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TRANSACTIONS COSTS AND AGRICULTURAL PRODUCTIVITY: IMPLICATIONS OF ISOLATION FOR RURAL POVERTY IN MADAGASCAR

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ABSTRACT

This paper examines the mechanisms that transmit isolation into poverty in Madagascar using household survey data combined with a census of administrative communes. Given the importance of agriculture to the rural poor, where nine out of ten poor persons is engaged in farming, we concentrate on isolation manifesting itself in the form of high transaction costs such as the cost of transporting agricultural commodities to major market centers. We find that (a) the incidence of poverty in rural Madagascar increases with remoteness; (b) yields of major staple crops fall considerably as one gets farther away from major markets; (c) and the use of agricultural inputs declines with isolation. Simulation results using output from rice production function estimates suggest that halving travel time per kilometer on major highways (feeder roads) will increase primary season rice production by 1.3 (1.0) percent.

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TRANSACTIONS COSTS AND AGRICULTURAL PRODUCTIVITY: IMPLICATIONS OF ISOLATION FOR RURAL POVERTY IN MADAGASCAR

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I. INTRODUCTION

In their study of poverty dynamics in Madagascar in the 1990s, Razafindravonona et al. (2001) discovered a systematic relationship between higher levels of rural poverty and the degree to which households were isolated. For example, while 66 percent of the least isolated quintile of rural households was found to be poor in 1999, almost 83 percent of the most isolated quintile of households was poor. Given data limitations, however, their analysis was limited in the degree to which the mechanisms driving these results were understood.

Considering that the 78 percent of the national population that resides in rural areas accounted for almost 84 percent of all the poor in Madagascar in 1999, and that nine out of ten rural poor persons lived in farming households (Razafindravonona et al., 2001), understanding the nature of rural poverty and the potential policies that may be employed to address it is critical. As such, Cornell University and the World Bank worked together with Madagascar's National Statistical Institute (INSTAT) to redesign the latter's household survey questionnaire to *inter alia* capture more information on the livelihoods of the rural poor. While this survey was in the field in the Fall 2001, Cornell University[4] independently conducted its own census of communes (the lowest

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administrative level above the village) in which measures of remoteness were collected. By combining the two datasets, it is now possible to analyze in more detail the mechanisms that transmit isolation or remoteness into poverty.

The objective of this paper is to do just that. In particular, after examining the broad implications of isolation on rural households in Madagascar, we concentrate specifically on the impact of the subsequent high transaction costs[5] that accompany isolation on agricultural productivity. Given the importance of agriculture as the primary source of livelihoods in rural areas, this link between agricultural productivity and poverty is an important one (Randrianarisoa and Minten, 2001; Razafindravonona et al., 2001; World Bank, 2001). Further, as we shall see, the link between agricultural productivity – rice productivity, in particular – and isolation is also strong. This was the case for Binswanger et al's (1993) findings in India in the 1970s where improved roads contributed directly to growth of agricultural output, as well as of fertilizer use (see also Ahmed and Hossain, 1990, for Bangladesh), due to "reduced transaction costs of all sorts." Clarifying this link between transaction costs associated with isolation and agricultural production in Madagascar, we believe, will shed further light on avenues through which policy interventions intended to alleviate rural poverty may be directed.

We note that although the line of empirical literature has thus far concentrated on the extent to which rural road construction – one particular policy intervention – affects income inequality[6] and not poverty (Jacoby, 2000; Howe and Richards, 1985), we believe

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[5] We define transaction costs as any costs that drive a wedge between buyer and seller prices (e.g. farmgate and market prices). As such these costs include transportation costs as well as marketing margins of intermediary traders. We concentrate, however, on the former.

[6] This interest has followed, in large part, because of the significance that inequality has on the political constraints related to the allocation of infrastructure investment.

that in the current climate of debt relief for Madagascar under the Highly Indebted Poor Country (HIPC) initiative, an emphasis on the relationship between isolation and poverty is equally, if not more important.

An outline of the remainder of this paper is a follows. In section II, we discuss the methodology used to define isolation and to estimate production functions for rice. The data sources and methods of merging them are discussed in section III, while an initial analysis of the implications of being isolated are described in section IV. In section V, the results of econometric estimations of rice production functions and input demand functions are analyzed with particular emphasis on the effect of isolation on production and input decisions. We wrap up with concluding remarks in section VI.

