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SAGA Working Paper
April 2007

Agricultural Technology, Productivity, Poverty and Food Security in Madagascar

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Strategies and Analysis for Growth and Access (SAGA) is a project of Cornell and Clark Atlanta Universities, funded by cooperative agreement #HFM-A-00-01-00132-00 with the United States Agency for International Development.

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Abstract

This paper uses a unique, spatially-explicit dataset to study the link between agricultural performance and rural poverty in Madagascar. We show that, controlling for geographical and physical characteristics, communes that have higher rates of adoption of improved agricultural technologies and, consequently, higher crop yields enjoy lower food prices, higher real wages for unskilled workers and better welfare indicators. The empirical evidence strongly favors support for improved agricultural production as an important part of any strategy to reduce the high poverty and food insecurity rates currently prevalent in rural Madagascar.

Keywords: Poverty, agriculture, technology adoption, spatial analysis, Sub-Saharan Africa, Madagascar

Acknowledgements:

We thank Luc Christiaensen for his continuous help throughout this project. We further would like to thank Christine Moser, David Stifel, Jean-Claude Randrianarisoa, Lalaina Randrianarison, Eliane Ralison for useful discussions on the topic, participants in seminars in Antananarivo and Washington, and three anonymous referees for helpful comments on an earlier draft. This work has been made possible by support from the World Bank, through the Norwegian Trust Fund for Environmentally & Socially Sustainable Development, and the United States Agency for International Development (USAID), through grant LAG-A-00-96-90016-00 to the BASIS CRSP, the Strategies and Analyses for Growth and Access (SAGA) cooperative agreement, number HFM-A-00-01-00132-00, and the Ilo program, No. 687-00-00-00093-00. The views expressed here and any remaining errors are the authors' and do not represent any official agency.

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1. INTRODUCTION

The poor in developing countries remain disproportionally rural, with most employed or self-employed in agriculture. There has therefore been a longstanding interest in understanding the relationship between agricultural growth, rural development and poverty reduction.[1] The quantitative evidence on this crucial and longstanding question is especially – and surprisingly – thin for Sub-Saharan Africa, often due to lack of reliable data. This paper makes a step toward filling this void, using a comprehensive, spatially explicit data set from Madagascar with proper controls for biophysical conditions to study how agricultural technology adoption and crop yields affect staple food prices, real wages for unskilled workers and key welfare indicators.

Where prior analyses have been focused at macro-level, in the case of most CGE models (de Janvry and Sadoulet, 2002; Winters and al., 1998; Sarris, 2001), or at micro-level, using household survey data (Datt and Ravallion, 1998 a,b; Ravallion and Datt, 1996, 2002; Foster and Rosenzweig, 2003a,b; Lopez and Anriquez, 2003; Lopez and Valdez, 2000a, 2000b), we use meso-level data from a nationwide commune census to study within-country variation in technology adoption and crop yield patterns and the resulting effects of crop yields on various welfare indicators, including staple food prices and real wages for unskilled workers. The extensive literature on agricultural technology adoption has paid close attention to the question of whether or not improved inputs and methods are pro-poor (David and Ostuka, 1994; Evenson and Gollin 2003). But these analyses typically stop short of empirical assessment of the effect of agricultural technology adoption or crop yields on the real wages earned by poor unskilled laborers or the staple food prices paid by poor consumers.

Madagascar is a rice economy par excellence. Per capita rice consumption is always at or near the top of world tables, a majority of cultivable land in the nation is sown in rice and Malagasy culture and politics are symbolically structured around rice. We therefore focus on rice in this paper as a reasonable proxy for staple crops more broadly. Given the poor past performance of the staple crop production sector in sub-Saharan Africa and the long-term trend in international markets, one might be inclined to think that there is no hope for agriculture-led poverty reduction. Yet differences among rural areas within Madagascar demonstrate how improved agricultural productivity can indeed make a significant difference for poverty and food insecurity. Faced with the same macroeconomic and sectoral policies and global marketplace, some areas within rural Madagascar fare demonstrably better than others. The meso-level variation within a large, poor country such as Madagascar affords an uncommon opportunity to identify those factors associated with higher yields, greater farm profits, lower consumer prices, and higher real wages – all key ingredients for rural poverty reduction.

The contribution of this paper is twofold. First, it is one of a very few empirical studies on the link between agriculture and poverty in Sub-Saharan Africa. Given the structural differences between African agriculture and that of Asia or Latin America (de Janvry and Sadoulet, 2002; Todaro, 2000) and the fact that poverty is proportionately more widespread, acute and rural in Africa than on any other continent, new empirical insights on agriculture-poverty linkages are essential to better policy design. Second, we rely on spatially-explicit data from a complete census of Madagascar's communes – the smallest administrative unit with direct representation from central or provincial government – to undertake novel meso-level analysis not previously conducted anywhere else, to the best of our knowledge.

The structure of the remainder of the paper is as follows. In section two, we present a simple and brief conceptual framework. Sections three and four present the data and descriptive statistics, respectively. We study the linkages between agriculture and poverty in section five. Section six explores the determinants of agricultural technology adoption and rice yields. Section seven draws out the conclusions of our results.

2. CONCEPTUAL FRAMEWORK

When do increased adoption of improved agricultural production technologies and higher crop yields benefit the poor? The answer to this question obviously depends on who is poor. At risk of some relatively mild oversimplification, let us distinguish among three distinct subpopulations that frequently include many poor people. First, there are poor farmers who have enough land and livestock that they do not need to depend on off-farm employment for income and who enjoy a net marketable surplus of food. Their incomes depend heavily upon their productivity and the price their produce fetches in the market. While net surplus farmers are not often the poorest members of rural African communities, they nonetheless often fall well below national poverty lines.

The complementary group to farmers with net marketable food surpluses is net food buyers. This subpopulation includes farmers who do not produce enough to cover their own household's consumption requirements. Widespread empirical evidence suggests that a significant fraction of farmers in low-income countries, including Madagascar, are net buyers of the crops they produce (Mellor, 1966; Weber et al., 1988; Barrett and Dorosh, 1996). This subpopulation also encompasses those not engaged in agriculture, whether due to landlessness, residence in a town or city or employment in the non-farm sector. The wealthiest are typically net food buyers as they choose high-return, non-agricultural occupations. But the poorest are commonly net buyers as well as they lack access to sufficient land to produce enough to meet their own household consumption needs.

A third and final group cuts across each of the previous two: unskilled workers who earn part or all of their income from wages. Unskilled labor is the dominant source of non-farm income for the poorest African farmers, who commonly earn a significant share of their total income from off-farm labor, commonly in the fields of larger farmers (Reardon, 1997; Barrett et al., 2001). The real wage and employment rates are key determinants of the welfare of the subpopulation of the poor who depend in whole or in part on the unskilled labor market for income. There is an obvious overlap with the net buyer subpopulation since real wages depend partly on rice prices. Yet this subpopulation is distinct because its welfare also depends on induced changes in demand for unskilled labor and the resulting effects on nominal wages and employment opportunities for unskilled workers.

We can explore how the adoption of improved agricultural production technologies and increased crop yields affect the welfare of each of these three groups using a very simple, partial equilibrium analytical model. Let V(p,y) represent the indirect utility of a representative household. Because the indirect utility function reflects a household's optimal welfare given prices and income, this approach offers a simple heuristic for studying how exogenous change in agricultural technology adoption and productivity affect welfare and poverty. Income can be broken down into two components, farm earnings and off-farm labor earnings:

$$y = pAf(T,L^H \mid E) + w(L-L^H)$$

where A is a Hicks-neutral coefficient reflecting the productivity of the underlying production technology, $f(\cdot)$.[2] A higher level of A implies greater output per unit cultivated area, T, or per unit household labor employed in agriculture, L^H, given underlying environmental conditions, E. Let w represent the prevailing wage rate for unskilled workers and L the total stock of available labor.[3] Under standard assumptions, an improvement in the underlying production technology, reflected by an increase in A, boosts agricultural output, $Af(T,L^H \mid E)$, for those with land (T>0) and adequate environmental conditions (E>0) who allocate labor to crop production (L^H>0).[4]

The effects of agricultural technology and productivity on welfare then operate through three distinct pathways. The first is straightforward: the effect of technical change on prices and thereby on welfare. Let $Q \equiv Af(T,L^H \mid E)$ represent agricultural output quantity. Totally differentiating and dividing through by dA yields

$$dp/dA = dp/dQ \cdot dQ/dA$$

or, in words, the induced price change depends on (i) how output responds to technical change and (ii) how prices respond to the induced change in output. We study each of these effects empirically below but effect (i) should be positive, by definition, and effect (ii) is negative so long as the aggregate demand curve slopes down, yielding negative net effects on prices. The welfare effects of induced price changes are well-established (Deaton, 1997): net buyers benefit from decreased prices, while net sellers lose. Abstracting from output changes that induce price change, therefore, the price-mediated welfare effects of productivity-enhancing technical change accrue to consumers, benefiting the second of the three subpopulations among the poor identified earlier.

Productivity-enhancing technical change obviously affects incomes as well as prices, however. We can see this by totally differentiating the expression for income and then dividing through by dA:

$$dy/dA = dp/dA \cdot Q + p \cdot dQ/dA - w dL^H/dA + dw/dA \cdot (L-L^H)$$

This helps us identify the effects on the other two poor subpopulations: farmers with net marketable surplus and those who earn part or all of their income through off-farm labor. The first three terms apply to net surplus farmers while the latter term applies to workers.

Net surplus farmers enjoy increased income from technical change in agriculture so long as the elasticity of output with respect to technical change is greater than the elasticity of price with respect to technical change.[5] Somewhat more intuitively, if output increases faster than prices fall in response to technical change, net surplus farmers enjoy increased real income and higher welfare, even if some of the gains from technical change accrue to consumers in the form of lower prices. We will test this proposition directly below.

Hicks-neutral technical change necessarily increases the marginal revenue product of labor, thereby inducing increased employment. In general equilibrium, wages will adjust in the same direction as employment. If the marginal physical product of labor increases faster than prices fall in response to technical change, labor demand will increase and off-farm household labor supply from farm households will fall, causing off-farm real wages to rise, benefiting the third group of the poor in the framework above. While our data do not permit direct testing of the impact of technical change on labor productivity, we are able to estimate the net effect of improved agricultural productivity on real wages.

This simple framework thereby enables identification of the three distinct pathways through which productivity-enhancing technical change in agriculture can affect welfare and thus poverty – through (1) lower real food prices, thereby benefiting net food consumers, (2) output response that outpaces price declines, thereby benefiting net food suppliers, and (3) increased real wages, thereby benefiting unskilled workers. The latter two effects, especially, are by no means automatic. But, as we show in the following sections, the empirical evidence from Madagascar suggests that there are indeed significantly pro-poor effects for all three subpopulations from increased adoption of improved agricultural technologies and associated gains in crop yields.

