while taking care to account potential biases from changing incentives for other outputs.[13]

The production function for faculty output can be written as:

$$Y = A * F(L, X; Z)$$

where Y is output (e.g., journal articles); L is the amount of a faculty's labor time in research; X represents other inputs, including capital budget; Z are demographic controls; and, A is the standard Solow residual, a measure of average factor productivity[14]. We are interested in two potential phenomena, increases in average factor productivity, A, and changes to the productivity

[13] We would ideally like to place these activities in a multiple-input multiple-output model where we could fully account for all the work product of faculty, including public research output (e.g., books and journal articles), private research output (e.g., patents and commercialization activities), and teaching. Outside of public research, however, we lack consistent data on these outputs across years. While this necessarily produces a partial output measure, the biases we expect would push our results toward zero. Teaching time has remained constant over time and while the potential to patent has increased substantially, days of consulting has remained a negligible average of 3.5 days across the sample years. By not measuring patents and other commercial outputs beyond consulting, we would tend to under-estimate the effects of research time on output, biasing our results toward zero.

[14] Since we are estimating a production function for one of the multiple outputs in the production process, this measure is average factor productivity rather than total factor productivity.

of individual factors of production, faculty labor in particular. Since we are unable to measure "A" directly, we employ the standard approach, which allows us to identify changes in average factor productivity (AFP) over time. At the same time, an estimation of the interaction between labor inputs and time dummies allows for a test of the relative productivity of an additional input of labor in specific years. Our baseline estimation equation takes the form:

$$Y = \phi + \theta T + \gamma_1 L + \gamma_2 (T * L) + \boldsymbol{X}' \boldsymbol{\beta} + \boldsymbol{Z}' \boldsymbol{\delta} + \epsilon \qquad (1)$$

To measure changes in average factor productivity (AFP), after controlling for labor inputs (L), other inputs and controls (X), and individual demographic factors (Z), we can test the significance of θ, the coefficient on a series of time dummies (T). In terms of labor productivity, T*L is a switching variable capturing labor productivity changes over time and our coefficient of interest is γ_2 , which measures how the marginal product of labor changes over time.

While we also do regressions on a composite research output measure, our main dependent variable, the number of journal articles written in the past five years, is subject to some criticism, since we observe neither the number of co-authors, nor the quality of the paper. If faculty respondents are publishing more papers in "easier" journals; or the well-documented increase in co-authorship requires less output per author; or, if the overall number of journals has increased – thereby making publishing easier, our productivity measures would be biased upwards.[15] There are, however, several countervailing forces that suggest it could be harder to publish in 2005 than in 1979. First, many journals, especially top journals have become more

[15] There has been a dramatic increase in the number of published authors in life science journals (over 11 million citations in PubMed/MEDLINE between 2000 and 2004 as compared to just 3 million between 1975 and 1979).

selective, rejecting a higher proportion of articles.[16] Second, as more international scientists publish in US and European journals, there is a larger pool of authors vying for these same spots in journals. Arguably, as demonstrated by Jones (2009), there is also an increased "burden of knowledge," which makes innovation and innovative journal articles more difficult.

A third issue is that since we cannot measure quality, secular changes in the quality of articles over time might bias our labor productivity and technological change results. The aggregate Land Grant university data from 1981 to 1998 used in Foltz et al. (2011) show a 5% and statistically significant positive increase in relative citations rates per article that mirrors a similar increase from other major research universities.[17] Also where Foltz et al. (2007) presents results for quantity and quality adjusted measures of agricultural research together the quantity measures provide the same inference as the quality adjusted measures. Thus we expect at most a small downward bias in our estimates because we are not fully accounting for quality differences. With these potential countervailing arguments in mind, the use of publication counts as a measure of output is well-established in the literature, and we have consistent data across a number of years to identify the effects of research inputs (including time) on research output.

Count Data Model in the Cross-Section Data

In order to account for a discrete integer dependent variable, the regressions use a count data framework. Of the various count data models available, Poisson and negative binomial models are most frequently used for this type of analysis. Within our data, the sample mean

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[16] Leading journals report declining acceptance rates for submitted articles over the past several decades. For instance, the acceptance rate of Nature decreased by nearly a third in the last decade from 11.5% in 1997–99 to 7.6% (2009–2011)

[17] The authors own analysis from the data used in Foltz et al. (2011). For a description of the Foltz et al. relative citation methodology and data sources, please see Foltz et al. (2011).

