TECHNOLOGICAL ADOPTION IN RURAL COCHABAMBA, BOLIVIA[1]

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A survey of about one thousand smallholder households in the Department of Cochabamba, Bolivia, is used to examine the determinants of adoption of new farm technologies. A historical analysis shows that government policies since colonial days have made it difficult for smallholders to accumulate assets and improve farm productivity. The survey is used to identify the ecological and socioeconomic determinants of the adoption of chemical fertilizers and pesticides among smallholders in four altitude zones: highlands, high valleys, low valleys, and tropics. Ecological zone did not prove to be a statistically significant determinant of adoption in the pooled sample. Within any one altitude zone, no determinant predicted the adoption of both technologies. Standard determinants of adoption in other countries (e.g., education, income, land tenure) did not explain adoption across zones or for either of the two technologies. The conclusion contains a discussion of the role of history in adoption and the possible consequences of adoption for smallholders and Bolivia.

ANTHROPOLOGISTS HAVE LONG STRESSED the ecological heterogeneity of the Central Andes (Murra 1975). Among ecological zones in Bolivia, the valleys have been singled out as an economically lively region because they enjoy lower climatic risks, denser populations, larger markets, greater prevalence of private land tenure, widespread rural credit markets, and much exposure to the outside world since colonial days. Lying between the highlands and the tropics, valley dwellers have lower transport costs to reach lands either far above or far below them and can produce crops and raise animals adapted to the ecological extremes. In parts of Bolivia, smallholders with access to lands in the valleys had higher income than smallholders with access to plots only in the highlands or only in the lowlands (Dorsey 1975a, 1975b).

Owing to the more favorable ecological and economic endowments of the valleys, some scholars have noted that the adoption of new farm technologies in Bolivia (e.g., chemicals, tractors) tends to be more marked at lower elevations (Zuvekas 1977). Policy analysts thus suggest that future efforts to produce and diffuse new production technologies in agriculture in Bolivia should focus on the valleys, with the highlands reserved for grazing and the tropics for biodiversity.

To explore these ideas, we use a survey from the Department of Cochabamba of about one thousand farm households in four ecological zones (Figure 1). We use the survey to achieve two goals. First, we test whether ecological zone matters in the adoption of modern farm technologies. In particular, we

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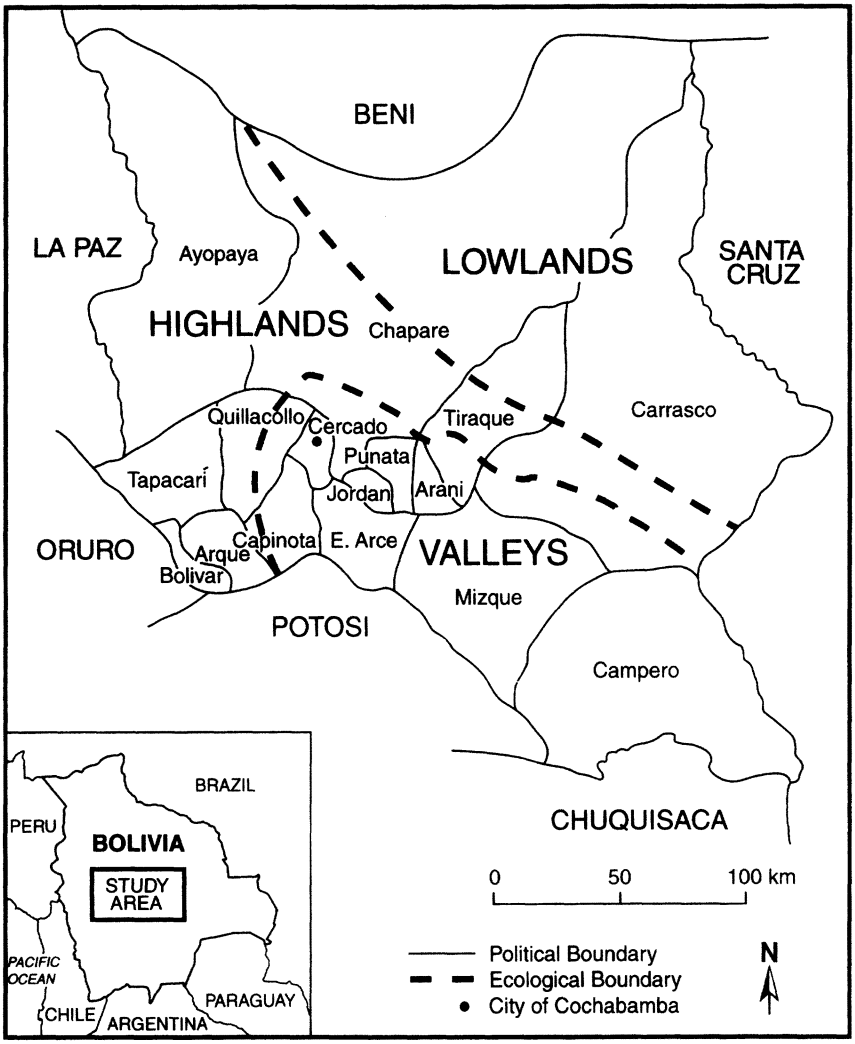

Figure 1. Political and Ecological Divisions of Cochabamba, Bolivia (Adapted from Painter 1995:146 and Muñoz 1994:135)

test whether smallholders who live in the valleys have a higher probability of adopting new technologies than smallholders who live in the highlands or than smallholders who live in the tropics. Second, we test whether conventional determinants of adoption identified in other countries (e.g., education) (Rogers 1995) also predict the adoption of technologies in different ecological zones of Cochabamba. By modern farm technology we mean new ways of producing crops, raising livestock, or processing and storing goods produced on the farm.