3. DATA AND METHODOLOGY

The data for this study originate from three sources: a commune-level census conducted in 2001, the national population census of 1993, and geographical data from secondary sources. Our unit of analysis is the commune, a geographically defined administrative unit in Madagagascar. Madagascar has six provinces (*faritany*), which are divided into 111 *fivondronona*. The *fivondronona* are made up of nearly 1400 communes, the smallest administrative units with direct representation and funding from the central or provincial government. Rural communes are further divided into *fokontany*, i.e., local villages.

Cornell University, in collaboration with INSTAT (the national statistical institute) and FOFIFA (the national center for agricultural research), implemented a socio-economic survey at commune level in 2001.[6] The remoteness of some communes and the general lack of national data on certain subjects meant that little was known about the spatial distribution of public goods, services, or economic activity. In spite of this remoteness and physical insecurity problems in a few places, the census covered more than 99 percent of the nation's communes (1381 of 1392). The survey relied on the responses of focus groups chosen to be as representative as possible of the population of the commune and on administrative data readily available at commune level. The questionnaire was mostly geared towards agricultural practices but also contained questions on demographics, service delivery, infrastructure, prices, security, well-being and the environment.

While this meso-level census is, to our knowledge, unique in sub-Saharan Africa – perhaps in the developing world more broadly – and contains a wealth of information, there are nonetheless several disadvantages that should be noted. The most important are the following:

1) The problem of the representativity of the focus groups. While it was insisted upon during enumerator training that people of different background take part in the focus groups (mostly administrators, teachers, health personnel and farmers), they were in practice, however, not always representative of the population of the commune as a whole. One reason was that Malagasy communes are sometimes vast and some focus groups were chosen only from people living near the administrative center of the commune. To the extent that people in the center of the commune are not well aware of the situation in neighboring *fokontany*, this may cause measurement error. Second, some communes were impossible to reach due to insecurity. In this case, one or two inhabitants (usually people from the commune administration) were invited to travel to the capital of the fivondronana and the interview was conducted there. It is obvious that this procedure leads to less representativity and more subjectivity.

2) Given that all information was gathered during one visit only, there may be recall bias for some questions.

3) There is a subjective element as well as potential measurement error in other questions (e.g., perceived number of poor in the commune, average rice productivity, percentage of the population that adopts specific technologies, etc.). These measurement error effects will tend to bias estimated regression coefficients towards zero in the results that follow.

4) The data are merely a cross-section and aggregate across households within communes. This limits the causal inferences we can responsibly make from the data, although they permit unprecedentedly rich identification of important associations among variables, associations that may be usefully suggestive of key mechanisms for poverty reduction in Madagascar.

The second data source is the 1993 population census organized by INSTAT. This census collected standard population census data, such as education levels, age groups, access to infrastructure, etc. These data were, however, collected on the basis of *firaisana*, an administrative unit roughly equivalent to a commune. *Firaisana* were abandoned in a 1996 reorganization of government, however, so we used GIS techniques to convert the 1993 population census *firaisana* data to commune level by redrawing the borders and converting the *firaisana* means, weighted by area, to commune means.[7] Although the population data date back eight years earlier than the commune census data, our extensive personal observations of rural Madagascar over the past fifteen years give us confidence that these data provide an acceptable proxy for the situation in 2001.

Finally, in trying to explain intra-national variation in agricultural productivity and to simulate the prospective effects on poverty, we need to control for biophysical attributes of communes. We therefore gathered spatially-explicit cartographic information on soil conditions (Raunet, 1996), temperature, altitude, and rainfall patterns, put them in GIS format and overlayed these data with the national commune map.

Our analysis relies on multivariate regression techniques. Spatial autocorrelation may be a problem in these data if there exist common unmeasured factors that vary across space. Standard errors are therefore corrected as described in Conley (1999) to account for both spatial dependence and heteroskedasticity. Following Moser (2004), the measure of spatial dependence is based on the coordinates (latitude and longitude) of the centroid of each commune. The estimation requires specification of a cut-off point, and the communes within this specified distance of a given commune are considered spatially interdependent. The cut-off distance used here is ten kilometers, which was chosen to capture roughly contiguous communes (Moser, 2004).

Two variables that are used in the analysis deserve some extra explanation. The first is the ethnicity variable. The earliest known settled communities in Madagascar date only from 800 A.D. (Wright and Raokotarisoa, 2003). The modern Malagasy's ancestors came mainly from Polynesia and east Africa. While all Malagasy speak one common language, roughly twenty distinct ethnic groups exist, as identified by common traditions and by a group consciousness (Ramamonjisoa, 2002). We aggregated the ethnic groups into larger categories based on similar agricultural customs, following Le Bourdiec (1974). Based on a nationwide rice characterization study, she distinguished among: 1) highland rice cultivators (Betsileo, Merina); 2) the southeastern ethnic groups (Antambahoaka, Antaimoro, Antaifasy, Antaisaka, Antanosy); 3) the southwestern ethnicities (Antandroy, Mahafaly, Vezo, Masikoro);[8] 4) the forest peoples (Betsimisaraka, Tanala); and 5) the cattle-rice cultivators (Antankarana, Bara, Bezanozano, Sakalava, Sihanaka, Tsimihety). Precisely because these groups have different traditions, and thus different social norms governing agricultural production, the hiring of laborers, etc., we want to be able to control for such effects directly.

Second, as infrastructure development is clearly a major determinant in explaining poverty and agricultural productivity in developing and developed countries alike, but given the correlation and arbitrariness in the choice between different types of infrastructure to include in the analysis, we use a remoteness index based on factor analysis of various isolation measures that were collected in the commune census: distances to health facilities, banks, post offices, schools, taxis, courts, input markets, agricultural extension services, veterinarians; access to national or provincial roads, public services, media, and various markets; and various measures of access to transportation (Stifel and Minten, 2003). We assume that there is a common factor, “remoteness,” that explains the common covariation in the isolation measures, and allow the factor analysis to define that factor as a weighted sum of the individual measures. By construction, the index has a zero mean and a standard deviation of one, and as such the index value is not interpretable. Nonetheless, it does permit us to rank communes by degree of isolation, and consequently to define quintiles of isolation. The latter are estimated using commune population sizes as weights (Stifel and Minten, 2003).

4. DESCRIPTIVE STATISTICS

Before moving to our estimates of the effects of agricultural productivity on poverty, it is instructive first to consider simple descriptive statistics of the current state of welfare in Madagascar. First, we look at the importance of the three subpopulations discussed in the conceptual framework in rural areas in Madagascar and their link with poverty. For this, we rely on data from the national household survey fielded by the National Institute for Statistics (INSTAT) at the same time as the 2001 commune census. For simplicity, we focus on rice only but the argument could be extended to staple crops more broadly. Table 1 shows that 71%, 7% and 21% of the population overall are net rice buyers, autarkic (i.e., zero net sales, reflecting subsistence) households or net sellers of rice. While about 70% of the rural population grows rice, 66% of them are nonetheless net buyers of rice in quantity terms.[9] Almost 80% of the rural population reported buying rice at some point in the previous year. Only one quarter of the rural population are net sellers of rice. These proportions are similar to calculations based on earlier datasets by Barrett and Dorosh (1996) and Minten and Zeller (2000).

Rice buyers are overall relatively richer, in rural as well as urban areas. Rice buyers own also less land, lowland as well as upland. In rural areas, rice buyers rely more on off-farm income (46%) and on wage labor income more specifically (33%) than do autarkic or net rice seller households. While there is no difference of the number of households belonging to the poorest quintile between net buyers and sellers, there are significantly more households that belong to the richest quintile in the net buyers' category (Table 1). This reflects the positive association between household welfare and diversification into high-return non-agricultural activities. A significant number of farmers (about one-third) sell rice during the harvest period, then buy back rice in the lean period, often driven by liquidity constraints (Barrett, 1996; Barrett and Dorosh, 1996; Moser et al., 2005).

Seasonal switching between net sales and net purchases is more common among poorer farming households.

Unskilled wages are an important indicator of welfare since they account for much of the earnings of the poorest subpopulations. Randrianarison (2003) uses data from the 2001 national household survey to show that the poorest people in Madagascar, often unskilled and landless, rely disproportionately on agricultural wage labor income to survive. Based on a smaller but more detailed dataset from 1997, Minten and Zeller (2000) estimate that 27% of the total income of the poorest quartile of the rural population in Madagascar originates from wage labor. This compares to only 10% for the richest quartile. The 2001 national household survey data indicate that 25% of agricultural plots were at some point cultivated using wage labor during the preceding agricultural season. This proportion rises to 40% of the plots among the richest quintile of agricultural households (Minten et al., 2003). This phenomenon is representative of many countries (Reardon, 1997; Datt and Ravallion, 1998a; Barrett et al., 2001). The importance of wage labor in agricultural activities in Madagascar differs spatially and temporally. Commune-level correlation coefficients between rural wages and the head-count poverty ratio, the percentage of population that is food insecure and the average length of the pre-harvest lean period (*soudure*) – in which individuals consume fewer nutrients and less diverse diets, commonly reflected in the absence of rice from the diet - are -0.30, -0.24 and -0.16, respectively. These statistically significant correlations evince the strong inverse relation between wage rates and welfare indicators in rural Madagascar.

The level of food insecurity, defined as the percentage of the population that permanently or temporarily does not have enough to eat, is evaluated at the national level at more than 50% (Table 2). We interpret this as a proxy for extreme poverty.[10] This stated level of food poverty by focus groups is consistent with more quantitative income methods: Roughly 70% of the population is estimated to fall below the national annual per capita income poverty line of FMG988,600, equivalent to roughly US$0.43 per person daily (Razafindravonona et al., 2001; Mistiaen et al, 2002). Poverty is highly seasonal in Madagascar. The average lean period in a Malagasy commune lasts four and a half months (Table 2), typically November through February before the main harvest begins in March-April. Mean nominal agricultural wages in Madagascar are roughly US$1 a day even in harvest season of peak labor demand, significantly below the poverty line even for those fully employed throughout the growing season, given gaps in the agricultural calendar and prevailing dependency ratios (i.e., children and elderly people supported by working age adults).

In order to evaluate the purchasing power of agricultural wages, one would ideally divide nominal wages by a composite index of the prices of a basket of local goods. However, no such index is available at this disaggregated level. So we instead divide the nominal wage by the local rice price (by any standard, the most important food in the country) and by the price of some local basic products (*produits de première nécessité* or PPN), such as salt and sugar to yield strong proxies for real wages. During the lean period, a daily wage is worth 3.2 kgs of rice for the country as a whole. Given the significant drop in rice prices after harvest, the real wage improves dramatically during that season, to a national average of 4.5 kgs of rice.[11] Laborers in the highlands provinces of Antananarivo and Fianarantsoa suffer the lowest real wages. Wages are highest in the northernmost province of Antsiranana. The same patterns appear when wages are expressed in purchasing power of PPN equivalents. Overall, the results of the different welfare indicators confirm the precarious situation of the poor in Fianarantsoa, which has been identified in multiple other analyses using other data as the poorest province in all of Madagascar (Razafindravonona et al., 2001).