(12.82) of journal articles is significantly lower than the variance (132.2), which could result from a long upper tail to the distribution caused by a small percentage of "star" faculty producing large numbers of publications.[18]

The standard mathematical notation for a negative binomial model is as follows:

$$y_i \sim Poisson(\mu_i)$$

$$\mu_i = \exp(\boldsymbol{x_i}\boldsymbol{\beta} + \epsilon_i)$$

$$\exp(\epsilon_i) = Gamma\left[\frac{1}{\alpha}, \alpha\right]$$

where y is our measure or research output, $\boldsymbol{x}$ is a vector of input variables including capital and labor and α provides the overdispersion parameter that adjusts the Poisson model into a negative binomial regression. The negative binomial framework estimates dispersion as $V[y_i|\boldsymbol{x_i}] = \mu_i + \alpha\mu_i^p$ where p is specified and α is an estimated parameter of the model. In this analysis, we employ the widely used option where $p = 2$ (the NB2 model). Our results, however, are robust to alternate specifications of the negative binomial model and to using the Poisson model.[19] We

[18] A likelihood ratio test generates a test statistic that rejects the null hypothesis of no overdispersion, indicating a negative binomial regression model, which allows for overdispersion, is appropriate (Cameron and Trivedi, 1998). The likelihood ratio test statistic is equal to 4916.05 , which exceeds the 1% critical value of 5.41 = $\chi^2_{0.98}(1)$

[19] In the NB2 model, the conditional variance is of the form $V[y_i|\boldsymbol{x_i}] = \mu + \alpha\mu^2$ which has the following density:

$$\Pr(y|\mu,\alpha) = \frac{\Gamma(y+\alpha^{-1})}{y!\ \Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right)^{\alpha^{-1}}\left(\frac{\mu}{\alpha^{-1}+\mu}\right)^{y}$$

where Γ() is the gamma function. Accordingly, we estimate the log likelihood function:

$$\ln L(\alpha,\beta) = \sum_{i=1}^{n}\left\{\sum_{j=0}^{y_i-1}\ln(j+\alpha^{-1}) - \ln y! - (y_i+\alpha^{-1})\ln\left(1+\alpha\exp\left(\boldsymbol{x_i}'\ \beta\right)\right) + y_i\ln\alpha + y_i\boldsymbol{x_i}'\ \beta)\right\}$$

estimate the model using university fixed-effect dummy variables and robust standard errors. This allows us to control for the unobserved institutional differences of universities (such as promotion rules, collaborative culture, emphasis on teaching), while the general error term structure allows for the errors to be correlated with other covariates, such as disciplines or years.[20]

Average Factor and Labor Productivity

In order to test for differences in average factor and labor productivity over different time periods, we use time dummies and interact the labor allocation variable with time variables, allowing the marginal product of labor to vary across time periods. The estimation uses the following equation:

$$\ln(Y_i) = \phi + \theta T_t + \gamma_{1a} L_i + \gamma_{1b} L_i^2 + \gamma_{2a}(L_i * T_t) + \gamma_{2b}(L_i^2 * T_t) + \boldsymbol{X'\beta} + \boldsymbol{Z'\delta} + \eta_j + \epsilon_{ij} \qquad (2)$$

where T_t is a time trend, L_i is the actual allocation of time to research, and $(\eta_j + \epsilon_{ij})$ is a two part error term including both university fixed, η_j and a standard error term. ***X*** represents a vector of other inputs including the number of graduate students and post-docs working in the lab or on the faculty member's research team as well as the average annual research budget and budget-squared. Finally, **Z** is a vector of control variables including demographic characteristics of the faculty member; namely, years since PhD, years since PhD-squared, a faculty gender dummy variable, and tenure status. The vector **Z** also includes four disciplinary dummy variables

[20] Our results are robust to using other standard error structures such as clustering and omitting the university fixed effects.

to account for field differences in journal publication. Appendix table 3 describes each of these variables. To measure average factor productivity, θ, the coefficient on time is estimated using year dummies to measure the change between earlier years and 2005. For labor productivity, γ_{2a} and γ_{2b}, are the parameters that test for the change in the effect of faculty research time allocation on article output across the four time periods. We expect that $\gamma_{1a} > 0$ since the proportion of time spent on research should positively affect output, but if there is an increase in output per unit time after controlling for other factors, then $\gamma_{2a} < 0$. Because of diminishing marginal returns, we predict the signs on the squared terms γ_{1b} and γ_{2b} should be the opposite of linear terms. We include terms that separately test the 1979, 1989, and 1995 research time slopes to estimate the productivity of faculty labor time, relative to 2005, the baseline year.