2. METHODOLOGY

ISOLATION

Rural isolation can be defined in many ways. While distance to urban centers or markets is generally a measure of choice (McCabe, 1977; Ahmed and Hossain, 1990; Minten and Kyle, 1999; Jacoby, 2000; and Fafchamps and Moser, 2002), there is an implicit recognition that the degree of isolation can be ameliorated through public interventions such as infrastructure development and/or the provision of public goods. In this paper we attempt to capture isolation in Madagascar through three measures (a) travel time to the nearest primary urban center; (b) cost of transporting a 50 kg sack of rice to the nearest primary urban center; and (c) a remoteness index that is the result of a factor analysis on various measures of access, or lack thereof.

Travel time to the nearest primary urban center is more precisely the dry season travel time from the commune center to the nearest large city to which commune residents actually travel on a regular basis. This information was collected in the commune census, and was determined in steps. For instance, if multiple forms of travel (e.g. foot, ox-cart, automobile) are necessary, then actual travel time per form of transport was recorded along with waiting time.

The cost of transporting a 50 kg sack of rice was also collected in the commune census, and is the cost of dry season transport between the commune center and the nearest primary urban center to which residents travel on a regular basis. As we shall see, the distance to the urban center and the average travel time per kilometer (interpreted loosely as road quality) each has an independent effect on the cost of transportation. Since the latter has direct policy implications, we use both distance and road quality as proxies for isolation defined by transportation costs in the econometric estimation in section V.

Finally, in an effort to create a broad measure of isolation that also captures access, we construct a remoteness index that is the outcome of a factor analysis[7] of various isolation measures 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. We assume that there is a common factor, "remoteness," that explains the variance in the isolation measures, and

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[7] See Sahn and Stifel, 2001, for a description of the factor analysis methodology applied to household assets to create household asset indices.

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 to consequently define quintiles of isolation. The latter are estimated using commune population sizes as weights.

MODEL OF RICE PRODUCTION AND INPUT DEMAND

To analyze the effects of isolation on agricultural productivity, and on rice production in particular, we estimate a rice production function model. We opt to estimate the primal production function, rather than the dual profit function, primarily because the latter is conditioned on prices. And while we employ prices as instruments, we caution that their usefulness as signals is limited. The reasons for this are several. The use of realized *ex post* output prices is complicated by the timing of the input quantity decisions which are made well in advance of the harvest. In fact, these decisions are made conditional on the *ex ante* expected value of these prices. Given the uncertainties in agricultural production and prices, the correspondence between the expected and realized prices is unlikely to be a tight fit. In addition all of the prices available in the data suffer from some degree of aggregation bias (Deaton 1988, Barrett 1996, Barrett, 1997). The commune average prices available for and used in this analysis fail to capture intertemporal and spatial variations in transaction prices within the commune. This uncaptured variation can result from the timing or the volume of sales, inter-linked contracts, differences in quality, and intra-commune isolation.[8] Further, the non-separability of household decision-making and the market failures that arise as households selectively opt out of certain markets (often due to high transactions costs), can give rise to household-specific shadow prices that vary considerably from the commune average (de Janvry et al., 1991). As such, we prefer to estimate the production function directly and address the endogeneity of input decisions with instrumental variables methods.

We assume a translog functional form of production:

$$\ln(y) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln(x_i) + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} \ln(x_i)\ln(x_j) + \sum_{i=1}^{n} \beta_{ii} \left(\ln(x_i)\right)^2 + \sum_{k=1}^{m} \delta_k z_k + \mu$$

where, y represents rice output from a plot of land, x is a vector of variable factor inputs (e.g. land, labor, fertilizer, seed, traction), z is a vector of productivity shifters (e.g. soil quality, irrigation, plot characteristics, household characteristics, and isolation measures), and μ is an error term distributed with zero mean and unknown variance

In order to estimate the model, a constant value of one is added to all the inputs before the logs are taken because the natural log of zero is undefined. Further, given that the choice variable inputs are likely correlated with unobserved ability, and as such are correlated with the error term, we estimate the model using instrumental variable (IV) methods. Once the model is estimated, the elasticities of the different factor inputs for each plot can be computed as:

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[8] We attempt to control for remoteness within the commune with the variable measuring distance from the plot to a passable route. But we note that this captures only part of the effect. In fact, this point highlights a limitation of this analysis in that remoteness is defined at the commune level, not the household level. Nonetheless, this is unlikely to be a first order problem.

$$\varepsilon_{y,x_i} = \alpha_i + \sum_{j<i}^{i-1} \beta_{ji} \ln(x_j) + \sum_{j>i}^{n} \beta_{ij} \ln(x_j) + 2\beta_{ii} \ln(x_i) .$$

The elasticities reported in the tables are averages of the plot specific elasticities for each factor. Note that given that the elasticities are non-linear functions of the inputs, the average of the plot elasticities for a particular factor is not equal to the elasticity evaluated at the means of the inputs. Average elasticities are estimated for the entire sample and for each isolation quintile (where isolation is defined by travel time). Because we estimate the model with IV methods, and then evaluate the elasticities as averages within the samples of interest, we cannot determine the standard errors for the elasticities analytically. As such, the model and the elasticity estimates are bootstrapped (Brownstone and Valletta, 2001). Means of the bootstrapped average elasticities along with their t-statistics are reported in the tables.