5. AGRICULTURAL PRODUCTIVITY AND POVERTY: PRICE AND WAGE EFFECTS

Rice is by far the most important crop in Madagascar. It makes up around 50% of the value added in agriculture and represents 45% of the calories consumed for an average Malagasy person. Yet median rice yields in Madagascar have changed little over time and stayed stable at roughly two tons per hectare (Dorosh et al., 2003). Yields vary markedly across the island, however, creating an opportunity to explore whether agricultural productivity within the nation seems to affect the welfare status of Madagascar's rural populations. For example, the central highlands enjoy significantly higher yields than the rest of the island. Yet this is also the region suffering the lowest real wages. If that, hypothetically, reflects a negative causal relationship between yields and unskilled wages – as might occur from labor-saving technologies such as mechanization, for example – that would sound an important cautionary note about the efficacy of productivity-enhancing agricultural technologies as an engine for poverty reduction. In this section, we therefore test the effect of rice yields – as a proxy for agricultural productivity more broadly – on poverty and food insecurity measures, staple food prices and real wages, with proper controls in place for possible confounding variables, spatial correlation and endogeneity in rice yields.

(a) Productivity and extreme poverty

To study the link between productivity and extreme poverty we rely on two readily available indicators for poverty: the perceived percentage of food insecure households in each commune and the average length of households' lean period in the commune. These welfare indicators are regressed on geographical and physical characteristics and on socio-economic conditions in the commune, including our main agricultural variables of interest (Table 3). A Davidson-MacKinnon test indicates endogeneity of rice yields in both regressions.[12] We therefore report only two-stage least squares (2SLS) results. For the 2SLS estimates, we instrument for rice yields using the percentage of rice land in the commune with improved irrigation infrastructure and the proportion of the commune population belonging to the 'forest ethnic group'. An F-test shows these identifying variables explain enough of the endogenous variable to be considered valid instruments. Moreover, the r^2 statistic for the instrumenting equation is reasonable without being so high as to suggest overfitting. [13] Even with statistically defensible instrumentation to try to identify effects correctly, we remind readers that these cross-sectional data limit our ability to make strong causal inferences about the statistical associations we report.

In all specifications, communes with a higher yield level have higher commune-level welfare, on average.[14] A doubling of the rice yields in the commune is associated with a reduction of the number of food insecure by 38% and a 1.7 months shorter lean period, or, expressed differently, a reduced average length of the lean period at the national level by about one-third. Plainly, rice yields matter greatly to basic measures of food insecurity in Madagascar. In the subsequent sections we unpack this result a bit more precisely, exploring the three mechanisms – via lower real food prices, higher farm profits, and higher real wages – so as to understand better which poor subpopulations seem to benefit.

Cash cropping likewise seems also to have mostly a beneficial effect on food security indicators. A dummy variable created for those communes that consider vanilla or cloves their most important agricultural product by value is likewise significantly positively associated with improved welfare. However, as the survey year was one of exceptionally high international prices for cloves and vanilla,[15] one might wonder to what extent this was a one-off event.

The presence of non-farm income in the commune, as measured by the presence of the mining of precious stones (the most important off-farm activity in rural Madagascar) has little apparent effect on food insecurity measures. While this type of income might create wealth in the commune, it is often only limited to relatively few people and thus leads to little poverty alleviation. The lack of trickle down to a larger population might also be linked to governance problems in the sector (World Bank, 2003).

Finally, remoteness is an important determinant of food security status. Moving from the least to the most remote quintile is associated with an increase in the number of food insecure by 10% and in the length of the lean period by 0.7 months. Similar findings on the large and significant effect of isolation have been reported in Madagascar (Razafindravonona et al., 2001; Stifel and Minten, 2003) and elsewhere (Fafchamps and Shilpi, 2003). Recognizing that remoteness as measured here reflects not just physical distance – which is obviously not amenable to policy interventions – but also the quality of the transport network that determines travel times, it becomes apparent that the quality of transport infrastructure matters to food security, primarily due because of its impact on prices for both producers and consumers, as we see in the next subsection.

Agricultural performance plainly affects overall food insecurity and its close correlate, extreme poverty. In the next sections, we explore the channels by which agricultural productivity impacts the specific subpopulations discussed earlier by looking separately at price and wage effects.

(b) Productivity and prices

The commune census collected four observations on rice prices covering the crop year 2000-2001 (October-December, January-March, April-June, July-September). Rice prices in Madagascar exhibit extreme variability, both intertemporally and spatially. This reflects highly segmented markets and lack of nationwide market integration. Due to high transportation costs, large parts of Madagascar are not well connected with each other, nor with international markets. Prices are therefore often determined by localized supply and demand conditions (Moser et al., 2004). Rice prices also exhibit large seasonal swings. This variation reflects the high opportunity cost of capital and limited inter-seasonal commercial arbitrage.[16] These conditions may make Madagascar a bit more an extreme case than would be typical of all low-income agrarian nations, although the market integration literature suggests such conditions are widespread in much of the developing world. Moreover, even where domestic and international markets are better integrated the qualitative point remains, as price transmission is incomplete even in highly integrated economies.[17]

To evaluate the relative importance of different determinants in rice price formation, we regress the logarithm of rice prices, expressed in Malagasy franc per *kapoaka*[18], on supply and demand factors (and on provincial dummies in an effort to control for unobserved factors). The results appear in Table 4. A Davidson-MacKinnon test indicates a potential endogeneity problem. We therefore use a 2SLS estimator, again instrumenting for the rice yield variable. A Wald overidentification test cannot reject the null hypothesis that the instruments used are exogenous in the price regression.[19]

Most coefficient estimates are as expected. The degree to which the harvest is concentrated in a single calendar quarter significantly affects price patterns. Prices are much lower in the harvest quarter and higher in one or more non-harvest periods. A harvest concentrated entirely within a specific quarter reduces the rice price, ceteris paribus, by 30-50% in the lean period (October-March) and by about 10% in the main harvest period (April-September). The larger effect in the lean period, which coincides with the rainy season, at least partly reflects the poor condition of transport infrastructure, as many roads become impassable, separating large swathes of the country from urban markets and impeding traders' ability to arbitrage across space and thereby smooth prices. This amplifies the effect of local supply conditions during the lean period due to production and storage conditions within the commune itself.

This phenomenon is also reflected in the impact of remoteness on rice prices. Greater remoteness is associated with higher rice prices during the lean period and significantly lower rice prices during the harvest period, consistent with findings by Barrett (1996) and Moser et al. (2004). Traders mainly store rice in cities, buying up rice in rural communes during the harvest period, hauling it to urban storage sites, then transporting it back to rural areas to resell during the lean period. These flow reversals lead to price reversals, with rural prices lower than urban rice prices in the harvest period and higher in the lean season, yielding larger seasonal rice price swings in more remote areas. Our results are consistent with this pattern.

Insecurity is associated with lower rice prices, especially during the harvest period. Improvement from very bad to very good security conditions is associated with a statistically significant 16% estimated increase in post-harvest rice prices. This likely reflects a risk premium paid to traders who are willing to venture into insecure regions. While insecurity in rural areas is mainly linked to cattle theft in Madagascar, it spills over into other areas such as crop theft and road banditry, discouraging trade and investment more generally (Fafchamps and Minten, 2004, 2006; Fafchamps and Moser, 2003).

The impact of cash crops and access to mining activities are included as indicators of greater local market demand for staple commodities. The results show that communes where vanilla and cloves are the main crops experienced significantly higher rice prices during the period that these crops are harvested. The presence of mining activities also exerts statistically significant upward pressure on rice prices in several periods.

Our main variable of interest, local rice yields, exhibits a strongly statistically significant and sizable negative association with commune-specific rice prices in each season, indicating the strong effect of local production conditions and reflecting limited spatial market integration across the island (Moser et al. 2004). A doubling of rice yields in the commune is associated with a significant reduction of rice prices of 31-44%, ceteris paribus, in the harvest periods (April-September) and 18-26% in the lean season (October-March).[20]

Because they drive down staple food prices, increases in local rice yields benefit local net staple food buyers considerably. Moreover, since the instantaneous welfare effects of price changes are proportional to a household’s budget share spent on that good (Deaton, 1997), and because the poor spend significantly more of their income on staple foods such as rice (Minten and Zeller, 2000), improving rice yields has a strongly progressive effect even within the ranks of the poor, benefiting the most poor proportionately more than less poor households.

Nonetheless, the estimated magnitudes of the price effects of yield gains indicate that net food sellers also gain from improved rice productivity. Although much of the gains accrue to consumers through lower food prices, following the standard technology treadmill effect (Cochrane, 1958), since prices fall by only 18-45% for every doubling of rice yields, farmers are able to capture 10-60% of the welfare gains from improved rice productivity in rural Madagascar. This is an important finding. Since even many net rice sellers fall below the poverty line, the apparent sharing of the benefits from improved crop productivity between producers and consumers in rural Madagascar underscores the poverty reduction benefits of agricultural productivity enhancements.

(c) Productivity and wages

Timmer (1988) argues that low food prices are the primary engine for rural growth as relatively low food prices lead to higher real but lower nominal wages, which will attract off-farm investment. This leads us directly to the welfare of the third subpopulation of the poor, those who depend on unskilled wage labor for part or all of their earnings. Workers' welfare is affected by induced changes in real wages, not just by rice prices, which are but a component of the real wage. We therefore conclude this section by exploring the correlates of real wages for male and female unskilled workers labor, both in the first and third quarters of the year, so as to take seasonal effects into account.[21]

The results presented in Table 5 again indicate the significant effects of remoteness. The least remote areas have real wages 25% higher than the most remote ones in the lean season. Better security conditions depress real wages, probably because fewer migrant workers are willing to venture to riskier areas in search of seasonal employment. Higher population density leads to lower harvest period wages. A doubling of the population density reduces nominal and real wages by 6-7% for men and women, respectively.

Communes with higher yield levels have real wages that are much higher. A doubling of rice yields is associated with an increase between 65% and 89% in real agricultural wages, depending on gender and time of the year, with the effect biggest for male workers in the lean season.[22] Notice that during the harvest season (July-September) real wage effects are slightly less than one would expect purely from the downward effect of yields on prices, consistent with Timmer's hypothesis.[23] However, the lean season real wage effects are more than double those that would result purely from induced price effects. This likely signals an induced labor demand effect during the growing season. This effect is likewise manifest in the large difference between the 2SLS and the OLS estimates of the real wage equations, since only the former effectively strips out that portion of yield changes that is correlated with the errors in the real wage equation, allowing us to isolate the unidirectional effects of yields on real wages, which might otherwise be masked by the induced decrease in labor demand (and thus lower yields) caused by increasing real wages.[24]

The presence of labor-intensive cash crops, cloves and vanilla, also leads to higher real wages. Curiously, mining activities do not have the same effect. If anything, they have a negative effect, especially in the lean season, likely because the prospect of finding valuable stones induces excess seasonal migration by the poor, creating an overabundance of unskilled laborers relative to the limited absorptive capacity of the mining industry. The resulting seasonal excess supply of workers puts downward pressure on overall real wage levels.