The information we use is unique. First, unlike other departments of Bolivia, the Department of Cochabamba straddles most vertical zones of the Andes. The survey allows us to test, with quantitative data, well-established ideas about the effects of access to ecological zones. Second, the survey is among the first large rural household surveys for Bolivia; it allows researchers to complement qualitative and historical studies that have characterized much of the past research in rural Bolivia. Last, since the Department of Cochabamba contains the densest rural population of Bolivia, findings from Cochabamba can teach us something about a large portion of Bolivia's rural population.

ECOLOGICAL ZONES

Researchers have found it useful to describe the ecological heterogeneity of the Andes by dividing it into three to four horizontal belts corresponding to different altitudes (Guillet 1981). Each belt is an ideal type with its own flora, climate, fauna, land type, etc. Since zones blend with each other at the upper and lower limits, the pattern resembles a continuum rather than a ladder with discrete steps (see Figure 1).

The highlands of Cochabamba, about 3,500–4,000 meters above sea level, are a broad swath exhibiting mixed agropastoral production. Several varieties of Andean tubers and barley grow well; livestock activities center around llamas. Agricultural technology is simple: planting is done with digging sticks. The main form of settlement is the village, which is often depopulated after the harvest when people migrate to seek seasonal employment (Pérez-Crespo 1991b).

The high valleys (3,000–3,500 meters) lie below the highlands. They are warmer and more fertile than the highlands and sustain a more intensive and varied mix of agropastoral production. Cereals, squash, maize, fruits, legumes, and Andean tubers grow well in this tier. Stock raising is also broader than in the highlands, encompassing more European and indigenous animals. In settlement pattern, highlands and high valleys differ in degree rather than in kind. In both zones, the nucleated village is the essential community type, but villages become denser as one moves down in altitude.

The low valleys (2,000–3,000 meters) are warmer and lusher; yet they are still semiarid and contrast with the humid tropics of the lowest zone. Pepper, maize, fruits, medicinal herbs, and cotton grow well here. Cattle and goats prevail, though sheep are also found. Llamas are less common, but yoked bullocks are more common. This is also the area with the greatest irrigation.

The lowland tropics (below 2,000 meters) exhibit much ecological variation, from moist tropical rain forests in the coca-growing region known as Chapare to drier forest abutting the Department of Santa Cruz. Chapare has become a center for the production of coca and its derivatives.

THE VALLEYS AND TECHNOLOGICAL INNOVATIONS IN BOLIVIA

Research in Bolivia suggests that valley dwellers may enjoy environmental and economic advantages in agricultural production over people in the highlands or in the tropics. The valleys of Bolivia have less hail and frost than the highlands and fewer floods than the tropics, though the risk of drought and pest infestation may be greater (Thomas 1979). A gentler topography, flatter lands, more possibilities for irrigation (World Bank 1992), more private land tenure, and a denser population and network of roads have made it easier for valley dwellers to intensify production since colonial days (Larson 1988).

Case studies from Bolivia show that the adoption of modern farm technologies has been more prominent in the valleys because of greater security of land tenure (Dorsey 1975b), larger farm sizes (Pou 1972), more credit facilities (Muñoz 1994), and lower natural risks (Rice 1974). This situation has allowed smallholders in the valleys to use modern inputs (Zuvekas 1977).

The economic dynamism of the valleys and lowlands, coupled with their population density and their political clout since the Revolution of 1952, has influenced policy makers' decisions about where public investments in agriculture should go (Schuh, Roe, and Godoy 1994; Zuvekas 1977). For instance, researchers from the World Bank concluded that public investments in the highlands should focus on reducing poverty through better education and health, and not so much through improvements in agricultural productivity for smallholders, because the highlands face a harsh climate (World Bank 1992). The authors recommend greater investments in agricultural research, land titling, and irrigation in the highlands, but only in the short run; in the long run, they see smallholders leaving the highlands. In contrast, the authors put investments in agricultural research and extension at the core of the development for the valleys because the valleys do not face "natural-resource constraints" (World Bank 1992).

Although the Bolivian countryside has two agricultural technologies—an archaic technology in the highlands and a modern technology in the valleys and in the lowlands—it remains unclear the extent to which ecological zone matters in the adoption of new farm technologies once we control for the socioeconomic attributes of different zones. Put differently, valley dwellers may be more likely to adopt these technologies than highlanders, but it is unclear whether this reflects the ecological advantages of living in the valley or, instead, access to credit, proximity to roads, or the demographic characteristics of households in the valley. In the balance of this article, we estimate the pure effect of ecology after controlling for the socioeconomic and demographic attributes of different zones.

THE SURVEY

We use a household survey collected in the Department of Cochabamba in 1991 by several national and international organizations (Cuevas 1993). The survey was designed to collect information on the determinants of income among smallholders to gain better knowledge of the countryside because the last large rural survey in Bolivia had been done in 1987. About 1,100 households were surveyed; the response rate reached 86 percent. We use information only from farming households (n = 997).

THE HISTORICAL CONTEXT

From colonial days to the present, small farmers in Cochabamba have found it difficult to increase their income and to accumulate capital owing to discriminatory policies by the Spanish Crown and, later, by the Bolivian government (Pérez-Crespo 1991b).

Colonial and Republican Era: Taxes

By the 1580s, soon after the conquest, Spaniards had already taken over the most fertile lands in the valleys of Cochabamba and had pushed Indians to marginal lands (Larson 1988). Had Indians been able to compete in colonial markets, they could have increased their income, but the Crown made it difficult for them to do so. The Church established an inflexible system of tithes in Cochabamba, by which it auctioned to large landowners the right to tax private grain production from peasant and Indian communities (Larson 1988). Taxes drove many small producers into poverty and wage labor and pushed them into cities, particularly when droughts struck (Larson 1988).