Panel methods

In addition to the cross-sectional data collected in each of the surveys, the surveys contain panel data for the years 1995 and 2005, which allow us to track the evolution of time allocation and research output over these ten years for a consistent sample of panel respondents. In order to estimate productivity effects in the faculty panel, we deploy a fixed-effects negative binomial econometric model.[21] Under this specification, we assume that $Y_{it}|\mu_{it} \sim Poisson(\mu_{it})$, where $\mu_{it}|\alpha_{it} \sim \Gamma(\lambda_{it}, a_{it})$, and $\lambda_{it} = \exp(x_{it}B)$. As in the cross-section version, α_{it} is the dispersion parameter to be estimated except that α_{it} will be the same in both time periods for a given panel observation (Hausman et al., 1984). The panel specification is estimated as a conditional log-likelihood function and follows equation (2):

[21] Results using the fixed-effects Poisson model, which makes weaker distributional assumptions, yields similar (and more statistically significant) results. The poisson model also avoids the incidental parameters problem. The drawback of this model is that it does not allow for overdisersion of the independent variable.

$$\ln(Y_{it}) = \phi + \theta T_t + \gamma_{1a} L_{it} + \gamma_{1b} L_{it}^2 + \gamma_{2a}(L_{it} * T_t) + \gamma_{2b}(L_{it}^2 * T_t) + \boldsymbol{X'\beta} + +\nu_i + \epsilon_{it}. \quad (3)$$

In equation (3) neither individual characteristics (**Z**) nor university fixed effects, η_j, enter the model. Instead, ν_i, the individual fixed effects, capture both individual and university-specific characteristics. As in equation (2), the coefficients of interest are γ_{2a} and γ_{2b}.

Relative Prices

Across universities, an individual faculty's research, teaching, and grant raising efforts will likely vary with the value that her university places on each activity for evaluating salary, tenure and promotion. In each of the four surveys, however, we have information on the incentives for tenure and promotion which guide faculty time allocation and output.[22] Using these data, we create a measure of relative "reward" of these activities and use them to price inputs in the faculty's production function. [23] These relative prices provide a control measure for incentives that may have shifted faculty effort toward outputs other than public research and thereby bias our results. Using the reward for "many" journal articles as the numeraire good, we create relative prices for faculty teaching, grant raising and high quality journal articles. For teaching, the adjusted measure is:

$$AdjTeaching_i = \frac{p_{teaching_{j,t}}}{p_{many_{j,t}}} * TeachingPct_i$$

[22] The survey asks faculty to place a value between 1 and 5 on the "reward" associated with 'many journal articles', 'high-quality journal articles', 'teaching evaluations' and so forth.

[23] Using the 2968 observations which report information on the reward to various activities, we create an index of relative prices for each year and university. In each university-year reward category, there are an average of 13 observations, with values ranging between zero and 60.

where $p_{many_{j,t}}$ is the reward for "many" journal articles at university j in year t; $p_{teaching_{j,t}}$ is the reward for teaching, and $TeachingPct$ is the actual percentage of time spent teaching for that faculty member. Using an adjusted measure for teaching and five-year budget, we modify equation (2) above and estimate the following equation:

$$\ln(Y_i) = \phi + \theta T_t + \gamma_{1a} L_i + \gamma_{1b} L_i^2 + \gamma_{2a}(L_i * T_t) + \gamma_{2b}\left(L_i^2 * T_t\right) + \boldsymbol{X'\beta} + +\boldsymbol{Z'\delta}$$
$$+ AdjTeaching_i + AdjTeaching_i^2 + AdjBudget_i + AdjBudget_i^2$$
$$+ RelPrice_{high_{j,t}} + \eta_j + \epsilon_{ij}$$

where the adjusted measures are defined above and the $RelPrice_{high_{j,t}}$ term is the reward of high-quality journal articles divided by $p_{many_{j,t}}$, the reward for many journal articles.

5 Results

The baseline productivity estimations, reported in table 3, test AFP and labor productivity. The results provide no evidence for across the board changes in average factor productivity. They do, however, provide compelling evidence of rising labor productivity of faculty after controlling for inputs and the fields and demographics of researchers. As expected, our measure of research time, research percentage, increases faculty output significantly in both journal articles and our measure of composite output, although at a declining rate. The primary coefficients of interest—faculty research time interacted with time period intercepts—provide a measure of how labor productivity has changed over time. In column 1, using journal articles as the dependent variable, we find that there are significant differences in labor productivity between 1979, 1989 and 2005 as evidenced by the significant coefficient on the interaction between research percentage and the 1979 and 1989 dummies. Column 2 repeats this specification using the composite output variable, and gives even stronger results than column 1 in terms of showing a progression of rising faculty productivity from 1979 to 2005.[24] We also find strong positive effects of increased research budget, and more graduate students and post-docs.

Next, we test for differences in our estimates of AFP and labor productivity changes across top-ten and non-top-ten universities. With the sample split in this way, table 4 shows that the significant labor productivity increase in the full sample appears to be based on significant changes at non-top ten universities. At these universities, the coefficients on the switching terms are all negative and significant at the 5% level in 1979 and 1989, providing strong evidence of productivity growth in non-top ten schools from 1979—2005 and 1989—2005. Meanwhile the key coefficients on research productivity in column 1 are not significant for the top-ten universities, although their signs are primarily in the same direction. As found in the research on BITNET's effect on universities (Agrawal and Goldfarb, 2008; Ding et al., 2009) and Foltz et al.'s (2011) aggregate productivity work, the non-top ten Land Grant universities appear to be the ones which gained the most in terms of research productivity after the revolution in computation and improvements in the suite of life science technologies available to researchers. These split sample results underscore the potential heterogeneity of research processes across Land Grant universities as well as a potentially equalizing effect of new technologies in agriculture and life sciences.