In brief, our findings provide strong empirical evidence that better agricultural performance – as proxied by higher rice yields – are strongly correlated with real wages, as well as rice profitability and consumer prices for the staple food, reinforcing the conclusion of the previous subsection that greater rice productivity reduces extreme poverty in Madagascar, for all the major subpopulations of the poor: net rice buyers, net rice sellers, and unskilled workers. The next, key question is how to stimulate technological change in order to achieve higher rice yields.

6. HOW TO IMPROVE AGRICULTURAL PERFORMANCE?

The Green Revolution - based on high rates of fertilizer application and use of improved rice seed varieties - underscored the importance of improved technology adoption for agricultural transformation and poverty reduction in Asia (David and Otsuka, 1994; Evenson and Gollin, 2003). Unfortunately, the Green Revolution bypassed Madagascar. Adoption of improved agricultural inputs and technologies lags in Madagascar, with the consequence that rice yields remain well below potential output. The critical policy question is what factors most directly affect rice yields so that agricultural productivity policy can focus on those interventions most likely to reduce rural poverty.

(a) Determinants of agricultural productivity

To explore the key determinants of agricultural productivity in Madagascar while controlling for biophysical conditions, we regress rice yields on land quality, labor inputs, stocks of livestock, mechanical and infrastructure capital, an index of farmer adoption of land intensification technologies, and climatic shocks. Technology adoption might be endogenous, with farmers choosing to adopt better technologies on better soils, in communes with better extension agents, and where higher ex ante yields generate surpluses that farmers plough back into the adoption of these technologies. We therefore tested for endogeneity using a Davidson-MacKinnon test. Somewhat to our surprise, this test does not reject the null hypothesis of exogeneity (Table 6). It seems that our biophysical and provincial controls adequately account for those potentially confounding factors. We therefore report the results of ordinary least squares estimation, subject to the same caveats as before about making strong causal inferences based on cross-sectional data on complex phenomena.

For this analysis, we constructed an adoption index, consisting of an average of the percentage of people in a commune that employ land productivity increasing technology, i.e., adoption of fertilizer, seedling transplanting, improved rice seeds and a new system of rice intensification known as the *système de riz intensive* (SRI).[25] The coefficient estimates (Table 6) show that an increase in the number of farmers who adopt improved land-intensification technologies is significantly and positive associated with rice yields, controlling for all other inputs and biophysical attributes of the production systems.

Access to improved equipment in the commune is positively associated with rice yields, but with only about half the magnitude of the overall land intensification technologies adoption index. Irrigation is strongly associated with higher rates of uptake of improved technologies – as we discuss in section 6.2 – but is also directly associated with higher rice output, likely due to better water management. An improvement of the irrigation system so that the whole commune would move from no irrigation to a system where all rice fields are hooked up to such a system is directly associated with a higher yield of 12%, on average. These results underscore that staple crop yields respond to a range of production factors: advances in equipment and seed, better water management and improved land management practices. Each plays a role in advancing agricultural productivity, although not in equal measure.

The number of livestock is highly significantly, positively associated with rice yields, even controlling for use of animal traction in field preparation. This likely reflects the benefits of organic fertilizers (manure) for soil structure and nutrient content. Organic fertilizer is often mentioned as one of the most important constraints for improved agricultural productivity in sub-Saharan Africa in general (Barrett, Place and Aboud, 2002) and Madagascar in particular (Freudenberger, 1998). Animal traction likewise is statistically significantly, positively associated with rice yields, demonstrating multiple pathways through which livestock positively affects crop agriculture in systems such as those found throughout rural Madagascar.

(b) Determinants of technology adoption

As shown, adoption of land-intensifying improved technologies is strongly associated with better agricultural yields. We therefore further analyze the adoption of six improved agricultural technologies: inorganic fertilizer, off-season crops, transplanting, improved rice seeds, SRI, and agricultural equipment (such as plows and harrows). Table 7 presents ordered probit regressions to evaluate the determinants of adoption of each of these improved practices or inputs.[26] The non-policy regressors include provincial dummy variables, temperature, altitude, soil variables, ethnic groups and climatic risks. The policy variables we include are literacy rates, access to irrigation, distance to extension agents, remoteness – which reflects travel time, not just distance – security and land titling.

Most of the coefficient estimates conform to expectations. Access to improved irrigation infrastructure has a statistically significant, positive association with adoption in almost all these regressions.[27] This is not a surprising result. Access to improved irrigation infrastructure allows better water management and reduces the risk of investment in a new technology. It is clearly an important necessary – but not sufficient - initial condition to achieve agricultural transformation, as has been shown in other countries (Ravallion and Datt, 2002). However, the coefficient estimates are small indicating that irrigation alone is unlikely to stimulate rapid uptake of improved technologies.

Along with irrigation, remoteness is the most consistently significant correlate of adoption of improved agricultural technologies. More remote communes have statistically significantly lower likelihood of adopting each of the six technologies. This might reflect both poorer information flow to more remote locations and weaker profit incentives for innovation in those communes that are less well integrated into the commercial trading system, thus facing higher input and lower output prices or alternatively, these technologies do not work as well in remote areas, due to unobserved (or non-linear) variation in land or location quality. The coefficient estimates are especially highly significant for technologies that have to be imported from abroad – such as chemical fertilizer - given that access to roads is a necessity.

Other policy variables matter to technology adoption patterns as well, but less significantly or consistently than irrigation and remoteness. Lower illiteracy levels in the commune are generally associated with significantly higher adoption rates. This is consistent with Randrianarisoa and Minten's (2002) results, based on national household survey data. This is not unexpected given the notoriously low education levels overall in rural areas. Based on the 1993 data, 44% of the population is illiterate. Marginal benefits to extra levels of education thus appear quite high. On the other hand, Fraslin (2002) argues that most education in rural Madagascar is not geared towards agricultural knowledge and is therefore of little direct use to farmers.

The presence of land titles has a mostly positive association, statistically significant in a few cases, including with the overall adoption index.[28] However, we are unable to deal with an endogeneity problem in the commune-level data that results from the fact that the demand for titles is higher on better endowed land, i.e., on land close to cities or more fertile land. By contrast, Jacoby and Minten (2005), using household level data in a specifically designed survey to measure the impact of land titling, found very little effect of formal land titling on agricultural productivity, investments or land values in Madagascar. We therefore urge caution in interpreting this result in our estimations.

Distance to extension agents is highly significant in the case of SRI adoption and early rice transplanting, which is one component of the SRI package of agronomic practices. Moser and Barrett (2003) similarly find that access to extension is extremely important for successful adoption of SRI in rural Madagascar. However, access to extension services has no statistically significant relation with adoption of any other agricultural technologies.

Given the longstanding literature on induced innovation, the effect of population density on agricultural technology adoption is surprisingly small, negative, statistically insignificant or all three in each of the regressions reported in Table 8. Hayami and Ruttan (1985) argue that farmers search for technical alternatives that economize on the use of increasingly scarce factors of production and that exploit increasingly abundant factors. This would lead to relatively more land-intensification investments in areas with land pressure associated with higher population densities (Boserup, 1965; Ruthenberg, 1980; Pingali et al., 1987; Pender et al., 2001). However, other factors seem to limit the applicability of the induced innovation hypothesis in rural Madagascar as it relates to the uptake of land productivity increasing technologies. Given that land intensifying technologies are not taken up in high density populated areas, these areas suffer significantly lower real wages, as shown in Table 5.

Finally, ethnic group identities have a statistically significant effect on technology adoption patterns, as well as on rice yields (Table 7). This is consistent with Le Bourdiec's (1972) observations that different ethnic groups in Madagascar started off with quite different rice cultivation systems and that the time required for the adoption might differ by ethnic group due to cultural reasons. An alternative explanation is that ethnicity patterns across communes are associated with unobserved differences in land and location quality or in land tenure, generated by historic patterns of ethnic conflict or sociopolitical dominance. Physical and location characteristics likewise matter significantly to agricultural technology adoption, as manifest by the estimated coefficients on rainfall, the presence of volcanic and alluvial soils as well as the provincial dummies.

To summarize this section's results, agricultural productivity is, as one would expect, strongly and positively associated with the adoption of improved agricultural technologies, access to agricultural extension, the availability of irrigation and market access. The latter two variables have both direct and indirect effects – through induced technology adoption – on rice yields in rural Madagascar. The commune-level data from Madagascar therefore suggest these are perhaps the most potent policy levers available if one wants to improve agricultural productivity so as to reduce poverty and food insecurity.[29]

7. CONCLUSIONS

This paper uses a unique, spatially-explicit dataset to study the link between agricultural performance and rural poverty in Madagascar. We show that, controlling for geographical and physical characteristics, communes that have higher rates of adoption of improved agricultural technologies, broader access to irrigation and, consequently, higher crop yields enjoy, on average, significantly lower real food prices, higher real wages for unskilled workers, greater profitability for farmers, and better welfare indicators, in particular, fewer people in extreme poverty. The empirical evidence strongly favors support for improved agricultural productivity as an important part of any strategy to reduce the high poverty rates currently prevalent in rural Madagascar.

Agricultural technology adoption for staple crops might potentially have a differential impact on three distinctive groups in rural Madagascar: the net sellers of these crops, net buyers (both small farmers and those who do not cultivate staples) and wage laborers. Our results show that increased agricultural yields are strongly associated with gains for each of these subpopulations of the poor. Greater rice productivity outstrips local market price declines and therefore benefits net sellers. However, higher rice yields appear primarily to help the two other subpopulations, i.e., the poorest in rural areas, by driving down consumer food prices and boosting unskilled workers' real wages.

The net effect is manifest in shorter lean periods and fewer extremely poor, food insecure people in communes with higher agricultural productivity. We also find that cash crop production, but not mining activities, is associated with improved welfare conditions. Moreover, Boserupian induced technological innovation does not seem to occur in response to population pressure in rural Madagascar. As a consequence, more densely populated areas experience worse welfare indicators controlling for physical and geographical characteristics.

Our results further indicate that there are no magic bullets for better agricultural performance. Improved agricultural technology diffusion seems the most effective means of improving agricultural productivity and reducing poverty and food insecurity in rural Madagascar. But improved rural transport infrastructure, improved irrigation systems, maintenance of livestock herds, improved physical security, increased literacy rates, secure land tenure and reasonable access to extension services all play a positive role in encouraging productivity growth and poverty reduction. None of these factors is easy to influence and all require a long-term commitment to agricultural and broader rural development.

8. NOTES

[1] For some classical analyses, see Johnston and Mellor, 1961; Schultz, 1964; Mellor, 1966; Southworth and Johnston, 1967; Johnston and Kilby, 1975; Timmer, 1988.

[2] The Hicks-neutrality of technical change is not important to the analysis, it merely simplifies the depiction of an exogenous increase in productivity. This model aims merely to motivate the subsequent empirical work that is the focus of this paper.