Taxes on small producers continued well into the nineteenth century, because the government relied on such taxes for its revenues (Rodríguez Ostria 1977). The government tried to privatize and tax the holdings of peasant and Indian villages to stimulate the development of private land markets (Klein 1988). Although attempts at privatization met with resistance from rural people in the highlands, the government continued to tax farm production in the valleys of Cochabamba, where resistance was weaker owing to greater ethnic heterogeneity (Rodríguez Ostria 1993). Writing before the 1952 Revolution, Thibodeaux (1946) noted that small producers did not have incentives to adopt innovations in farming because of production taxes.

Colonial and Republican Eras: Pro-Mining and Anti-Agriculture Bias

Besides colluding with large landowners and taxing peasants, the Crown (and later the republican governments) helped mining entrepreneurs rather than small farmers, because it saw in mining a source of quick revenues for the government. Since colonial days, the government has put in place many policies to lower food prices for miners and urban consumers at the expense of rural producers. These policies have included price ceilings on crops grown by Indians and subsidies to import food from neighboring countries (Rodríguez Ostria 1995).

Reliance on the exports of minerals has produced an overvalued exchange rate since colonial days and has made food imports cheaper than domestic goods. During the late eighteenth century, agriculture flourished in many of the valleys of Cochabamba and neighboring Northern Potosi. But the prosperity ended for smallholders when the exports of silver ores grew (Mitre 1981; Grieshaber 1986).

The Land Reform of 1953

The Revolution of 1952 did not represent a break with the past in the way that the government treated small rural producers (Pérez-Crespo 1991b). The government continued to discriminate against smallholders by increasing public investments in the newly nationalized tin mines and by giving land grants, subsidies, and inexpensive credit to commercial farmers (Eckstein 1983). The land reform of 1953 and colonization projects in the lowland made it easier for the government to downplay investments in technological innovations or to redistribute assets to the poor (Gill 1987). Production from smallholders in Cochabamba grew after the reform of 1953 owing to greater use of chemical fertilizers (Sanabria 1993), but the increase in productivity did not last because of the lack of sustained public investments in agricultural research.

After the 1953 land reform, the government did not finance research into the production of new farm technologies for smallholders, nor did it make credit available to smallholders so that they could improve the quality of their physical capital (Dandler 1984). Agricultural researchers did not pay attention to the "immediate problems and interests of farmers in the region" and did not offer extension services to smallholders (Heath, Erasmus, and Buechler 1969:453). The only program of agricultural research and extension after the 1952 Revolution was financed by the United States, but it ended suddenly when the flow of foreign aid stopped (Godoy, De Franco, and Echeverría 1993).

The Modern Era

From the 1970s until the present, many of the discriminatory policies against agriculture and small rural producers have continued. The government supported marketing boards to control the price of selected staples until 1985, continues to dump food donations of wheat from the United States (thereby depressing domestic prices), and still taxed many farm products (Flores 1984). Public investments continue to go to the lowlands rather than to smallholders in the valleys and highlands (Morales 1990). The terms of trade between countryside and city have deteriorated to the disadvantage of the countryside, and real rural incomes in Cochabamba and other rural areas of Bolivia have declined (Dandler 1984).

The government of Siles Suazo (1982–1985) was an exception to these trends. It subsidized transport, increased public employment (and therefore the demand for food), and imposed several restrictions on the imports of food (Godoy and De Franco 1993). The policies raised the income of smallholders, but at a great macroeconomic cost. In Cochabamba, stabilization and structural adjustment galvanized smallholders to migrate to cities and to coca-growing regions (Urioste 1989).

Although recent governments have tried to reverse centuries of discrimination through new land tenure legislation, decentralization, and the provision of credit, they have done little to provide small farmers in Cochabamba or elsewhere with new technologies for growing crops or raising animals or with more and better schooling (Muñoz and Lavadenz 1997). Bolivia's public investment in agricultural research and extension is the lowest of any country in Latin America. Bolivia's yields for staples have declined for decades and remain among the lowest in the Southern Cone (De Franco and Godoy 1993). The government is still not investing in producing technologies appropriate to the needs of smallholders. The technologies released are often inappropriate and do not offer smallholders tangible economic advantages (Lagos 1994).

Coping Strategies

The persistent neglect of and discrimination against the countryside have induced smallholders to develop coping strategies that have survived since colonial days. Since the seventeenth century, smallholders in Cochabamba, unable to make ends meet, have supplemented their income through petty trade (Larson 1988), such as the sale of corn beer (Rodríguez Ostria 1990), or through providing local transport, controlling irrigation (Larson 1988), and migration to the Chapare (Sanabria 1993). During recessions in the countryside, many large landowners sold their properties; at those times, smallholders with capital were able to buy land, but such episodes were rare (Rodríguez Ostria 1990).

When set against this larger historical context, the current pattern of adoption of new farm technologies by smallholders in Cochabamba becomes clearer. Smallholders have been too poor to invest in innovations of doubtful usefulness for their farms or for their needs (Painter 1995). In the late 1980s and early 1990s, only 15 percent of smallholders used fertilizers and only 5 percent used improved seeds (Painter 1995). The low rates of adoption reflect the limited capacity of the government to produce appropriate technologies and the insufficient incomes of smallholders to buy the technologies.