Overall, the cross-section data results provide strong evidence for a temporal trend of higher labor productivity associated with declining research time for faculty in part due to more time spent on grant administration or competition. Using an analysis of factor change in 2005, we find that a one unit increase in research time percentage would increase productivity by 2.9

[24] In the regressions that follow, we use journal articles rather than the composite output measure as the dependent variable. The results using the composite measure, available from the authors, are equally strong and provide the same inference.

percent. If researchers were able to dedicate just 5% more of their time to research, the model predicts journal output would increase by 1.69 articles over each five-year period. While faculty labor is important, it is worth noting that other inputs matter as well. We find that the marginal effect of an additional graduate student raises expected output by 6.4% and a post-doc by 22.6%, holding all other variables constant.

Panel results

The cross-sectional results could be subject to the criticism that it is unobserved or unobservable faculty characteristics that drive the observed productivity increases. If, for instance, faculty in 2005 are intrinsically more able or better trained than in past years this could account for the observed productivity change. The panel data estimates in table 4, by following the same faculty members over a 10-year period, account for any unobservable time-invariant biases or changes in sample makeup that might exist in the cross section. For comparison purposes, columns 1 and 2 of table 5 show the results from the random-sample cross-sectional data from just 1995 and 2005, while columns 3 and 4 show the results of the fixed effects negative binomial using the panel, which contains information on 147 faculty in 1995 and 2005. The columns use, respectively, the “Research Percentage” and “Doing Research” variables to measure faculty labor input and have the standard set of control variables. The consistency in the parameter estimates between the panel and cross-section is remarkable: for example the estimated parameters on the labor variables, “Research Percentage” and “Doing Research” and their squares, are the same to 3 decimal places across the cross-section and panel data estimates.

When we consider the key variable of interest, the interaction of labor time with the 1995 dummy, the panel estimates show significantly lower levels of labor productivity in 1995 than in

2005. While the panel data show a more statistically significant effect for the research percentage than in the cross section, the doing research measure goes from significant at a 5% level to merely a 10% level in the panel data estimate. In the case of both the research percentage measure and the doing research measure, the net productivity of labor in 1995 is quite small while that of 2005 is significantly positive. Because we control for age and experience of the faculty in the panel through the variable "Years since PhD" and its square, this implies that it is not lifecycle effects, but rather improvements in labor productivity, which are driving the increase in productivity. Overall, these panel data results provide strong evidence that the results in this work are not driven by changes in the cross-sectional sample or unobserved productivity improvements of faculty over the years, rather they show consistent evidence of labor productivity improvements.

Relative Prices

Table 5 depicts the results of our estimations using the relative price measures to capture how incentives for teaching and grants may have affected journal article output. These results include the adjusted measures of teaching percentage and five-year budget, with these variables normalized by their relative importance in the university, as well as a variable measuring the relative price of high-quality journal articles. If faculty are at a university where particular attention is paid to teaching, grantsmanship or high-quality articles, they may be produce fewer articles.[25] Columns 1 and 2 show the results of this estimation using journal articles and composite output, respectively, as the dependent variable. As in our main result, there is a

[25] Across all of the faculty members, producing many journal articles was rated higher (4.19/5) than producing high quality journal articles (3.59/5), but 15% of the respondents ranked high-quality journal articles as being more important.

negative and significant coefficient on the 1979 and 1989 labor productivity terms. The amount of time spent teaching had an insignificant effect on the research output of faculty, using both journal articles and the composite measure.[26] Columns 3 and 4 split the sample into those faculty with teaching responsibilities above and below 15 percent of their total time, as a way of testing differences between primarily research faculty and others. As with first two columns, there is no effect of teaching time allocation on output. However, faculty with light teaching loads are affected by their university's focus on high-quality journal articles; among this subgroup, they produce slightly fewer articles. In addition, the increase in productivity for 2005 relative to 1979 and 1989 is higher in both magnitude and significance for this subgroup than for those with higher teaching loads.

Robustness Checks

The last two tables address potential concerns associated with the budget and with our dependent variable. Table 6 adds two robustness checks related to our measure of a faculty's budget. One concern is that we might induce multicollinearity by double counting the budget, since a large portion of research budgets used for the salaries of faculty, graduate students, and post docs, which are already accounted for in our regression. A separate concern is that the Huffman-Evenson deflator we use does not fully or adequately account for changes in laboratory machinery or computational power, which could bias the results. Column 1 of table 6 addresses the first concern by dropping the budget variable. These results have similar and significant negative coefficients on the switching terms, as compared to our main results. The second column includes six terms interacting the budget variable (and its square) with year dummies, to

[26] This same effect is robust to using raw teaching time percentages rather than the incentive adjusted value.

account for potential problems in our deflators. None of the coefficient on the interacted budget terms are statistically significant and our main results hold here as well.