The identifying instruments in the first stage models are output and input prices, household demographics and measures of institutional constraints in the commune. The latter perhaps needs some clarification. Each household in the dataset is asked if they have problems with regard to access to land, animal traction, labor, equipment and credit. They are also asked if they consider financial security to be a problem. Given the potential endogeneity of these variables, we enter as explanatory variables the non-self (household) commune means of the responses (Lanjouw and Ravallion, 1999; Alderman and Christiansen, 2002) as measures of local institutional constraints. Further, the estimates are made using ordinary least squares for the entire sample, including those plots on which zero quantities of the inputs are applied. This estimation procedure is adopted instead of a censored regression (Tobit), because we are interested in consistent estimates of the effect of input use on rice production, and consistency of these second-stage estimates does not depend on correctly specifying the functional form of the first-stage estimates. As Angrist and Krueger (2001) note, "using a nonlinear first stage to generate fitted value that are plugged directly into the second-stage equation does not generate consistent estimates unless the nonlinear model happens to be *exactly* right."

Given that the instruments used in the first stage estimates include output and input prices, and if we assume that farming households maximize profits (more on this below), these models can be interpreted as input demand functions.[9] To see this, define the profit function as:

$$\pi(p, w; z) = \max_x pf(x; z) - wx ,$$

where p is the price of rice, w is the vector of input prices, and $f(.)$ is the production function for rice. We note that a necessary property of the profit function is that it is non-increasing in w and non-decreasing in p. A further useful property of the profit function (Hotelling's Lemma) is that its derivative with respect to the price of an input is equal to the (negative) demand function for that input,

$$x_i(p, w; z) = -\frac{\partial \pi(p, w; z)}{\partial w_i} .$$

Thus, by interpreting the first-stage estimates as demand functions in this manner, we can expect the functions to be non-decreasing in p and non-increasing in w_i.

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[9] The major caveat being that these first-stage equations are estimated using ordinary least squares instead of Tobits.

A caveat is worth discussing at this point. These demand functions are estimated as reduced form models, not structural ones. As such, the effects of the explanatory variables on input demand are simply net effects. The significance of this is that we recognize that estimating structural parameters is complicated by the non-separability of consumption, labor supply and production decisions for small-scale farmers when markets are missing or incomplete. Quantity decisions for the use of particular inputs in production in the presence of incomplete markets and market failures need to be considered in the broader context of a bundle of inter-related decisions including some which are not directly related to profit maximization alone (e.g. household labor supply[10], information gathering, insurance, storage) (Singh et al., 1986, Barrett, 1997). To the extent that the household-demographic and institutional-constraint variable (instruments), z_{IV}, have significant explanatory power in the first-stage estimation equations,

$$\ln(x_i) = \phi_0 + \sum_{j=1}^{n} \phi_k w_j + \lambda p + \sum_{l=1}^{q} \gamma z_{IV,l} + \sum_{k=1}^{m} \eta z_k + v_i ,$$

at least some markets can be assumed to be incomplete, and non-separability becomes an issue.

In our interpretation of the estimation results, we are cognizant of the fact that particular parameter values can and do represent the net effects of the explanatory

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[10] In the discussion that follows, we loosely use the term household labor demand. To be precise, the choice of the quantity of household labor used in the production of rice is the result of the simultaneous supply and demand decisions which are not separable in the presence of externalities and incomplete markets.

variables transmitted through multiple simultaneous decisions. In addition, we are cautious in our interpretation of these models because of our concern about the quality of the price data. Nonetheless, we proceed in the manner described above in large part because our interest in this exercise lies in estimating the net effect of isolation on input decisions.

3. DATA

The 2001 *Enquete Prioritaire Aupres des Menages* (EPM) was a nationally representative integrated household survey of 5,080 households. The data were collected during the months of September, October and November 2001. The sample was selected through a multi-stage sampling technique in which the strata were defined by the *faritany* (province) and *milieu* (rural, secondary urban centers, and primary urban centers), and the primary sampling units (PSU) were communes. Each of the communes was selected systematically with probability proportional to size (PPS), and sampling weights defined by the inverse probability of selection are necessary to obtain accurate population estimates.