THE THEORETICAL FOCUS

Researchers who use quantitative methods to study the adoption of new farm technologies have drawn on three approaches. Since Griliches's 1956 study, many researchers have used quantitative historical information to map patterns of technological diffusion over time. These studies have shown, for example, that smallholders adopt new technologies because of favorable changes in the relative prices for crops. A second group of researchers relies on cross-sectional information and stresses the socioeconomic and demographic attributes of the person or household (e.g., Rogers 1995). A third group has recently started using panel information to study the role of village neighbors in learning about and adopting new farm technologies (e.g., Foster and Rosenzweig 1996).

We rely on the second method—a statistical analysis of a cross section—because we do not have quantitative information on adoption or observations of individual households over time. In line with other scholars who use the second approach, in our model, socioeconomic and demographic variables enhance adoption if they lower the cost (or risks) or raise the benefits of adoption to the household.

THE VARIABLES AND THE INFORMATION

Table 1 contains a summary and definition of the variables used in the analysis.

TABLE 1
Summary and Definition of Variables

Variable	Definition	*N*	Average	SD	Minimum	Maximum
Dependent						
Fertilizer	Expenditures (in bolivianos)[a]	997	43	139	0	2,100
Pesticides	Expenditures (in bolivianos)[a]	997	38	171	0	3,000
Explanatory						
Ecological						
Highlands[b]	Produces only potatoes	997	.22	.41	0	1
High valley[b]	Produces maize/potatoes	997	.30	.45	0	1
Low valley[b]	Produces only maize	997	.19	.39	0	1
Tropics[b]	Produces tropical crops (e.g., cassava)	997	.13	.34	0	1
Community						
Irrigation[b]	Irrigation present	769	.31	.46	0	1
Near road[b]	<0.5 hour to reach road	769	.76	.42	0	1
Household						
Male[b]	Sex of household head	997	.87	.33	0	1
Monoq[b]	Monlingual Quechua	997	.37	.48	0	1
Absence[b]	>1 month/year absence by household head	997	.20	.40	0	1
Title[b]	1 = title secure; 0 for all others (e.g., renters, sharecroppers)	769	.66	.47	0	1
Status[b]	If house has tin roof, or brick walls, or separate room for bathroom/ kitchen, or electricity	997	.88	.31	0	1
Animals	Total number of animals	997	31	35	0	356
Land	Hectares/household	816	3.6	4.8	.25	25
	0.50 hectares	160	19			
	0.75 hectares	140	17			
	1.50 hectares	178	22			
	3.50 hectares	172	21			
	7.50 hectares	94	12			
	15.00 hectares	57	7			
	25.00 hectares	15	2			
Age	Age of household head (years)	997	47	15	17	98
Education	Maximum education of household head (years)	997	3.0	3.2	0	13
Hh size	Number of children and adults in household	996	4.6	2.0	1	8
Grossinc	Bolivianos[a] from income earned inside and outside the farm (thousands)	989	5.5	12	0	169
Grosofin	Bolivianos[a] from income earned outside the farm (thousands)	985	1.4	4.7	0	89

a. 5.35 bolivianos = U.S. $1.00 in 1991.
b. Dummy variable. Name of dummy variable = 1.

Dependent Variable: Chemical Fertilizers and Chemical Pesticides

We focus on chemicals used in farming rather than on other technologies, such as the use of tractors or the use of improved plant varieties, because chemicals had greater variance and were easier to identify. It is more difficult to decide whether a plant variety is modern or traditional.

We used two technologies (expenditures on chemical fertilizers and on chemical pesticides) for three reasons. First, smallholders split the kit of modern technology and adopt inputs independently and often sequentially (Figueroa 1993). Second, the adoption of new technologies in the Andes takes many forms owing to the ecological heterogeneity of the area (Brush, Taylor, and Bellon 1992). Last, the share of farmers who adopt varies by technology. Only 32 percent of the sample adopted chemical fertilizers, but 47 percent adopted chemical pesticides. Farmers in Cochabamba typically use chemical fertilizers to grow tubers (Lagos 1994), and a growing number are using insecticides (Painter 1995).

A bivariate analysis of adoption against ecological zone (not shown here) suggests wide differences in adoption for both innovations across zones. About half of the sample in the valley adopts, a quarter in the highlands, and only about 13 percent in the tropics. This information would appear to confirm casual observations and previous research suggesting that adoption occurs mainly in the valleys. Forty-eight percent of the adopters live in the high and in the low semiarid valleys, with the balance split between the highlands and tropics. As we shall see however, the prominence of the valley as a determinant shrinks once we control for other attributes of the zone.

Explanatory Variables

We group explanatory variables into three types: ecological, community, and household.

Ecological. The survey did not contain information on altitude, so we used crops as proxies for ecological zones. In accordance with previous historical and ecological research in Cochabamba, we defined four ecological zones—highlands, high valleys, low valleys, and tropics—that correspond to the four different altitudes discussed above. If farmers only grew potatoes, we classified the zone as highland because farmers who only grow potatoes tend to live in the highlands. If farmers grew maize and potatoes, we classified the zone as a high valley. If smallholders cultivated only maize, we classified the zone as a low valley. The tropics include smallholders who grew crops which only grow in the tropics. We also used animals as proxies for ecological zones and combined animals with crops to define ecological floors; but the results did not vary, so we decided to only use crops.

These definitions naturally produce crude categories for different zones. The definition fails to include all the smallholders who adopt new technologies. About 12-13 percent of adopters do not grow potatoes, maize, or tropical crops and so defy our ecological classification. Our approach also misclassifies smallholders who grow crops diagnostic of one zone in another zone. Ethnographers have long noted the shortcomings of using crops or animals to proxy for ecological zone because many crops and animals can be found in several zones (Murra 1975).