Finally table 7, as best as we can with the available data, addresses concerns that our measure of output does not take into account the quality of the articles produced. Although we do not have information on citation rates for articles from the 1979, 1989 and 1995 surveys, we obtained publication and citation counts from the Web of Science for faculty respondents of the 2005 survey for journal articles produced between 2001 and 2005.[27] Using OLS we regress the log of the average number of journal articles per year on the same explanatory variables used in our main specification, while the second column uses the log of quality-adjusted journal articles as the dependent variable. [28] If normalizing by the number of citations had a substantial effect on the analysis, the results would show different coefficient estimates on research time. Instead, we cannot reject the null hypothesis that the coefficient estimates on our two variables of interest, research time and its square, are same between the number of journal articles and the quality-adjusted measure.[29] Thus we believe that any bias from quality differences is likely to be small.

[27] Faculty names were searched in the Web of Science database generating article counts and the number of times each of their articles had been cited. We dropped 76 respondents because their names could not be uniquely identified (e.g., John Smith). The correlation between the Web of Science and self-reported article counts was 0.823. Given that Web of Science omits lesser journals it is not surprising that there is not a 100% correlation.

[28] Quality is adjusted by multiplying the scientist's journal article count by his citation count divided by the average number of citations per article within the faculty's discipline. In order to keep researchers with zero articles, a small number (0.000001) was added to this variable before the log was taken.

[29] Test statistics of inequality of the coefficients, $\chi^2(1)$, ranged from 1.05 to 0.01, which were not significant at even a 25% confidence level, allowing us to accept the null hypothesis of coefficient equality.

6 Conclusion

Our main finding is that increases in faculty labor productivity supported stable public research output in an era of diminishing faculty time for research and increased incentives for commercially oriented, private, research. This result is a critical addition to the literature on university agricultural research, because it explicitly incorporates the issue of whether scientists are able to make time for science. We find direct evidence that faculty struggle to do so, but that they are also benefitting from an era of improved productivity associated with major breakthroughs in life science and informational technology and tools.

This analysis also demonstrates that productivity advances and rising administrative time demands on faculty cut in opposite directions in their effects on faculty research outputs. It appears that technological change produced a significant labor research productivity boost among agricultural and life scientist faculty at US universities in the three decades leading up to 2005. The estimates presented here of significant labor productivity changes are likely an underestimate of the full productivity change, since they do not account for rising Land Grant university research quality and increasing alternate demands of commercialization and patenting. At the same time increases in administrative workloads of faculty in both explicit and implicit forms, perhaps in part fostered by technological change (Acemoglu et al., 2007), have reduced faculty time allocation to research sufficiently to leave the core scholarly research activities at the same output level as before the productivity improvements. The evidence from these data suggests that the benefits of increased faculty productivity substantially have been swallowed by increases in administrative work and the search for competitive grants rather than either generating new scientific output or freeing up faculty time to teach the next generation of scholars. This finding raises serious questions about whether the rising administrative demands on faculty time at US universities from both declining support staff and increased administrative rules are reducing the benefits of the technological revolution in the life sciences and whether time allocation is optimal at US Land Grant institutions. If time allocation were optimal, it would mean that the marginal value of faculty time allocated to administration had risen over time relative to the value of research efforts.[30]

In summary, our empirical analysis reveals robust evidence that explains an apparent productivity paradox in research output produced by agricultural and life science faculty at U.S. Land Grant universities. On the one hand, improvements in faculty research productivity measured in terms of output per unit time increased significantly from 1979 to 2005, as much as 30%. On the other hand, those same faculty faced increasing demands on their time for a range of administrative tasks, some associated with research and others not. These findings raise important questions about whether universities should be encouraged and supported to find ways that would free up more time for faculty actually doing research. Given the high return to agricultural research activities and public research output for US agricultural production identified elsewhere, it would seem important to foster more faculty time for research. Most faculty members would be likely to respond enthusiastically to that type of organizational endeavor, especially if it were to come at the margin of administrative duties.

[30] As suggested by a reviewer, such an increase in the marginal value of faculty time in administration could be the case if the time were necessary to secure large competitive grants and it was those grants that allowed faculty labor productivity to increase. Our data do not, however, show that competitive grants have a significant effect on journal article productivity.