The comprehensive household questionnaire includes sections on education, health, employment, housing, agriculture, non-agricultural enterprises, and household expenditures and assets. The agriculture section is particularly detailed for a nationally representative survey with plot- and crop-level information. For a measure of household well-being, in this analysis we use the estimated household-level consumption aggregate constructed by INSTAT and the World Bank.

The commune census used in this research was conducted over a three-month period in 2001 in collaboration between the Ilo program of Cornell University, the Malagasy agricultural research institute (FOFIFA) and INSTAT. The remoteness of some communes meant that little was known about the spatial distribution of goods and services and economic activity prior to this study. This census gathered information on health centers, educational enrollments, commune budgets, and crime figures from the relevant government offices in the commune. More subjective questions, such as those concerning local prices, transportation, access to various goods and services, major economic activities, and community perceptions of existing conditions were answered for each commune by a focus group which was representative of the composition of the population of the commune. The survey was conducted at the commune's administrative center. A total of 1385 out of 1392 communes were visited. Finally, commune-level information from this census was merged with the 163 rural communes that appear in the EPM data.

4. INITIAL EVIDENCE

MEANING OF ISOLATION

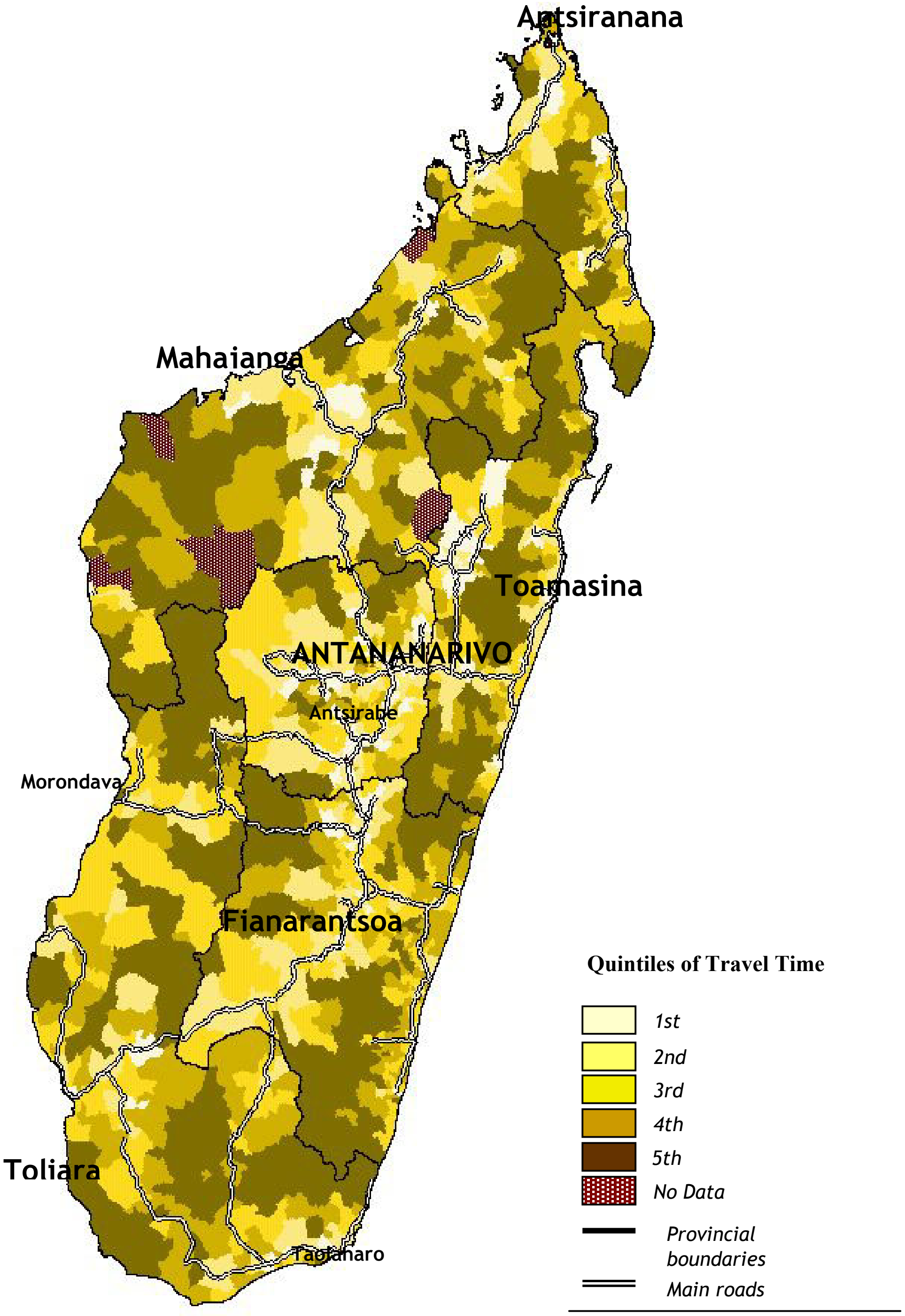
Before examining the implications of being isolated, let us characterize isolation itself for households not situated in major urban areas. The disparities in distance to major cities and markets that exist in Madagascar are apparent in Table 1. Those in the most isolated 20 percent of the rural population must travel 32 hours on average to reach the nearest major city, using travel time as a measure of isolation. This is some 32 times longer than it takes for those living in the least isolated quintile of the rural population (see Figure 1 for a map of the communes by travel time). When we use the more inclusive isolation index, the disparity falls (see Figure 2 for a map of the communes by quintiles of the remoteness index). Nonetheless, the gap between 22 hours of travel time for the most isolated quintile, as opposed to 3 hours for the least isolated quintile is remarkable. The typical journey for those living in the more isolated areas involves multiple legs starting with an extended walk to a taxi brousse station, and substantial waiting periods.