[3] This formulation assumes a neoclassical labor market with no unemployment and uniform wage rates with no frictions between the marginal return to labor on-farm and wages earned through hired labor. This is clearly a significant oversimplification of rural labor markets in developing countries, including Madagascar. But we lack data on unemployment and our commune-level data do not permit estimation of prospective wedges between wage rates and marginal returns to labor. Thus we can only estimate the effects implied by this simpler model. With richer micro-level data, one could usefully generalize the labor market structure that underpins the simple typology we employ.

[4] In particular, we assume $f(\cdot)$ obeys the usual weak monotonicity and weak concavity assumptions of production functions, with $f(0)=0$ for any argument (i.e., there is no agricultural output without labor, land or essential biophysical inputs such as rain or soil nutrients) .

[5] Slightly more formally, rearranging the total derivate implies that $dy/dA > 0$ iff $dQ/dA \cdot A/Q > -dp/dA \cdot A/p$.

[6] For more information on the commune census, see Minten, Randrianarisoa and Radrianarison (2003).

[7] Special thanks go to Christine Moser for performing this task.

[8] The Antandroy were not studied by Le Bourdiec (1972) but we include them to make the categorization complete for the country as a whole.

[9] Prices and quantities were both asked for in the consumption and agricultural production sections of the survey. They thus allowed us to calculate the status based on values as well as quantities. No significant differences exist between these two types of calculations.

[10] Relative to conventional money metric measures of poverty, duration of adequate access to food has the advantage of obviating two common problems: determining appropriate geographically specific deflators for nominal incomes/expenditures, and measurement errors common to both productivity and welfare measures that lead to spurious correlations in data series.

[11] The median wage rates exhibit a qualitatively identical pattern, with slightly lower levels given modest positive skewness in the wage rate distribution across communes. Details are available from the authors by request.

[12] As an anonymous reviewer emphasizes, agricultural productivity might be related to poverty levels for more indirect reasons. For example, there might be reverse causation: suppose that places with lots of poverty have low wages, so that farmers employ high levels of labor. This would tend to drive up yields, leading to a positive correlation between poverty levels and yields. Alternatively, poverty levels and yields might both be affected by unobserved institutional differences at the community level (e.g., honest local government), leading to a negative correlation between poverty levels and yields. The multiple possible pathways in play merely underscore that cross-sectional analysis, even with serious attempts at identification through use of instrumental variables, can

commonly only establish associations. Inferences of causal relations require further, stronger, longitudinal evidence.

[13] These instruments are used for all 2SLS regressions we report in the paper. In case these instruments failed the overidentification test, the proportion of the cattle/rice cultivators ethnic group was added in Table 4 for the rice price regression in the fourth and the first trimester or was replaced by the forest ethnic group variable in the length of the lean period regression (Table 3). By doing so, all overidentification tests are satisfied at the 5% significance level.

[14] Note that we evaluate this at the average level for the level of a commune, which does not exclude the possibility that some individuals lose while others gain, even though poverty measures improve overall.

[15] Cash crop prices have been extremely volatile. For instance, vanilla prices increased by 600% between 1997 and 2001. Similarly, prices of cloves increased by over 500%. On the other hand, coffee prices plummeted over 50% (World Bank, 2003). The influence of world market conditions on local price variability was further illustrated after the commune census as prices of cloves dropped 90% while vanilla prices dropped 40-50% from 2001 to 2002.

[16] However, given the unexpectedly low prices during the lean period due to massive imports in 2001 (supposedly linked with low international prices as well as presidential elections and "*blanchissement de l'argent*"), this seasonal variation might be lower than compared to a regular year. For example, Minten (1998) estimated rice price variation in rural areas between harvest and lean period at just over 100% based on a 1998 survey in 200 *fokontany*.

[17] See Fackler and Goodwin (2002) for a review of the relevant literature.

[18] A *kapaoka* is a small standardized tin can that is universally used for retail sales in Madagascar. It contains around 280 grams of rice.

[19] Except for the price during the last/first quarter of the year. The instruments were changed accordingly (see footnote Table 4).

[20] The regression results reflect the effect of marginal changes in independent variables on prices. In the event of large changes in yields, one would have to consider aggregation effects and incorporate these in the analysis of changing market structures and of changing market integration to be able to evaluate effective price changes in every commune. That sort of general equilibrium analysis lies outside the scope of this paper.

[21] Nominal agricultural wages are relatively rigid over the course of the year, exhibiting, on average, less than 3% variation during crop year 2000-2001 for the country as a whole. The variation is real wage levels is closely linked with nominal wages, i.e., the correlation coefficient between these for male labor in the July-September and January-March period is 0.85 and 0.79 respectively. Correlation coefficients of real wages and rice prices for the same periods are -0.28 and -0.18 respectively.

[22] This type of analysis implicitly assumes little integration of labor markets across communes (which might reflect the reality). However, if all communes in Madagascar would experience the same large shock, there might be regional or even macro-economic impacts ignored in this marginal statistical analysis. This issue is left for future research.

[23] Since real wages reflect nominal wages normalized by prices, the reciprocal of the price effects reported in Table 4 provide an estimate of the real wage effects attributable

to price movements alone. These are not statistically significantly different from the direct real wage effects estimated in Table 5.

[24] The OLS estimates are available from the authors by request.

[25] SRI uses no purchased inputs but relies on a suite of agronomic adjustments: very early transplanting and wide spacing of seedlings, frequent weeding, and controlling the water level to allow for the aeration of the roots during the growth period of the plant, i.e., no standing water on the rice field (Uphoff et al., 2002; Moser and Barrett, 2003; Barrett et al., 2004). SRI has been shown to increase yields sharply on Malagasy farmers' fields, from an average of 2 tons/hectare to 6 or more (Uphoff et al. 2002, Barrett et al. 2004).

[26] We use an ordered probit estimator because the dependent variable was recorded in one of five ordinal categories, ranging from 0 = no adopters, 1 = 1-25% farmers adopt the method, to 5 = 100% adopters.

[27] Focus groups were asked to estimate the percentage of the rice fields that were irrigated by pumps, dams, rainfall or from a natural source. The first two variables were aggregated into a measure of access to improved irrigation infrastructure.

[28] Given the high percentage of declared titled land, there is seemingly confusion on the exact definition of titles by the focus groups, confounding *'terres titrés'* with the local informal *'petits papiers'* system. For a more detailed discussion, see Jacoby and Minten (2005).

[29] There are essentially two types of technologies: semi-irreversible ones such as investment in irrigation, leading to a permanent treadmill effect, and reversible ones such as the use of variable inputs (e.g., improved seeds and fertilizer), potentially leading to price fluctuations in the face of inelastic demand for food. In our estimates, effects of

yields on welfare and prices have largely been identified from yield differences due to long-term investments, i.e., irrigation infrastructure (the key instrument). The argument carries through equally when yield increases are achieved through better farm practices or modern inputs. Yet, the costs of both technologies can be vastly different and are often borne by different agents, public investment in the case of large-scale irrigation versus farmers in the case of improved variable inputs. This topic deserves further research as it cannot be tackled with the cross-sectional commune census data, given the lack of information on costs/investments.

9. REFERENCES

Barrett, C. (1996), "Urban Bias in Price Risk: the Geography of Food Price Distribution in Low-income Countries," *Journal of Development Studies* 23 (6): 193-215.

Barrett, C.B. and P. Dorosh (1996), "Farmers' Welfare and Changing Food Prices: Non-parametric Evidence from Madagascar," *American Journal of Agricultural Economics* 78 (3): 656-669.

Barrett, C.B., C.M., Moser, O.V. McHugh and J. Barison (2004), "Better Technology, Better Plots or Better Farmers? Identifying Changes in Productivity and Risk among Malagasy Rice Farmers," *American Journal of Agricultural Economics* 86 (4): 869-889.

Barrett, C.B., F. Place, and A.A. Aboud, editors (2002), *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices*. Wallingford, UK: CAB International.

Barrett, C.B., T. Reardon and P. Webb (2001), "Nonfarm Income Diversification and Household Livelihood Strategies in Rural Africa: Concepts, Dynamics, and Policy Implications," *Food Policy* 26(4): 315-331.

Boserup, E. (1965), *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*, Chicago: Aldine Publishing Co.

Cochrane, W.W. (1958), *Farm Prices: Myth and Reality*, Minneapolis: University of Minnesota Press.

Conley, T.G. (1999), "GMM Estimation with Cross Sectional Dependence," *Journal of Econometrics* 92: 1-45.

Datt, G. and M. Ravallion (1998a), "Farm Productivity and Rural Poverty in India", *Journal of Development Studies* 34 (4): 62-85.

Datt, G. and M. Ravallion, M. (1998b), "Why Have Some Indian States Done Better than Others at Reducing Rural Poverty?" *Economica* 65: 17-38.

David, C.C. and K. Otsuka (1994), *Modern rice technology and income distribution in Asia*, Boulder: Lynne Riener Publishers.

Deaton, A. (1997), *The Analysis of Household Surveys: A Micro-econometric Approach to Development Policy*, Baltimore: Johns Hopkins University Press for the World Bank.

De Laulanié, H. (2003), *Le riz à Madagascar: Un développement en dialogue avec les paysans*, Antananarivo : Editions Karthala.

DeJanvry, A. and E. Sadoulet (2002), "World Poverty and the Role of Agricultural Technology: Direct and Indirect Effects," *Journal of Development Studies* 38(4): 1-26

Dorosh, P., S. Haggblade, C. Lungren, T. Razafimanantena and Z. Randriamiarana (2003), *Moteurs Economiques pour la Réduction de la Pauvreté à Madagascar*, Antananarivo : INSTAT

Evenson, R. and D. Gollin, "Assessing the Impact of the Green Revolution: 1960 to 2000," *Science* 300 (2 May 2003): 758-762.

Fackler, P.L. and Goodwin, B.K. (2002). "Spatial Price Analysis". In B.L. Gardner & G.C. Rausser (Eds.), *Handbook of Agricultural Economics.* Amsterdam: Elsevier Science.

Fafchamps, M. and B. Minten (2006), "Crime, Transitory Poverty and Isolation: Evidence from Madagascar", *Economic Development and Cultural Change* , in press.

Fafchamps, M. and B. Minten (2004), “Insecurity and Welfare,” Oxford University working paper

Fafchamps, M. and C. Moser (2004), “Crime, Isolation and Law Enforcement,” *Journal of African Economies*.

Fafchamps, M. and F. Shilpi (2003), “The Spatial Division of Labor in Nepal,” *Journal of Development Studies* 39(6): 23-66.

Foster, A.D. and M.R. Rosenzweig (2003), “Agricultural Productivity Growth, Rural Economic Diversity, and Economic Reforms: India, 1970-2000,” mimeo.

Foster, A.D. and M.R. Rosenzweig (2003), “Agricultural development, Industrialization and Rural Inequality,” mimeo.

Fraslin, J. (2002), “Quel Avenir pour le Paysans de Madagascar?,” *Afrique Contemporaine* Trimestriel no 202-203: 75-92.

Freudenberger, K. (1998), *Livelihoods without Livestock: A Study of Communities and Households in the Village of Andalandranovao*, Madagascar: LDI.