Community. We took into account whether households had access to irrigation and whether it took people less than thirty minutes to reach a road. In Cochabamba, as in other parts of Peru, communities (rather than districts) manage irrigation (Mitchell and Guillet 1994), though before the 1952 Revolution, units larger than the community played a prominent role in irrigation. Because communities manage irrigation today, irrigation is still partly a community variable; however, it also partly reflects household attributes and thus may also proxy for access to capital and entrepreneurial skill.

Household. The chief household variables included: (1) whether the household head was absent for more than one month per year, (2) herd size, (3) farm size, (4) demographic and socioeconomic attributes of the household head and household, (5) human capital attributes of the household head, (6) land titling, and (7) socioeconomic status.

We used a Tobit model because 68 percent of the households did not use chemical fertilizers and 53 percent did not use chemical pesticides. Tobit models are appropriate when the dependent variable (chemicals for farming in this case) contains a large share of zeros. We also ran ordinary least square (OLS) regressions with Huber robust standard errors as a check and obtained qualitatively similar results. Much in the same way that income can drive adoption, so too can adoption affect income. To break the two-way direction of causality, we ran two-stage ordinary least squares using off-farm income as an instrument for gross income.

RATIONALE FOR THE CHOICE OF COMMUNITY AND HOUSEHOLD EXPLANATORY VARIABLES

As discussed earlier, explanatory variables take on a positive sign if they lower the costs (or risks) or raise the benefits of the adoption of new farm technologies.

Irrigation should encourage adoption in part because it lowers risks and complements the use of chemicals, although it may also mask unobserved attributes of the land (Mukhopadhyay 1994). In Cochabamba, irrigation is found in all zones, though it is more prevalent in the low valleys; it is used with all crops, but principally with cash crops. Larson's (1988) research shows that since colonial days, access to irrigation has allowed producers to lower variability in yields and to increase production. Pérez-Crespo's (1991a) contemporary research echoes these findings. We expect that people with access to irrigation would be more likely to intensify production and to use chemicals in farming.

Farm size may or may not matter depending on whether the technology is divisible or neutral to scale (Barham, Carter, and Sigelko 1995). Farm size can mask access to credit, modern inputs, access to information, and capacity to bear risk. In general, in Cochabamba, larger farms are associated with greater wealth.

Researchers have shown that education beyond a threshold of about four years speeds the adoption of improved plant varieties, though the threshold seems higher in Latin America or for other technologies (Phillips 1991). In the Department of Beni, education speeds the adoption of modern rice seeders (Godoy, Franks, and Alvarado 1997) because education makes it easier for adopters to obtain information about the innovation. In rural Cochabamba, we expect that smallholders with more education would find it easier to read the instructions on the use of chemicals and thus to adopt them before illiterate smallholders.

Age may influence people's willingness to bear risk and so may affect adoption (Barham, Carter, and Sigelko 1995). Some researchers find that younger farmers are more likely to adopt (Huffman and Mercier 1991), but others have found weaker evidence for the effects of age (Brush, Taylor, and Bellon 1992). We include age as a control.

Proximity to roads should enhance adoption because it lowers the costs of inputs and raises the price of outputs, thus making adoption more profitable (Brush, Taylor, and Bellon 1992). Proximity may also serve as a proxy for a household's degree of isolation. This situation will also yield a positive association of adoption and nearness.

The absence of the household head from the farm could produce ambiguous results on adoption. Absence could encourage the adoption of labor-saving technology. These technologies, however, also often have labor-intensive aspects. Moreover, absence could also rob the household of entrepreneurial talent and dull its dynamism. We include the absence of the household head because seasonal migration historically has been an important part of the coping strategies of rural households in Cochabamba.

We hypothesize that monolingual speakers of Quechua should adopt less frequently than bilingual speakers of Spanish and Quechua because monolingual speakers would find it harder to get information about new technologies such as chemicals. Monolingual speakers would also find it harder to read instructions on how to use chemicals. Bilingualism goes hand-in-hand with other socioeconomic attributes (e.g., income). Since we already control for these covariates of monolingualism, the estimated coefficient on monolingualism should give us the relatively pure effect of language ability on adoption. Several studies of bilingualism among Indian populations in Bolivia, Peru, and Guatemala have shown that language ability affects school performance and income, even after controlling for many of the socioeconomic covariates of bilingualism (Patrinos and Psacharopoulos 1992). Following those findings, we expect that language ability might also affect the choice of technology.

Wealth accumulated over time, proxied by herd size and housing quality (Muñoz 1994), should facilitate adoption because it makes farmers less averse to risk and makes it easier for them to get credit or to self-finance new investments.

Last, secure property rights to land should enhance adoption (Feder, Just, and Zilberman 1985). People with secure tenure feel safer about investing in their properties to raise production and the value of their homesteads (Alston, Libecap, and Schneider 1996).

RESULTS

Tables 2–3 contain the regression results for the full sample. Tables 4–7 contain the results of Tobit and OLS regressions for each of the four ecological zones. In the discussion below, we focus on determinants which are statistically significant at the 90 percent confidence level or above.