Table 1—Meaning of Remoteness

Averages

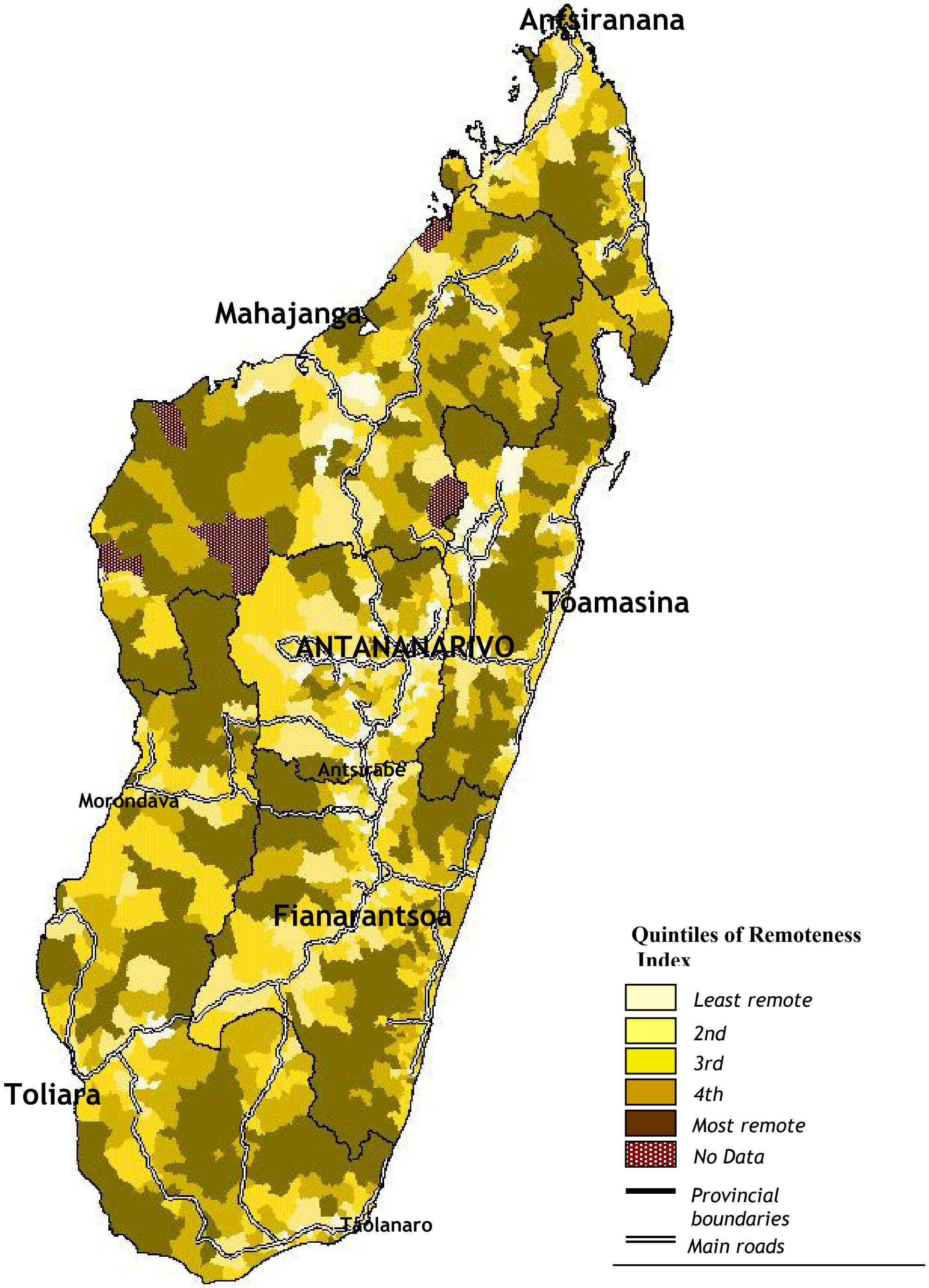
Quintiles	Travel time (hr) to nearest major city	Travel time (min on foot) - plot to accessible road	Ratio of Trans. Cost to Price of 50kg of rice
Remoteness Index			
Least Remote	3.38	18.1	0.05
2	5.32	17.4	0.07
3	10.03	21.0	0.20
4	17.63	27.3	0.20
Most Remote	21.51	30.8	0.27
Travel Time to Nearest City			
Least Remote	0.90	17.6	0.02
2	3.40	17.2	0.15
3	8.77	24.9	0.16
4	16.17	22.4	0.19
Most Remote	32.15	33.7	0.28
Total	10.99	22.7	0.15