Hayami, Y. and V. Ruttan (1985), *Agricultural Development: An International Perspective*. Baltimore: Johns Hopkins University Press.

Jacoby, H. and B. Minten (2005), “Is land-titling in Sub-Sahara Africa cost-effective? Evidence from Madagascar,” mimeo.

Johnston, B.F. and P. Kilby (1975), *Agriculture and Structural Transformation: Economic Strategies in Late-Developing Countries*. Oxford: Oxford University Press.

Johnston, B.F. and J.W. Mellor (1961), “The Role of Agriculture in Rural Development,” *American Economic Review* 51(4): 566-593.

Le Bourdiec, F. (1974), *Hommes et paysages du riz à Madagascar*. Antananarivo: FTM.

Lopez, R. and G. Anriquez (2003), "Poverty and Agricultural Growth: Chili in the 1990s," paper presented at the International Conference of Agricultural Economists, Durban.

Lopez, R. and A. Valdez, A. (2000), "Fighting Rural Poverty in Latin America: New Evidence of the Effects of Education, Demographics and Access to Land", *Economic Development and Cultural Change* 197-211.

Lopez, R. and A. Valdez (2000), *Rural Poverty in Latin America: Analytics, New Empirical Evidence and Policy*. New York: St Martin's Press.

Mellor, J.W. (1966), *The Economics of Agricultural Development*. Ithaca: Cornell University Press.

Minten, B. and M. Zeller (2000), *Beyond Market Liberalization: Welfare, Income Generation and Environmental Sustainability in Rural Madagascar*. Aldershot: Ashgate.

Minten, B., J.C. Randrianarisoa and L. Randrianarison (2003), "Agriculture, Pauvreté rurale et Politiques Economiques à Madagascar," Working paper Ilo program Cornell University/INSTAT/FOFIFA.

Minten, B. (1998), "Infrastructure, Market Access and Rural Agricultural Prices," IFPRI-MSSD discussion paper.

Mistiaen, J., B. Ozler, T. Razafimanantena and J. Razafindravonona (2002), "Putting Welfare on the Map in Madagascar," *African Region Working Paper* No. 34, The World Bank, Washington DC.

Moser, C. (2004), "Causes and Misconceptions: Population, Roads, Poverty and Deforestation in Madagascar," mimeo.

Moser, C. and C.B. Barrett (2003), “The Disappointing Adoption Dynamics of a Yield-increasing, Low External Input Technology: the Case of SRI in Madagascar,” *Agricultural Systems* 76(3): 1085-1100.

Moser, C., C.B. Barrett and B. Minten (2005), “Missing Markets or Missed Opportunities: Spatio-temporal Arbitrage of rice in Madagascar,” mimeo.

Pender, J., S.J. Scherr, and G. Duron (2001), “Pathways of Development in the Hillside Areas of Honduras: Causes and Implications for Agricultural Production, Poverty and Sustainable Resource Use,” in Lee, D.R., Barrett, C.B., Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment, CABI publishing: 171-196.

Pingali, P., Y. Bigot and H.P. Binswanger (1987), *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*. Baltimore: Johns Hopkins University Press.

Ramamonjisoa, J. (2002), “Les Relations entre Ethnies à Madagascar: Une Problématique Souvent mal Posée,” *Afrique contemporaine* Trimestriel no 202-203: 55-74.

Randrianarison, L. (2003), “Revenus Extra-agricoles des Ménages Ruraux et Pauvreté,” in Minten, B., Randrianarisoa, J.C., Randrianarison, L., Agriculture, Pauvreté rurale et Politiques Economiques à Madagascar, Cornell University/INSTAT/FOFIFA, 56-59.

Raunet, M. (1996), “Facteurs Physiques,” in Bilan et Evaluation des Travaux et Réalisations en Matière de Conservation des Sols à Madagascar, FOFIFA-CIRAD, Antananarivo.

Ravallion, M. and G. Datt (1996), “How Important to India’s Poor is the Sectoral Composition of Economic Growth,” *World Bank Economic Review* 10(1): 1-25.

Ravallion, M. and G. Datt (2002), “Why has Economic Growth been more Pro-poor in Some States of India than Others?,” *Journal of Development Economics* 68: 381-400.

Razafindravonona, J., D., Stifel and S. Paternostro (2001), *Dynamique de la pauvreté: 1993-1999*. Antananarivo : INSTAT.

Reardon, T. (1997), “Using Evidence of Household Income Diversification to Inform Study of the Rural Nonfarm Labor Market in Africa,” *World Development* 25 (5): 735-748.

Ruthenberg, H. (1980), *Farming Systems in the Tropics*, Oxford: Clarendon Press.

Sarris, A.H. (2001), “The Role of Agriculture in Economic Development and Poverty Reduction: An Empirical and Conceptual Foundation,” World Bank, mimeo.

Schultz, T.W. (1964), *Transforming Traditional Agriculture*, New Haven: Yale University Press.

Southworth, H.M. and B.F. Johnston (1967), *Agricultural Development and Economic Growth*. Ithaca: Cornell University Press.

Stifel, D. and B. Minten (2003), “Isolation, welfare and agricultural productivity,” Cornell University working paper.

Timmer, C.P. (1988), “The Agricultural Transformation,” in H. Chenery and T.N. Srinivasan, eds., Handbook of Development Economics, volume 1 (Amsterdam: North Holland).

Todaro, M.P. (2000), *Economic Development*. New York: Addison-Wesley.

Uphoff, N., E. Fernandes, Y. Longping, P. Jiming, S. Rafaralahy and J. Rabenandrasana (2002), "Assessments of the System of Rice Intensification," Proceedings of an international conference, Sanya, China, Cornell International Institute for Food, Agriculture and Development.

Weber, M.T., J.M. Staats, J.S. Holtzman, E.W. Crawford and R.H. Bernsten (1988), "Informing Food Security Decisions in Africa: Empirical Analysis and Policy Dialogue," *American Journal of Agricultural Economics* 70(5): 1044-1052.

Winters, P., A. de Janvry, E. Sadoulet and K. Stamoulis (1998), "The Role of Agriculture in Economic Development : Visible and Invisible Surplus Transfers," *Journal of Development Studies* 34(5): 71-97.

World Bank (2003), *Review of the Agricultural and Environmental Sector in Madagascar*, Antananarivo: World Bank.

Wright, H.T. and J.A. Rakotoarisao (2003), "The Rise of Malagasy Societies: New Developments in the Archaeology of Madagascar," in Eds. Goodman, S., Benstead, *The Natural History of Madagascar.* Chicago: The University of Chicago Press, 112-119.

Table 1: Net buyers and sellers of rice in Madagascar

	Market status			
	Rice buyer	Subsistence	Rice seller	Total
Overall				
% of households	71	7	22	100
Number of households (x1000)	2343	235	737	3315
Population (x1000)	10991	1085	3590	15667
% rural	71	85	91	76
Urban				
% of households	87	5	9	100
Population (x1000)	3040	155	316	3512
Quantity sold (kgs/year)	-460	0	478	-358
Expenditures per capita (1000 Fmg*/year)	1979	1255	836	1848
Lowland area cultivated (ares)	11	39	145	24
Upland area cultivated (ares)	14	30	64	19
Rural				
% of households	66	8	26	100
Population (x1000)	7952	930	3274	12155
Quantity sold (kgs/year)	-342	0	617	-104
Expenditures per capita (1000 Fmg/year)	1321	860	854	1185
% of people belonging to poorest quintile#	23	35	23	24
% of people belonging to richest quintile#	16	10	7	14
Lowland area cultivated (ares)	29	57	147	57
Upland area cultivated (ares)	45	61	77	53
% of income from wage income	33	12	14	26
% of income from off-farm income	46	20	17	36

Source: Own calculations based on 2001 National Household Survey, INSTAT

* 6500 Fmg=1USD

#: quintile defined at the national level; 100%=all rural households in same market status category

Table 2: Descriptive statistics

	Unit	Obs	Mean	Std. D.	Min	Max
Independent variables						
% of lowlands connected to improved irrigation infrastructure	%	1385	16.15	26.62	0.00	100.00
perceived security conditions commune (1=very bad; 5=very good)	1 to 5	1385	2.92	0.95	1.00	5.00
log (population density)	#/km2	1385	3.29	1.40	-0.36	9.67
remoteness quintile (1=most proximate, 5 = most remote)	1 to 5	1376	3.31	1.33	1.00	5.00
% of population that belongs to the highland ethnic group	%	1378	35.08	43.05	0.00	100.00
% of population that belongs to cattle/rice cultivators ethnic group	%	1378	23.74	36.04	0.00	100.00
% of population that belongs to the forest ethnic group	%	1378	16.49	33.02	0.00	100.00
% of population that belongs to eastern ethnic group	%	1378	15.56	29.23	0.00	100.00
% of population that belongs to western ethnic group	%	1378	9.13	24.25	0.00	100.00
log(distance to extension agent)	km+1	1385	2.71	1.89	0.00	6.41
% of the agricultural land that is titled	1 to 7	1380	2.13	1.23	1.00	7.00
% of population that is literate	%	1385	55.95	23.73	4.28	97.99
log(# of years in last three years when hit by major disasters)	0 to 27	1378	2.25	0.58	0.00	3.40
log ((number of cattle+1)/(population in commune))	#	1383	-1.68	1.84	-10.60	4.96
use of animal traction (% of farmers)	%	1402	41.49	41.57	0.00	100.00
% of the surface commune with sedimentary soils	%	1390	17.77	32.43	0.00	100.00
% of the surface commune with cristalline soils - North/Highlands	%	1390	36.64	43.54	0.00	100.00
% of the surface commune with cristalline soils - Midwest	%	1390	2.40	11.46	0.00	100.00
% of the surface commune with cristalline soils - East	%	1390	20.39	36.93	0.00	100.00
% of the surface commune with cristalline soils - South	%	1390	3.79	17.60	0.00	100.00
% of the surface commune with volcanic soils	%	1390	8.47	21.70	0.00	100.00
% of the surface commune with alluvial soils	%	1390	10.37	22.53	0.00	100.00
average temperature in the commune	C*10	1392	197.86	29.26	123.17	249.34
average rainfall in the commune	mm	1392	1605.16	604.55	352.84	3264.45
average altitude in the commune	m	1392	608.16	535.54	1.00	2086.62
% of the population that mines precious stones in the comm.	%	1238	0.33	2.25	0.00	40.00
girofle is the most important crop in the commune	1=yes	1374	0.03	0.18	0.00	1.00
vanilla is the most important crop in the commune	1=yes	1374	0.05	0.22	0.00	1.00
% of total rice production that is harvested during jan-march	%	1309	11.84	20.96	0.00	100.00
% of total rice production that is harvested during april-june	%	1309	69.99	29.96	0.00	100.00
% of total rice production that is harvested during july-sept.	%	1309	7.28	19.12	0.00	100.00
% of total rice production that is harvested during oct.-dec.	%	1309	10.89	20.41	0.00	100.00
Dependent variables						
% of hhs that adopt off-season crops	0 to 5	1385	1.32	1.68	0.00	5.00
% of hhs that adopt chemical fertilizer	0 to 5	1385	1.04	1.60	0.00	5.00
% of hhs that adopt improved seeds	0 to 5	1385	1.10	1.67	0.00	5.00
% of hhs that adopt SRI	0 to 5	1385	0.47	0.78	0.00	5.00
% of hhs that adopt agr. equipment	0 to 5	1385	2.70	2.11	0.00	5.00
% of hhs that adopt improved technology	0 to 5	1385	1.36	0.88	0.00	4.00
rice yields	kg/ha	1299	2099.39	782.91	666	4357
rice price in Oct.-Dec. 2000 per kapoaka	Fmg	1378	709.57	184.03	350.00	1500.00
rice price in Jan-March 2001 per kapoaka	Fmg	1376	723.34	199.47	300.00	1500.00
rice price in Apr-June 2001 per kapoaka	Fmg	1378	503.95	182.79	200.00	1250.00
rice price in July-Aug. 2001 per kapoaka	Fmg	1378	556.11	136.85	250.00	1000.00
Number of self-reported food insecure in the commune	%	1385	52.28	27.01	0.00	100.00
Length of the lean period	month	1385	4.62	1.40	2.00	11.00
'Real' wage level male July-Aug.2001	kap.*	1225	14.18	8.61	2.00	80.00
'Real' wage level female July-Aug.2001	kap.*	1183	12.79	7.75	1.67	80.00
'Real' wage level male Jan-March 2001	kap.*	1235	10.85	6.16	2.22	50.00
'Real' wage level female Jan-March 2001	kap.*	1199	9.89	5.78	1.50	50.00