The Determinants of Adoption in the Full Sample

The results shown in Tables 2 and 3 suggest that in none of the models do ecological zones matter once we control for the covariates of altitude. Although the size of some of the coefficients is relatively large, none of the ecological variables was statistically significantly different from zero. Furthermore, none of the determinants explained the adoption of both chemical fertilizers and pesticides. Only proximity to roads significantly drives the adoption

TABLE 2
Determinants of Adoption with Full Sample: Pesticides

	Tobit		OLS		2SLS	
Variable	Coefficient	t	Coefficient	t	Coefficient	t
Grossinc	.00	.02	.00	.04	–.00	–0.25
Irrigation	28	.84	–9	–.53	–9.8	–0.51
Near road	81	2.1*	32	2.64*	33	1.64**
Absence	–26	–0.65	1.1	0.04	1.40	0.06
Animals	.51	1.13	.17	.39	.24	0.71
Land	–.28	–0.08	–.15	–.07	–.22	–0.12
Male	60	1.14	31	1.43	34	1.18
Education	1.9	.34	.65	.35	.38	0.12
Age	.47	.46	.24	.27	.23	0.41
Monoq	–28	–0.87	–18	–1.31	–19	–1.06
Hh size	3.15	0.41	2.85	0.76	2.66	0.63
Title	4.75	0.14	20	1.40	20	1.10
Status	–119	–2.15*	–72	–1.21	–74	–2.29*
Highlands	4.67	0.10	–1.3	–0.04	–6.0	–0.21
High valley	–47	–1.08	–27	–1.24	–32	–1.19
Low valley	5.02	0.10	4.8	0.20	.55	0.02
Left-censored	327		n/a		n/a	
Uncensored	280		n/a		n/a	
N	607		607		603[a]	
Pseudo R^2	0.0036		–0.0049		–0.0051	

Note: Regressions include constant. OLS includes Huber robust standard errors. Two-stage least square includes off-farm income as instrumental variable for gross income. Regular R-square for OLS. n/a = not applicable.

a. Differences in the sample size between 2SLS and Tobit and OLS are due to missing values in instrumental variable.

* = significant at <5%; ** = significant at <10%.

TABLE 3
Determinants of Adoption with Full Sample: Fertilizer

	Tobit		OLS		2SLS	
Variable	Coefficient	t	Coefficient	t	Coefficient	t
Grossinc	-.00	-0.38	-.00	-0.12	.00	0.12
Irrigation	166	4.37*	55	3.16*	55	3.78*
Near road	82	1.84**	13	1.20	12	0.81
Absence	-117	-2.49*	-40	-3.50*	-41	-2.45*
Animals	-.31	-0.54	-.07	-0.66	-.10	-0.39
Land	-2.47	-0.62	-.36	-0.31	-.35	-0.25
Male	-65	-1.15	-7.9	-0.62	-8.01	-0.36
Education	14	2.31*	5.8	1.68**	5.89	2.45*
Age	-.84	-0.71	-.43	-0.82	-.43	-0.99
Monoq	-38	-1.03	-23	-2.26*	-23	-1.71**
Hh size	-10	-1.21	-1.41	-0.54	-1.42	0.43
Title	91	2.30*	28	2.72*	29	2.00*
Status	-15	-0.24	3.73	0.22	3.48	0.14
Highlands	22	0.43	7.95	0.43	9.33	0.43
High valley	28	0.58	13	0.77	15	0.73
Low valley	28	0.51	19	1.21	20	0.95
Left-censored	419		n/a		n/a	
Uncensored	188		n/a		n/a	
N	607		607		603[a]	
Pseudo R^2	0.0158		0.0391		0.0382	

Note: Regressions include constant. OLS includes Huber robust standard errors. Two-stage least square includes off-farm income as instrumental variable for gross income. Regular R-square for OLS. n/a = not applicable.

a. Differences in the sample size between 2SLS and Tobit and OLS are due to missing values in instrumental variable.

* = significant at <5%; ** = significant at <10%.

of pesticides, while irrigation, education, secure property rights, and the continual presence of the household head drive the adoption of fertilizers.

Monolingualism in Quechua in rural Cochabamba is associated with lower adoption of chemicals, but the results are statistically insignificant for pesticides and are statistically significant only for some of the econometric models of fertilizers. Language ability neither hinders nor facilitates adoption after we control for other variables, such as wealth, proximity to town, or education. Monolingual speakers probably rely on relatives and friends in the village to get information about new technologies without needing to read instructions directly or to speak to extension agents.

Although education and titles have a statistically significant, positive effect on the adoption of chemical fertilizers, they have a much weaker (though still positive) role in the adoption of chemical pesticides. The weak results likely reflect differences between "effective" property rights—which, for example, may be associated with length of tenure—and the legal definition used here. Gauging the enforceability of legal (and informal) rights is impossible with the available data.

The Determinants of Adoption across Ecological Floors

No determinant consistently explains the adoption of both technologies within each zone. In the highlands (Table 4), bilingualism encourages the adoption of both technologies, but the results are sensitive to the model used. Variables such as education and irrigation are associated with greater use of fertilizers, but not of pesticides, and even then the results hold only for the Tobit model.

In the valleys, we found even weaker determinants. In the high valleys (Table 5), only roads seem to be associated with greater adoption of pesticides, but only in the Tobit model. Land titling and prolonged absence from the household seemed to discourage the adoption of pesticides or fertilizers, but the results were sensitive to the model used. In the low valleys (Table 6), we only found one determinant that played a statistically significant role in adoption: irrigation. Irrigation was associated with greater adoption of fertilizers in both models.

In the tropics (Table 7), household and herd size bore a positive and statistically significant relation to the adoption of chemical pesticides. The absence of the household head discouraged the use of pesticides. Except for household size, the findings are sensitive to the model used. The adoption of chemical fertilizers bore a negative and a statistically significant relation to farm size and a positive and statistically significant relation to irrigation, but the results were not robust to model specifications.