Figure 1—Map of the Communes by Travel Time to Nearest City



Source : ***Commune Survey 2001, Programme Ilo, Cornell University***

Figure 2—Map of the communes by quintiles of the remoteness index



<u>Source :</u> Commune Survey 2001, Programme Ilo, Cornell University

An additional consideration in the calculus of transactions costs includes the distance from a household's agricultural plot to the nearest road accessible to animal-drawn carts. The middle column of Table 1, illustrates that in addition to road travel time to markets, farmers in more isolated areas must also contend with the basic task of getting the harvest to the road. The average walking time for the most isolated households is over half an hour, whereas plots for those in the least isolated 40 percent of the population are less than 19 minutes from the road.

The cost of transportation relative to local market prices can be viewed as a very rough measure of the degree to which prices must be forgone in order to sell the output in the cities (i.e. transaction costs). The average ratio of the cost of transporting a 50 kilogram sack of rice to the nearest major city during the dry season to the price of 50 kilograms of rice is illustrated in Table 1 by quintile. In the least isolated areas, transportation costs account for approximately five percent of the price of rice, whereas in the most isolated areas these costs take up more than a quarter of the price. In rural areas in general, the cost of transportation average 15 percent of the price of rice.

In light of the importance of these transactions costs, we present estimates of a very simple regression model to illustrate the correlates of transportation costs (Table 2). The explanatory variables are limited to distance, time in minutes per kilometer traveled, and the number of cattle thefts in the commune. Provincial dummies are also included to capture unobserved heterogeneity at the larger administrative level.[11] The general idea is

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[11] These results are qualitatively and statistically no different from another model estimated using Fivondronana (smaller administrative regions) fixed effects.

that costs are a function of the distance, the quality of the road and some risk premium that must be paid for transporting commodities through insecure regions. Although the latter turns out to be insignificant, distance and road quality (as captured by time per kilometer) are both positive and strongly significant. Since the variables are in logs, the parameter estimates represent estimates of the elasticities. This facilitates a simple exercise such as simulating the partial effect of road improvements or construction that halves the average time it takes to travel one kilometer from 4.16 to 2.08 minutes. Since the road quality elasticity of transportation cost is 0.66, a 50 percent improvement in quality will lead to a 33 percent drop in the cost of transporting rice ($\%\Delta cost = 0.66 * \%\Delta time = 0.66 * -0.5$), resulting in an average decline of FMG 3,664.

Table 2—Models of Cost of Transporting 50kg of Rice to Nearest Major City

Dry Season Transportation

	Mean	Std. Dev.	Coeff	t-stat
Cost of transportation (FMG)*	11,102	12,580		
Distance (km)*	220.4	247.7	0.59	16.38 **
Time (minutes) per km*	4.16	4.06	0.66	7.15 **
Number of cattle thefts in commune	49.4	170.9	0.00	1.48
Province Dummies				
Antananarivo	0.25	0.43		
Fianarantsoa	0.22	0.41	0.46	4.17 **
Toamasina	0.19	0.39	0.75	5.67 **
Mahajanga	0.11	0.32	0.20	1.32
Toliara	0.15	0.35	0.43	2.72 **
Antsiranana	0.09	0.28	0.56	2.98 **
Constant			4.94	23.64
R2			0.745	
No. observations			163	

* Logs in the regression

IMPLICATIONS OF BEING ISOLATED

Consistent with Razafindravonona et al's (2001) findings for the 1990s, we find a strong negative (positive) correlation between household consumption (poverty) and isolation, regardless of the measure of isolation. The mean household per capita consumption (Table 3) in the most isolated quintile is less than half of that in the least isolated quintile (FMG 484,000 versus FMG 1,010,000 using the travel time as the measure of isolation). Further, the largest gap is between the least isolated and the second quintile where the mean per capita consumption level is FMG 606,000. A similar pattern is reflected in the poverty figures, where more than 85 percent of the individuals living in isolated areas are estimated to be poor relative to approximately 55 percent in the least isolated rural areas.[12] Again, the biggest jump is between the first and second quintiles – some 75 percent of the individuals in the second quintile are estimated to be poor.