*: Number of kapoaka of rice that a daily wage buys in the commune

Table 3: Determinants of food security (2SLS)

Variable	Unit	% food insecure coefficient	t-value#	length lean period (month) coefficient	t-value#
average rice yield*	log(number)	-37.915	**-4.576**	-1.706	**-3.032**
vanilla is main crop	1=yes	-3.884	-0.758	-0.650	**-2.612**
cloves is main crop	1=yes	-18.165	**-3.737**	-0.673	**-2.153**
% of pop. that mines precious stones	%	0.471	1.658	-0.022	-1.479
remoteness quintile	1 to 5	2.003	**2.871**	0.130	**3.465**
perceived security conditions	1 to 5	-1.305	-1.576	-0.011	-0.235
population density	log(number)	1.438	1.659	-0.011	-0.232
% of adults in the commune that are literate	%	0.151	**2.390**	0.009	**2.466**
number of cattle	log(number)	-0.083	-0.121	-0.011	-0.331
Dummy province of Fianarantsoa	1=yes	-2.064	-0.648	0.187	1.016
Dummy province of Toamasina	1=yes	-1.534	-0.479	-0.279	-1.387
Dummy province of Mahajanga	1=yes	-15.560	**-4.985**	-0.596	**-3.876**
Dummy province of Toliara	1=yes	-17.109	**-3.862**	-1.182	**-5.186**
Dummy province of Antsiranana	1=yes	-18.647	**-3.881**	-0.710	**-3.237**
Intercept		332.745	**5.166**	16.989	**3.901**
Number of observations		1155		1155	
F(14, 1140)		12.15		12.41	
p-value (Prob>F)		0.000		0.000	
R^2		0.129		0.026	
Root MSE		27.412		1.3937	
Exogeneity and endogeneity tests					
A. Welfare regressions		Test stat.	p-value	Test stat.	p-value
a. Davidson MacKinnon endogeneity test					
Rice yields	t-value	3.78	0.00	2.43	0.02
b. Overidentification tests					
Test that instruments are exogenous					
Wald test	Ch2	2.11	0.15	2.36	0.12
B. Instrumenting regressions		Test stat.	p-value		
*Test that instruments are jointly significant***					
F-test	F(2, N)	31.58	0.00	23.26	0.00

#: t-values corrected for spatial dependence

* endogenous

** instruments in regression 1: % of riceland with improved irrigation infrastructure, % of population that belongs to forest ethnic group

** instruments in regression 2: % of riceland with improved irrigation infrastructure, % of population that belongs to cattle/rice cultivators ethnic group

Table 4: Determinants of rice prices (2SLS)

Dependent variable = log (price rice per kapoaka)		price oct.-dec.		price jan.-march		price april-june		price july-sept.	
Variable	Unit	coefficient	t-value#	coefficient	t-value#	coefficient	t-value#	coefficient	t-value#
average rice yield*	log(number)	-0.258	**-3.738**	-0.177	**-2.699**	-0.313	**-4.312**	-0.437	**-7.699**
% annual harvest in that period	%	-0.005	**-10.780**	-0.003	**-5.967**	-0.001	**-4.076**	-0.001	**-2.915**
remoteness quintile	1 to 5	-0.004	-0.675	0.005	0.744	-0.043	**-5.848**	-0.022	**-3.658**
perceived security conditions	1 to 5	0.007	0.765	0.001	0.071	0.036	**3.426**	0.035	**4.213**
vanilla is main crop	1=yes	0.159	**3.132**	0.031	0.651	0.054	0.903	0.114	**2.633**
cloves is main crop	1=yes	0.065	1.218	-0.010	-0.178	0.194	**3.395**	0.051	1.088
% of pop. that mines precious stones	%	0.000	-0.017	0.009	**4.603**	0.002	0.499	0.005	**1.962**
Dummy province of Fianarantsoa	1=yes	-0.090	**-3.212**	-0.244	**-8.213**	-0.212	**-7.021**	-0.123	**-4.737**
Dummy province of Toamasina	1=yes	-0.015	-0.509	-0.105	**-3.558**	-0.028	-0.867	-0.059	**-2.104**
Dummy province of Mahajanga	1=yes	-0.049	**-1.864**	0.056	**2.317**	0.239	**6.476**	-0.120	**-4.019**
Dummy province of Toliara	1=yes	-0.054	-1.419	-0.121	**-3.004**	0.081	1.763	-0.080	**-2.327**
Dummy province of Antsiranana	1=yes	0.016	0.471	0.108	**3.310**	0.196	**4.107**	0.022	0.732
Intercept		8.543	**15.463**	7.976	**15.277**	8.628	**14.942**	9.628	**21.136**
Number of observations		1160		1154		1157		1157	
F(13,N)		34.04		30.59		37.42		19.54	
p-value (Prob>F)		0.000		0.000		0.000		0.000	
R^2		0.269		0.218		0.250		0.003	
Root MSE		0.355		0.251		0.292		0.253	
Exogeneity and endogeneity tests									
A. Price regressions		Test stat.	p-value	Test stat.	p-value	Test stat.	p-value	Test stat.	p-value
a. Davidson MacKinnon endogeneity tests									
Rice yields	t-value	3.48	0.00	2.29	0.02	2.84	0.00	5.77	0.00
b. Overidentification tests									
Test that instruments are exogenous									
Wald test	Ch2	0.58	0.45	5.79	0.06	0.16	0.68	2.20	0.14
B. Instrumenting regressions		Test stat	p-value						
*Test that instruments are jointly significant***									
F-test	F(2, N)	53.36	0.00	41.13	0.00	58.25	0.00	58.38	0.00

standard errors and t-values corrected for spatial autocorrelation

* rice yields endogenous

** instruments: % of population that belongs to cattle/rice cultivators and forest ethnic group in regression 1,

% of riceland with improved irrigation infrastructure, % of population that belongs to cattle/rice cultivators and forest ethnic group in regression 2,

% of riceland with improved irrigation infrastructure, % of population that belongs to forest ethnic group in regressions 3 and 4

Table 5: Determinants of real agricultural wages (2SLS)

Dependent var. = log of daily wage in kapoaka of rice		male july - sept.		female july - sept.		male jan. - march		female jan. - march	
Variable	Unit	coefficient	t-value#	coefficient	t-value#	coefficient	t-value#	coefficient	t-value#
average rice yield*	log(number)	0.893	**7.818**	0.818	**7.246**	0.674	**5.334**	0.654	**5.222**
vanilla is main crop	1=yes	0.246	**2.964**	0.164	**1.925**	0.339	**4.005**	0.295	**3.218**
cloves is main crop	1=yes	0.502	**6.725**	0.441	**5.457**	0.655	**8.187**	0.606	**7.074**
% of pop. that mines precious stones	%	-0.006	-1.113	-0.008	-1.736	-0.013	**-3.003**	-0.013	**-3.265**
remoteness quintile	1 to 5	-0.017	-1.432	-0.024	**-2.004**	-0.050	**-4.206**	-0.053	**-4.526**
perceived security conditions	1 to 5	-0.048	**-3.199**	-0.048	**-3.084**	-0.027	-1.789	-0.020	-1.285
population density	log(number)	-0.059	**-4.329**	-0.070	**-4.889**	-0.008	-0.592	-0.012	-0.819
% of adults in the commune that are literate	%	0.002	1.745	0.003	**2.549**	0.000	-0.283	0.000	0.065
Dummy province of Fianarantsoa	1=yes	0.090	1.817	0.066	1.324	0.203	**3.890**	0.181	**3.540**
Dummy province of Toamasina	1=yes	0.176	**3.573**	0.245	**4.999**	0.244	**4.398**	0.302	**5.662**
Dummy province of Mahajanga	1=yes	0.554	**9.707**	0.577	**10.017**	0.398	**7.180**	0.410	**7.286**
Dummy province of Toliara	1=yes	0.300	**3.835**	0.305	**3.753**	0.345	**4.149**	0.367	**4.149**
Dummy province of Antsiranana	1=yes	0.833	**10.889**	0.876	**11.142**	0.717	**9.234**	0.744	**8.756**
Intercept		-4.255	**-4.821**	-3.770	**-4.298**	-2.867	**-2.958**	-2.833	**-2.948**
Number of observations		1066		1038		1060		1039	
F(13,N)		35.61		44.79		20.05		22.12	
p-value (Prob>F)		0.000		0.000		0.000		0.000	
R^2		0.070		0.167		0.010		0.050	
Root MSE		0.4951		0.4680		0.4751		0.4573	
Exogeneity and endogeneity tests									
A. Price regressions		Test stat.	p-value	Test stat.	p-value	Test stat.	p-value	Test stat.	p-value
a. Davidson MacKinnon endogenity test									
Rice yields	t-value	-6.19	0.00	-5.71	0.00	-4.67	0.00	-4.45	0.00
b. Overidentification tests									
Test that instruments are exogenous									
Wald test	Ch2	0.00	0.98	0.20	0.65	0.45	0.50	0.30	0.58
B. Instrumenting regressions		Test stat	p-value						
*Test that instruments are jointly significant***									
F-test	F(2, N)	39.54	0.00	39.93	0.00	39.48	0.00	40.40	0.00

standard errors and t-values corrected for spatial autocorrelation

* endogenous

** instruments: % of riceland with improved irrigation infrastructure, % of population that belongs to forest ethnic group

Table 6: Determinants of rice yields (OLS)