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Table 12: Research Output and Research Inputs, 1979 – 2005

Panel A: Research Inputs

		Sample Year			
		1979	1989	1995	2005
Actual Time Spent	Research (%)	60.2	58.2	52.4	45.9
	Teaching (%)	28.6	24.9	30.1	29.1
	Admin (%)	4.7	7.3	5.8	9.3
	Extension Appt. (%)	5.6	7.9	8.6	14.5
Research (%)	Top-ten schools	60.8	59.8	53.3	45.4
	Not Top-ten	59.1	55.5	50.1	47.2
Research Time	Grant Preparation (%)	-	-	13	20
	Administration (%)	-	-	14.6	21.6
	Doing Research (%)	-	-	71.6	58.4
Adjusted Actual Research Time (%)		-	-	37.6	26.7
Inputs	Grad students	2.73	2.47	2.85	2.38
	Post docs	0.17	0.38	0.4	0.43
	Technicians	1.39	1.17	1.3	1.14
	Research Budget ($1000)	180	152	137	168

Panel B: Research Outputs

Journal Articles	Full Sample	12.2	13.1	12.6	13.1
	Top-ten schools	14.2	15.6	14.4	14.6
	Not Top-ten	11.2	11.8	11.9	12.5
Output**	Full Sample	13.7	15.1	15	15.4
	Top-ten schools	16	18.1	17.5	17.1
	Not Top-ten	12.5	13.4	14.1	14.7

**Output is calculated according to the formula: Output = 1*(journal articles) + 3*(books) + 0.75* (book chapters) + 0.5* (edited books)

Panel C: Sample Composition		Sample Year			
		1979	1989	1995	2005
Demographic	Assistant Prof. (%)	14.6	20.2	13.1	19
	Associate Prof. (%)	26	27.9	26.9	27.4
	Full Prof. (%)	59.3	51.6	60	53.6
	Years since PhD	16.8	16.3	18.9	19.6
	Female (%)	4.5	7.5	5.5	18.4
Disciplines	Animal Science (%)	19.7	22.7	16.4	15.2
	Plant Science (%)	57.9	59.4	52	49.8
	Env. Science (%)	11.9	7.6	23.3	21.3
	Food Science (%)	9.2	7.5	6.6	13.8
	Other (%)	1.3	2.8	1.8	0.0

Table 2: Main Results: Negative Binomial Regression

VARIABLES	(1) Journal Articles	(2) Output	VARIABLES	(1) Journal Articles	(2) Output
Research (%)	0.0267***	0.0241***	Years Since PhD	-0.0233**	-0.0191**
	(0.00522)	(0.00504)		(0.00908)	(0.00865)
Research (%)^2	-0.000179***	-0.000164***	Years Since PhD^2	0.000192	0.000171
	(5.31e-05)	(5.07e-05)		(0.000208)	(0.000196)
Research Pct * 1979	-0.0165*	-0.0231**	Grad Students	0.0654***	0.0675***
	(0.00952)	(0.00948)		(0.00928)	(0.00903)
Research Pct * 1989	-0.0139*	-0.0162**	Post Docs.	0.170***	0.172***
	(0.00818)	(0.00733)		(0.0249)	(0.0236)
Research Pct * 1995	-0.00467	-0.00404	Extension Appt. (bin)	-0.00168*	-0.00101
	(0.00859)	(0.00819)		(0.000990)	(0.000915)
Research Pct^2 * 1979	0.000140*	0.000187**	5 Year Budget	0.0403***	0.0344***
	(8.44e-05)	(8.30e-05)		(0.0130)	(0.0129)
Research Pct^2 * 1989	0.000113	0.000136**	Budget^2	-0.000120***	-9.53e-05**
	(7.42e-05)	(6.76e-05)		(3.85e-05)	(3.82e-05)
Research Pct^2 * 1995	5.71e-05	5.20e-05	Tenure Status	0.311***	0.328***
	(8.57e-05)	(7.94e-05)		(0.0385)	(0.0373)
Year 1979	0.0659	0.264	Gender	0.105*	0.0816
	(0.253)	(0.256)		(0.0545)	(0.0511)
Year 1989	0.111	0.161	Disc: Ani Sciences	0.480***	0.479***
	(0.213)	(0.188)		(0.125)	(0.119)
Year 1995	-0.142	-0.135	Disc: Plant Sciences	0.387***	0.441***
	(0.202)	(0.197)		(0.122)	(0.116)
Constant	0.715***	0.777***	Disc: Env. Sciences	0.237*	0.321***
	(0.270)	(0.258)		(0.131)	(0.122)
			Disc: Food Sciences	0.565***	0.577***
				(0.132)	(0.125)
Observations	1,844	1,844			
Univ FEs	Yes	Yes			