The last column of Table 3 shows the mean shares of food consumption that derive from home production instead of purchases. While autoconsumption is positively correlated with poverty (correlation coefficient of 0.33, see also Razafindravonona et al, 2001), it also represents a measure of market development. For example, without the presence of markets for food, the 53 percent of the individuals in the least isolated quintile[13] (remoteness index) who reported no autoconsumption of food would have had to grow their own food. As households are situated in increasingly isolated areas, the

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[12] Note that the poverty line is defined by INSTAT 2002.

[13] Note that 37 percent of these individuals are estimated to be poor.

share of autoconsumption in total food consumption rises from under 20 percent to over 40 percent suggesting increasingly fragmented or weak markets.

Table 3—Consumption/Poverty by Quintiles of Remoteness

Averages

Quintiles	Poor*	Per capita consumption	Autoconsumption share in food consumption
Remoteness Index			
Least Remote	47.8	1,103,389	15.6
2	75.2	673,125	35.2
3	85.6	508,925	40.3
4	89.7	457,563	43.3
Most Remote	86.6	492,710	42.1
Travel Time to Nearest City			
Least Remote	53.6	1,009,716	19.7
2	76.9	605,396	37.1
3	85.3	495,581	37.8
4	85.3	523,482	41.4
Most Remote	85.5	483,565	41.9
Total	77.0	590,316	35.3

* Poverty line is defined by INSTAT 2002

Given the large share of rural households involved primarily in agriculture[14], the next logical step is to examine the relationship between isolation and agricultural production. Table 4 shows some surprising results in which we find that rice, maize and cassava yields differ substantially by degree of isolation (see Figure 3 for a map of the average lowland rice yields for each commune). For example, median rice yields drop

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[14] 83 percent of households report at least one member who's primary employment activity is agriculture.

from above 25 kilograms per are for the first two quintiles to less than 19 kilograms in the most isolated two quintiles. Comparing the least and most isolated quintiles as measured by the remoteness index, the rice yields of the latter are just over half of the former. Similar results are found for maize and cassava production where median yields in the most isolated areas are approximately 50 percent below those of the least isolated quintile.