Dependent variable = log of average rice yield in commune			
Variable	Unit	Coeff.	t-value#
% of hhs that adopt land intensification improved technology*	0 to 5	0.0368	**2.569**
% of lowlands connected to improved irrigation infrastructure	%	0.0013	**3.669**
% of hhs that adopt agr. equipment	0 to 5	0.0198	**2.225**
% of hhs that adopt off-season crops	0 to 5	0.0005	0.071
log(# of years in last three when hit by major disasters)	0 to 27	-0.0081	-0.495
log ((number of cattle+1)/(population in commune))	#	0.0284	**3.909**
use of animal traction (% of farmers)	%	0.0010	**2.727**
population density	log(number)	-0.0057	-0.570
% of population that belongs to cattle/rice cultivators ethnic group	%	0.0011	**2.387**
% of population that belongs to the forest ethnic group	%	-0.0014	**-2.196**
% of population that belongs to eastern ethnic group	%	0.0012	**2.293**
% of population that belongs to western ethnic group	%	0.0005	0.645
average temperature in the commune	C	-0.0249	-1.397
average temperature in the commune squared		0.0000	1.050
average rainfall in the commune	mm	0.0002	1.098
average rainfall in the commune squared		0.0000	-1.047
average altitude in the commune	m	-0.0001	-0.226
average altitude in the commune squared		0.0000	-0.939
% of the surface commune with cristalline soils - North/Highlands	%	-0.0002	-0.259
% of the surface commune with cristalline soils - Midwest	%	-0.0002	-0.271
% of the surface commune with cristalline soils - East	%	-0.0001	-0.090
% of the surface commune with cristalline soils - South	%	-0.0020	**-3.139**
% of the surface commune with volcanic soils	%	-0.0004	-0.635
% of the surface commune with alluvial soils	%	-0.0002	-0.354
Dummy province of Fianarantsoa	1=yes	-0.1420	**-3.899**
Dummy province of Toamasina	1=yes	-0.0522	-1.035
Dummy province of Mahajanga	1=yes	-0.0610	-0.979
Dummy province of Toliara	1=yes	-0.1033	-1.556
Dummy province of Antsiranana	1=yes	-0.1706	**-2.199**
Intercept		10.6338	**5.671**
Number of observations		1272	
F(29,1242)		22.69	
Prob > F		0.00	
R-squared		0.32	
Root MSE		0.34	
Exogeneity and endogeneity tests			
A. yield regressions		Test	p-value
a. Davidson McKinnon endogeneity test			
Adoption	t-value	1.06	0.29
b. Overidentification tests			
Test that istruments are exogenous			
Wald X^2		15.13	0.00
B. Instrumenting regressions			
Test that instruments are jointly significant**			
F-test	F-value	12.60	0.00

standard errors and t-values corrected for spatial autocorrelation

* endogenous in 2SLS

** instruments: population density, remoteness quintile, distance to agr. extension, security in the commune, % of titled land

Table 7: Determinants of adoption of improved agricultural technologies (ordered probit)

		off-season crops		fertilizer		early transplanting		improved seeds	
Variable	Unit	coefficient	z-value	coefficient	z-value	coefficient	z-value	coefficient	z-value
% of lowlands connected to improved irrigation infrastructure	%	0.002	1.210	0.004	**3.030**	0.005	**2.950**	0.004	**3.130**
perceived security conditions	1 to 5	0.010	0.250	0.023	0.560	-0.156	**-3.540**	-0.071	**-1.750**
population density	log(number)	-0.010	-0.250	0.038	0.910	-0.114	**-2.270**	0.021	0.490
remoteness quintile		-0.123	**-3.280**	-0.204	**-5.230**	-0.138	**-3.280**	-0.091	**-2.420**
% of population that belongs to cattle/rice cultivators ethnic group	%	-0.009	**-4.980**	-0.005	**-2.380**	-0.008	**-3.510**	-0.006	**-3.290**
% of population that belongs to the forest ethnic group	%	-0.007	**-3.300**	-0.011	**-4.180**	-0.002	-0.800	-0.002	-0.860
% of population that belongs to eastern ethnic group	%	-0.001	-0.570	-0.004	**-1.910**	0.002	0.740	-0.004	**-1.840**
% of population that belongs to western ethnic group	%	-0.011	**-3.800**	-0.005	-1.620	-0.020	**-5.730**	-0.007	**-2.270**
distance to extension agent	log(distance)	-0.023	-1.010	-0.034	-1.400	-0.054	**-2.040**	-0.034	-1.490
% of agricultural land that is titled	%	-0.047	-1.560	0.015	0.430	0.016	0.380	0.117	**3.910**
% of adults in the commune that are literate	%	0.006	**1.930**	0.008	**2.670**	0.005	1.500	0.007	**2.100**
log(# of years in last three when hit by major disasters)	0 to 27	0.175	**2.960**	0.047	0.710	0.220	**3.060**	0.096	1.550
average temperature in the commune	C	-0.156	**-2.700**	-0.294	**-4.530**	0.223	**3.080**	0.004	0.070
average temperature in the commune squared		0.000	**2.440**	0.001	**4.560**	0.000	**-2.460**	0.000	1.060
average rainfall in the commune	mm	0.001	**1.730**	0.000	-0.350	0.003	**4.710**	0.000	0.240
average rainfall in the commune squared		0.000	-0.920	0.000	0.380	0.000	**-3.860**	0.000	0.220
average altitude in the commune	m	0.001	0.740	0.002	**2.200**	0.001	1.600	0.005	**5.970**
average altitude in the commune squared		0.000	-0.960	0.000	**-3.250**	0.000	**2.630**	0.000	**-2.550**
% of the surface commune with cristalline soils - North/Highlands	%	0.000	-0.110	0.003	1.220	0.002	0.910	0.003	1.120
% of the surface commune with cristalline soils - Midwest	%	0.000	-0.120	0.004	1.340	-0.004	-0.800	0.001	0.390
% of the surface commune with cristalline soils - East	%	0.001	0.250	0.002	0.700	0.002	0.930	0.002	0.780
% of the surface commune with cristalline soils - South	%	0.008	**2.940**	0.000	0.010	0.020	**5.680**	0.007	**2.900**
% of the surface commune with volcanic soils	%	-0.001	-0.390	0.004	1.350	0.001	0.340	0.004	**1.680**
% of the surface commune with alluvial soils	%	-0.003	-1.030	0.003	1.160	0.005	**1.690**	0.008	**3.210**
Dummy province of Fianarantsoa	1=yes	-0.112	-1.080	-0.013	-0.110	1.228	**4.810**	0.375	**3.250**
Dummy province of Toamasina	1=yes	0.367	**1.890**	0.384	1.620	-0.816	**-3.050**	0.735	**4.050**
Dummy province of Mahajanga	1=yes	1.097	**4.630**	-0.565	**-2.090**	-0.046	-0.150	0.166	0.640
Dummy province of Toliara	1=yes	1.337	**5.400**	0.563	**2.230**	1.358	**3.790**	1.135	**4.510**
Dummy province of Antsiranana	1=yes	1.681	**6.780**	-0.317	-1.060	-1.261	**-3.840**	0.192	0.680
Number of observations		1342		1342		1342		1350	
Wald X^2		622.58		639.92		460.06		331.29	
p-value (Prob>X^2)		0		0		0		0	
Pseudo R^2		0.1767		0.2341		0.2254		0.0943	

Table 7: Determinants of adoption of improved agricultural technologies (ordered probit) - continued

		sri		agr. equipment		adoption index*	
Variable	Unit	coefficient	z-value	coefficient	z-value	coefficient	z-value
% of lowlands connected to improved irrigation infrastructure	%	0.006	**3.830**	0.002	1.280	0.006	**4.720**
perceived security conditions	1 to 5	-0.052	-1.150	0.008	0.210	-0.099	**-2.780**
population density	log(number)	-0.028	-0.620	-0.084	**-2.010**	0.002	0.040
remoteness quintile		-0.130	**-3.000**	-0.170	**-4.540**	-0.170	**-4.640**
% of population that belongs to cattle/rice cultivators ethnic group	%	0.000	-0.060	-0.002	-1.090	-0.004	**-2.480**
% of population that belongs to the forest ethnic group	%	0.000	0.070	-0.014	**-4.870**	-0.003	**-1.820**
% of population that belongs to eastern ethnic group	%	0.000	-0.130	-0.009	**-4.660**	-0.003	**-2.000**
% of population that belongs to western ethnic group	%	0.001	0.180	0.003	1.040	-0.011	**-3.730**
distance to extension agent	log(distance)	-0.097	**-3.780**	-0.009	-0.400	-0.054	**-2.410**
% of agricultural land that is titled	%	0.083	**2.450**	-0.012	-0.390	0.085	**2.370**
% of adults in the commune that are literate	%	0.011	**3.440**	0.017	**5.530**	0.007	**2.460**
log(# of years in last three when hit by major disasters)	0 to 27	0.118	**1.650**	0.247	**3.830**	0.149	**2.640**
average temperature in the commune	C	0.002	0.030	0.228	**3.460**	-0.024	-0.460
average temperature in the commune squared		0.000	0.530	0.000	**-3.190**	0.000	1.400
average rainfall in the commune	mm	-0.001	-0.850	0.003	**4.490**	0.001	**2.400**
average rainfall in the commune squared		0.000	1.020	0.000	**-4.670**	0.000	**-1.830**
average altitude in the commune	m	0.002	**2.360**	0.001	1.460	0.003	**4.670**
average altitude in the commune squared		0.000	-0.190	0.000	1.250	0.000	-1.000
% of the surface commune with cristalline soils - North/Highlands	%	0.004	1.470	0.003	1.530	0.003	1.250
% of the surface commune with cristalline soils - Midwest	%	0.002	0.420	0.008	**1.790**	-0.001	-0.150
% of the surface commune with cristalline soils - East	%	0.009	**3.000**	-0.005	**-2.310**	0.002	1.040
% of the surface commune with cristalline soils - South	%	0.005	1.380	0.007	**3.370**	0.008	**3.670**
% of the surface commune with volcanic soils	%	0.003	0.750	0.003	1.290	0.003	1.180
% of the surface commune with alluvial soils	%	0.004	1.370	0.002	0.680	0.006	**2.730**
Dummy province of Fianarantsoa	1=yes	-0.094	-0.810	-0.532	**-4.220**	0.308	**2.570**
Dummy province of Toamasina	1=yes	-0.255	-1.240	-0.002	-0.010	-0.302	-1.640
Dummy province of Mahajanga	1=yes	-0.513	**-2.030**	0.095	0.380	-0.501	**-2.430**
Dummy province of Toliara	1=yes	-0.314	-1.120	0.817	**3.340**	0.720	**3.460**
Dummy province of Antsiranana	1=yes	-0.562	**-1.890**	-0.098	-0.340	-0.990	**-3.950**
Number of observations		1342		1342		1342	
Wald X^2		439.44		741.92		554.2	
p-value (Prob>X^2)		0		0		0	
Pseudo R^2		0.2075		0.26		0.1814	

* adoption index = mean of adoption of land intensification technologies, i.e. fertilizer, transplanting, improved seeds, sri