TABLE 4
Determinants of Adoption of Chemicals in Highlands

	Pesticide				Fertilizer			
	Tobit		OLS		Tobit		OLS	
Variable	Coefficient	t	Coefficient	t	Coefficient	t	Coefficient	t
Grossinc	.001	.243	.001	.837	–.010	–.642	–.0003	–.422
Irrigation	84.0	1.043	28.8	.792	241	2.61*	66.63	1.38
Near road	57.8	0.612	47.6	1.21	–21.5	–0.20	–17.2	–.698
Absence	98.1	1.016	75.2	.838	–347	–2.57*	–77.5	2.24*
Animals	–.277	–.283	–.148	–.54	–3.03	–1.52	–.273	–1.50
Land	8.95	1.111	–1.91	–.74	2.81	.284	.172	.066
Male	114	0.744	.106	.003	–103	–.636	–64.6	–1.58
Education	4.69	0.354	4.17	.715	30.7	2.03*	6.643	1.34
Age	–1.04	–0.42	–1.47	–1.77**	1.22	0.44	–.983	–.814
Monoq	–208	–2.31*	–79.0	–1.50	–219	–2.02*	–43.1	–1.32
Hh size	–3.44	–0.18	.061	.009	–26.6	–1.28	–1.81	–.320
Title	60.6	0.75	55.7	1.33	116	1.22	25.1	.939
Status	–269	–2.1*	–220	–.976	–136	–0.92	–19.2	–0.46
Left-censored	72		n/a		95		n/a	
Uncensored	70		n/a		47		n/a	
N	142		142		142		142	
Pseudo R^2	0.0141		0.1160		0.0338		0.0700	

Note: Regressions include constant. OLS includes Huber robust standard errors. Regular R-square for OLS. n/a = not applicable.
* = significant at <5%; ** = significant at <10%.

TABLE 5
Determinants of Adoption of Chemicals in High Valleys

	Pesticide				Fertilizer			
	Tobit		OLS		Tobit		OLS	
Variable	Coefficient	t	Coefficient	t	Coefficient	t	Coefficient	t
Grossinc	.001	.429	–.0005	–.95	–.0006	–.076	–.0001	–.047
Irrigation	20.5	.808	9.88	.714	116	1.37	44.5	1.07
Near road	67.1	2.17*	20.8	1.60	58.1	0.58	5.06	0.15
Absence	1.98	0.06	9.09	0.53	–199	–1.75*	–40.9	–1.19
Animals	–.160	–.456	–.002	–0.02	–.323	–0.27	–.166	–.709
Land	4.24	1.47	3.73	0.92	–7.01	–0.66	–2.48	–1.23
Male	–4.62	–.110	–6.13	–.331	–111	–0.86	17.4	0.77
Education	2.43	.564	1.31	.398	24.1	1.72*	14.0	1.10
Age	.121	.151	–.158	–.55	–.295	–0.11	–.273	–.239
Monoq	–27.1	–1.10	–16.7	–1.37	–34.6	–.424	–28.7	–1.57
Hh size	2.39	0.42	.038	.014	14.1	.758	5.36	1.00
Title	–38.8	–1.56	–23.7	–1.70**	110	1.27	26.2	1.09
Status	–2.29	–0.05	11.1	0.71	111	.790	25.1	0.84
Left-censored	94		n/a		118		n/a	
Uncensored	77		n/a		53		n/a	
N	171		171		171		171	
Pseudo R^2	0.0113		0.0817		0.0164		0.0861	

Note: Regressions include constant. OLS includes Huber robust standard errors. Regular R-square for OLS. n/a = not applicable.

* = significant at <5%; ** = significant at <10%.

TABLE 6
Determinants of Adoption of Chemicals in Low Valleys

	Pesticide				Fertilizer			
	Tobit		OLS		Tobit		OLS	
Variable	Coefficient	t	Coefficient	t	Coefficient	t	Coefficient	t
Grossinc	–.012	–1.24	–.002	–.95	–.006	–.79	–.001	–1.15
Irrigation	–71.4	–0.61	–66.6	–1.4	219	2.34*	70.5	1.71**
Near road	114	.89	43.6	1.63	118	1.07	29.1	1.44
Absence	–187	–1.46	–60.7	–1.23	–8.23	–0.08	–37.6	–1.59
Animals	1.15	0.62	–.468	–1.02	–.60	–.361	–.23	–.55
Land	–2.83	–.24	–1.98	–.738	4.60	.526	2.89	.60
Male	246	1.61	69.4	1.02	–21.4	–.19	21.8	.78
Education	14.0	.816	.410	.091	11.6	.80	1.03	.31
Age	4.30	1.47	2.96	.687	–.303	–.125	.204	.15
Monoq	131	1.21	–13.2	–.28	25.3	.290	–21.0	–.68
Hh size	4.25	.160	–9.76	–.75	–14.2	–.655	–7.14	–.87
Title	97.7	.861	51.3	1.55	117	1.24	32.0	1.42
Status	–174	–914	–16.4	–0.21	–52.9	–.35	–1.91	–.04
Left-censored	62		n/a		80		n/a	
Uncensored	52		n/a		34		n/a	
N	114		114		114		114	
Pseudo R^2	0.0157		0.0776		.0262		0.1188	

Note: Regressions include constant. OLS includes Huber robust standard errors. Regular R-square for OLS. n/a = not applicable.

* = significant at <5%; ** = significant at <10%.