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 3: Top-ten vs. non-top ten

VARIABLES	(1) Top-ten Journal Articles	(2) Non Top-ten Journal Articles
Research (%)	0.0314***	0.0250***
	(0.0101)	(0.00546)
Research (%)^2	-0.000234**	-0.000162***
	(0.000101)	(5.55e-05)
Research Pct * 1979	-0.0102	-0.0205*
	(0.0145)	(0.0114)
Research Pct * 1989	-0.00412	-0.0216**
	(0.0174)	(0.00855)
Research Pct * 1995	0.00164	-0.00711
	(0.0170)	(0.00969)
Research Pct^2 * 1979	0.000116	0.000160
	(0.000136)	(9.96e-05)
Research Pct^2 * 1989	6.64e-05	0.000159**
	(0.000158)	(7.69e-05)
Research Pct^2 * 1995	-1.60e-05	8.00e-05
	(0.000174)	(9.38e-05)
Constant	0.689*	0.764***
	(0.397)	(0.277)
Observations	603	1,241
Univ FEs	Yes	Yes
Input and Control Vars.	Yes	Yes
Year Dummies	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Input variables are: Graduate students, Post Docs, Budget, Budget^2. Control Variables include: Gender, Years since PhD, Years since PhD^2, Tenure Status, Extension Appointment (%); Dummies for Animal Sciences, Plant Sciences, Food Sciences and Environmental Sciences.

Table 4: Panel Data Results

VARIABLES	(1) Cross-section Journal articles	(2) Cross-section Journal articles	(3) Panel data Fixed effects Journal articles	(4) Panel data Fixed effects Journal articles
Research (%)	0.0277***		0.0296***	
	(0.00466)		(0.00943)	
Research (%)^2	-0.000189***		-0.000265***	
	(4.73e-05)		(9.76e-05)	
Research Pct * 1995	-0.00702		-0.0324**	
	(0.00859)		(0.0139)	
Research Pct^2 * 1995	8.31e-05		0.000315**	
	(8.60e-05)		(0.000126)	
Doing Research (%)		0.0246***		0.0272***
		(0.00545)		(0.00937)
Doing Research^2		-0.000256***		-0.000360***
		(7.43e-05)		(0.000139)
Doing Research*1995		-0.0188**		-0.0215*
		(0.00836)		(0.0121)
Doing Research95^2		0.000231**		0.000272*
		(0.000105)		(0.000147)
Constant	0.550**	1.083***	3.004***	3.658***
	(0.241)	(0.283)	(0.776)	(0.974)
Observations	735	717	294	292
Groups			147	146
University Fixed Effects	Yes	Yes	No	No
Year Dummies	Yes	Yes	Yes	Yes
Input/Control Variables	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Input variables are: Graduate students, Post Docs, Budget, Budget^2. Control Variables include: Gender, Years since PhD, Years since PhD^2, Tenure Status, Extension Appointment (%)

Table 5: Relative Prices

	(1)	(2)	(3)	(4)
	Relative Prices		Teaching < 15%	Teaching ≥15%
VARIABLES	Journal Articles	Output	Journal Articles	Journal Articles
Research (%)	0.0274***	0.0234***	0.0298***	0.0363***
	(0.00532)	(0.00517)	(0.00720)	(0.00847)
Research (%)^2	-0.000210***	-0.000174***	-0.000206***	-0.000315***
	(5.54e-05)	(5.34e-05)	(7.08e-05)	(8.93e-05)
Research Pct * 1979	-0.0184*	-0.0251***	-0.0307**	-0.0190
	(0.00942)	(0.00943)	(0.0150)	(0.0121)
Research Pct * 1989	-0.0147*	-0.0167**	-0.0306***	-0.0208
	(0.00801)	(0.00721)	(0.0102)	(0.0140)
Research Pct * 1995	-0.00930	-0.00729	-0.0114	-0.0226
	(0.00883)	(0.00830)	(0.0120)	(0.0142)
Adj. Teaching %	-0.00335	0.000975	0.0314	-0.00581
	(0.00371)	(0.00359)	(0.0284)	(0.00633)
Adj. Teaching %^2	-4.76e-05	-9.15e-05*	-0.00218	1.29e-05
	(5.27e-05)	(5.12e-05)	(0.00317)	(7.77e-05)
Adjusted Budget ($000)	0.0363***	0.0323**	0.0647**	0.0430***
	(0.0135)	(0.0135)	(0.0257)	(0.0155)
Adjusted Budget^2	-0.000106***	-8.81e-05**	-0.00206***	-0.000125***
	(3.91e-05)	(3.91e-05)	(0.000703)	(4.49e-05)
Rel. Price High-Quality Articles	-0.0843	-0.171	-0.655	0.0148
	(0.238)	(0.226)	(0.522)	(0.250)
Constant	1.025***	1.106***	1.735**	0.750
	(0.366)	(0.344)	(0.679)	(0.467)
Observations	1,844	1,844	492	1,352
Univ FEs	Yes	Yes	Yes	Yes
Input and Control Vars.	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Input variables are: Graduate students, Post Docs, Budget, Budget^2. Control Variables include: Gender, Years since PhD, Years since PhD^2, Tenure Status, Extension Appointment (%); Dummies for Animal Sciences, Plant Sciences, Food Sciences and Environmental Sciences.