TABLE 7
Determinants of Adoption of Chemicals in Tropics

	Pesticide				Fertilizer			
	Tobit		OLS		Tobit[a]		OLS	
Variable	Coefficient	t	Coefficient	t	Coefficient	t	Coefficient	t
Grossinc	-.00	-1.01	-.00	-0.77			-.00	-0.17
Irrigation	10	0.10	-17	-0.49			56	2.03*
Near road	8	0.08	-.45	-0.01			-8.97	-0.35
Absence	-86	-0.81	-102	-1.68**			-2.65	-0.14
Animals	3.55	2.78*	2.78	1.20			.54	1.15
Land	7.35	0.96	6.00	0.82			-1.92	-1.92**
Male	-148	-0.55	-59	-0.79			6.42	0.23
Education	-2.24	-0.15	-8.93	-1.08			4.98	1.24
Age	-5.50	-1.52	-1.90	-1.20			-1.32	-1.37
Monoq	55	0.61	38	0.72			-3.92	21
Hh size	36	1.90**	27	1.69**			-1.51	-0.27
Title	20	0.21	43	1.35			29	1.26
Status	52	0.20	-20	-0.30			31	0.87
Left-censored	52		n/a				n/a	
Uncensored	42		n/a				n/a	
N	94		94				94	
Pseudo R^2	0.0185		0.1080				0.0226	

Note: Regressions include constant. OLS includes Huber robust standard errors. Regular R-square for OLS. n/a = not applicable.
a. The sample size was too small. Therefore, convergence was not achieved in the estimation.
* = significant at <5%; ** = significant at <10%.

DISCUSSION

The results of the study highlight three significant lessons for policy makers and for students of Bolivia and other Andean countries.

Ecological Zone Does Not Seem To Matter

The use of the pooled sample suggests that ecological zone *per se* only weakly affects adoption once researchers control for the covariates of ecological zone. We found that smallholders in the valleys are not intrinsically more likely to adopt new technologies than smallholders in the highlands or than smallholders in the tropics. Future public investments in agricultural research and extension in Bolivia (and perhaps in other Andean countries as well) should provide greater balance in the production and diffusion of new farm technologies to all ecological floors, not just to the valleys.

The Absence of Prime Movers

An analysis informed by the ecological and technological heterogeneity of rural Cochabamba produces a mosaic of determinants, with no clear prime mover for both technologies or for all ecological zones. Even more surprising are the negative findings of this analysis. Rogers (1995) and others (Feder, Just, and Zilberman 1985) have reviewed studies of adoption in many developing countries and have found that variables such as wealth, social status, education, and land titling tend to enhance adoption. But in Cochabamba, orthodox determinants fail to explain adoption either in the full sample, in different ecological zones, or across different technologies.

Implications of Research Findings for Public Policies

The absence of clear-cut prime movers suggests that policy makers in Bolivia, and perhaps in other Andean countries with similar ecological heterogeneity, may not have at their disposal an easy lever to pull to promote the diffusion of different technologies across all ecological floors. Policies to diffuse different technologies will have to be tailored to the specific needs of smallholders in different zones. Andean countries such as Bolivia that have long discriminated against the countryside can gain by increasing investments in the production of new farm technologies for smallholders. But it may be necessary to decentralize those investments to respond to the needs of constituents of different zones and socioeconomic characteristics.

The results above are strongly suggestive, but they should be replicated with other data sets before they serve as reliable guides for policy reform. The data set we used is one of the most comprehensive surveys currently available, but, like all rural surveys, the data are measured with error. This situation may partly explain the weak results, and future data sets may be able to provide sharper answers.

This study highlights several key issues on which future work should focus. First, the absence of the household head for part of the year reduces technological adoption in a number of instances. Absence is generally motivated by pursuit of alternative income-generating activities. The results show the hidden costs of mobility. Such mobility is far more common in rural Bolivia than in rural Asia, for example, and policies to enhance adoption will likely fail if they are not sensitive to this context.

The weak findings on the role of education reflect the generally low level of education and lack of variation across households. Such a situation is prone to result in "noisy" (i.e., not statistically significant) estimates. Improvements in education may still yield positive benefits for rates of adoption, but to determine this will require a more focused inquiry (e.g., Jamison and Lau 1982). A similar argument holds for the role of property rights. The present results suggest that simple, legalistic notions of property rights are likely insufficient and that rights should be reformulated in a broader economic and social context. In much of Cochabamba, titling by itself is probably not enough to confer a feeling of security over property or to increase investments. In the tropical lowlands at least, much of that feeling of security probably has more to do with whether a smallholder cultivates coca.

CONCLUSION

We conclude by speculating on the possible long-term consequences for smallholders and for a country such as Bolivia of adopting new farm technologies for producing staples. The large-scale adoption of new farm technologies for producing staples suited to the needs of smallholders will probably produce mixed effects in the Bolivian countryside. The technologies will increase productivity and the income of smallholders who can adopt. By increasing yields, new farm technologies will likely lower food prices. Faced with lower food prices, those smallholders who cannot adopt will see their incomes drop and may be forced to move to cities or to increase off-farm labor. This side of the story has been well documented in countries such as India and Indonesia, which have implemented far-reaching changes in the technology for producing staples (Lansing 1991).

But there is a parallel, "macro" side to the story that often is ignored. New farm technologies for staples increase productivity and lower food prices. Lower food prices benefit all consumers, particularly the urban poor who spend large proportions of their time and income obtaining food. Lower food prices also enhance the real exchange rate, make exports more competitive, and increase real wages when nominal wages remain constant. The massive adoption by smallholders of new farm technologies for producing staples will hurt those who cannot adopt, but it will help many firms, many people outside of agriculture (mainly the urban poor), and many adopters in the countryside (Hazell and Ramasamy 1991).

It may be premature to speculate how a technological transformation in smallholder agriculture will play itself out in rural Bolivia or other Andean countries and how different social groups will benefit or suffer from such a transformation. But before holding such a debate, the Bolivian government must reverse centuries of indifference to smallholders and to the rural poor by focusing on technologies that smallholders will find worth adopting.

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