Table 6: Robustness Checks (Budget variable variations)

VARIABLES	(1) Without Budget Journal Articles	(2) Budget Interaction Journal Articles
Research (%)	0.0287***	0.0261***
	(0.00507)	(0.00530)
Research (%)^2	-0.000195***	-0.000175***
	(5.13e-05)	(5.37e-05)
Research Pct * 1979	-0.0194**	-0.0166*
	(0.00939)	(0.00954)
Research Pct * 1989	-0.0174**	-0.0146*
	(0.00792)	(0.00820)
Research Pct * 1995	-0.00809	-0.00290
	(0.00863)	(0.00867)
5 Year Budget		0.0568**
		(0.0228)
Budget^2		-0.000168**
		(6.77e-05)
Budget*1979		-0.00148
		(0.0402)
Budget*1989		-0.00135
		(0.0283)
Budget*1995		-0.0209
		(0.0526)
Constant	0.718***	0.698**
	(0.265)	(0.272)
Observations	1,893	1,844
Univ FEs	Yes	Yes
Input and Control Vars.	Yes	Yes
Year Dummies	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Input variables are: Graduate students, Post Docs, Budget, Budget^2. Control Variables include: Gender, Years since PhD, Years since PhD^2, Tenure Status, Extension Appointment (%); Dummies for Animal Sciences, Plant Sciences, Food Sciences and Environmental Sciences.

Table 7: Robustness Checks: Citation-adjusted articles
(OLS with 2005 data only)

VARIABLES	(1) Web of Science: Ln(Journal Articles)	(2) Web of Science: Ln(Quality-Adjusted Journal Articles)
Research (%)	0.125***	0.123***
	(0.0326)	(0.0360)
Research (%)^2	-0.000702**	-0.000565
	(0.000299)	(0.000351)
Observations	710	710
R-squared	0.289	0.321
Univ FEs	Yes	Yes

Estimation includes the same control variables as in table 2.
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A1: Universities included in the Sample

University		
Auburn	U. Alaska	U. Nebraska
Clemson	U. New Hampshire	U. Nevada
Colorado State	U. Arizona	U. North Carolina
Cornell	U. Arkansas	U. North Dakota
Iowa State	U. Connecticut	U. Rhode Island
Kansas State	U. Delaware	U. South Dakota
Louisiana State	U. Florida	U. Tennessee
Michigan State	U. Georgia	U. Vermont
Mississippi State	U. Hawaii	U. West Virginia
Montana State	U. Idaho	U. Wyoming
New Mexico State	U. Illinois	UC-Berkeley
Ohio State	U. Kentucky	UC-Davis
Oklahoma State	U. Maine	UC-Riverside
Oregon State	U. Maryland	Utah State
Penn. State	U. Massachusetts	UW-Madison
Purdue	U. Minnesota	Virginia Polytechnic
Rutgers	U. Missouri	Washington State
Texas A&M		

Table A2: Departments included in the sample

Discipline / Departments	Frequency	Percent
Animal Sciences		
Animal sciences, dairy sciences, meat and poultry sciences	350	18.98
Environmental Sciences		
Atmospheric science, environmental science, ecology, fisheries, hydrology, natural resources	1028	55.75
Food Sciences		
Food chemistry, food engineering, food sciences, nutrition	173	9.38
Plant Sciences		
Agronomy, biometry, biostatistics, crop sciences, entomology, geography, plant pathology, soil sciences	268	14.53
Total	1844	100

Table A3: Variable descriptions

Variable	Description
Journal Articles	The number of sole or co-authored journal articles in the five year period preceding the survey
Output	A composite research output variable calculated as follows: Output = 1*(journal articles) + 3*(books) + .75* (book chapters) + .5* (edited books)
Research (%)	The percent of time allocated to research (additional options were: teaching, administration, extension and outreach, other)
Doing Research (%)	The percent of time allocated to research less time spent on administration or grant preparation
Years since PhD	The number of years since a faculty member completed his/her PhD
Grad Students	Respondents indicated the number of graduate students working “under their direction in their research program”
Post Docs	Respondents indicated the number of postdocs working “under their direction in their research program”
Extension Appt. (bin)	Binary variable equal to 1 if the faculty member had a formal extension appointment
Budget (5 year)	The average annual budget of a faculty member’s research program over the five years prior to the survey date. Data were converted into 2000 dollars using the Huffman-Evenson Agricultural R&D price index.
Tenure Status	Position of faculty member. 1=Asst. Prof; 2=Assoc. Prof; 3=Full Prof.
Gender	Binary variable equal to 1 if the faculty is male
Animal Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of an animal sciences department
Plant Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of a plant sciences department
Env. Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of an environmental sciences department
Food Sci. (Disc.)	Binary variable equal to 1 if faculty is a member of a food sciences department
Year	A dummy variable for each of the years 1979, 1989, and 1995. 2005 is the excluded year
Research Pct *(Year)	Interaction between the research percentage and the year dummy variable