Table 4—Crop Yields by Quintiles of Remoteness

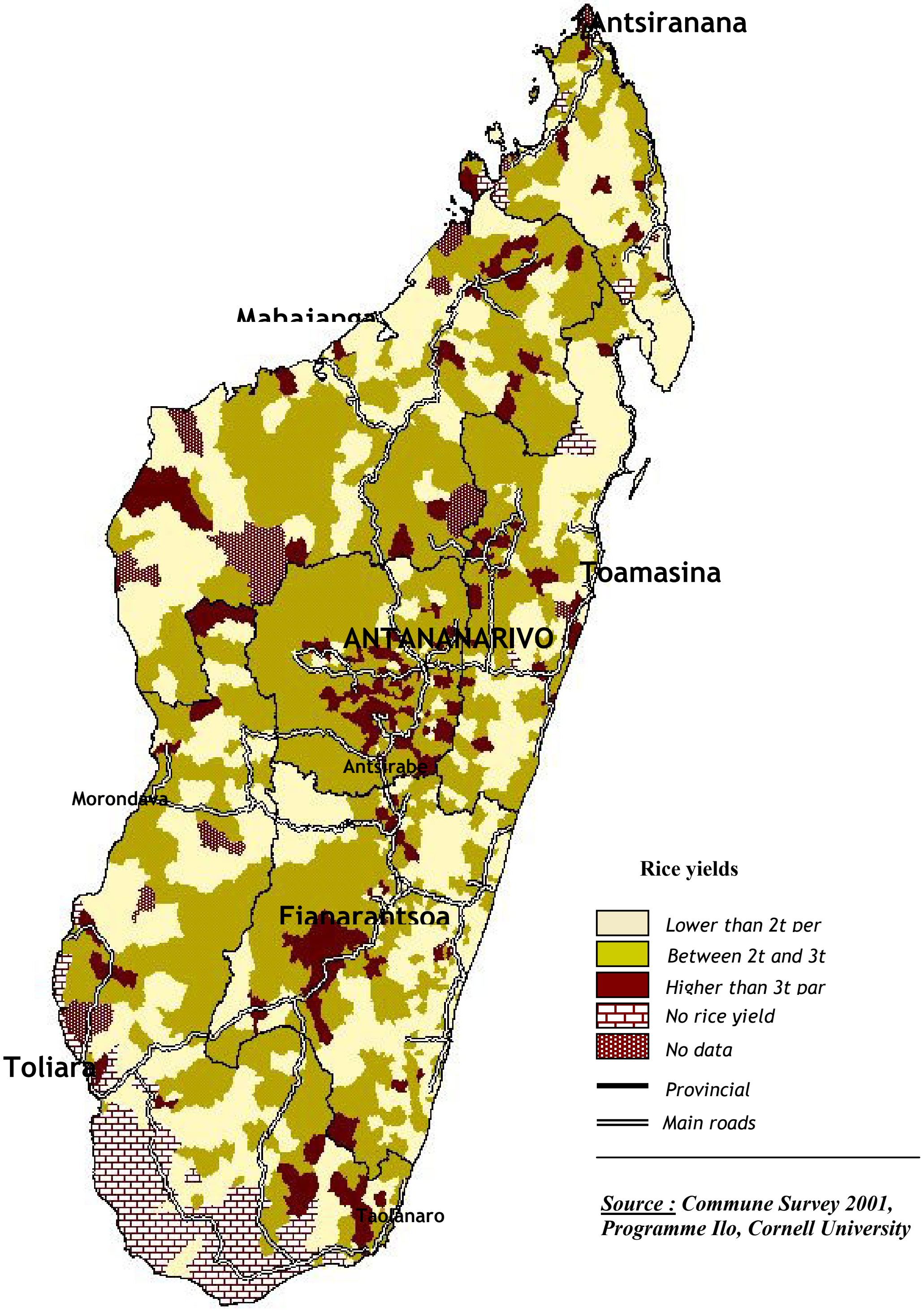
Median kilograms per are

Quintiles	Rice	Maize	Cassava
Remoteness Index			
Least Remote	35.0	17.0	90.0
2	25.0	15.0	32.0
3	19.5	8.3	26.7
4	16.7	8.0	25.0
Most Remote	16.7	10.0	20.0
Travel Time to Nearest City			
Least Remote	28.0	16.7	50.0
2	27.0	10.0	32.0
3	16.0	10.0	33.0
4	18.6	10.0	24.0
Most Remote	18.8	7.5	25.0
Total	22.7	10.0	30.0

With the competing demands for land and the subsequent higher land values in the least remote areas, it is not entirely surprising that yields should be greater there (Hayami and Ruttan, 1985). Nonetheless, these results are surprising in large part because, while we might expect output to vary substantially and yields to vary moderately in response to changes in transaction costs, it is not clear *ex ante* that the observed *magnitudes* of declining productivity associated with increased isolation should be so large. This is an important finding in that it sheds light on an avenue through which policies may be developed to raise the incomes of the poorest sector of the Malagasy economy (Razafindravonona et al, 2001, and World Bank 2000). To better understand the potential policy alternatives, we now turn to an analysis of the various factors that may plausibly contribute to this pattern of declining yields.

First, given the well-established inverse relationship between plot size and productivity (Carter, 1984, Feder, 1985, Bhalla and Roy, 1988, Barrett, 1996, and Heltberg, 1998), the increase in the median plot size by isolation quintile (see Table 5) may partially explain these differences. In fact, as we shall see in the subsequent econometric estimate, it appears to do so. The policy implications of this particular observation follow from the source of the inverse relationship whether it be due to labor market failures (Carter, 1984), unobserved soil quality differences (Bhalla, 1988, Bhalla and Roy, 1988, and Benjamin, 1995), land market failures or financial market failures (Barrett, 1996). Unfortunately, this remains an open question as the literature is far from a consensus on this topic and is beyond the scope of this paper.

Figure 3—Map of the average lowland rice yields for each commune



***Source :* Commune Survey 2001, Programme Ilo, Cornell University**

Table 5—Median Land Area

Are per plot

Quintiles	Remoteness Index	Travel Time to Nearest City
Least Remote	6	6
2	15	20
3	30	30
4	35	48
Most Remote	40	30
Total	24	24

Second, to the extent that the high transactions costs that follow from isolation drive a wedge between the value marginal product of inputs and the price of inputs (e.g. cost of fertilizer at the factory gate relative to the price paid by the farmer), input use per unit of land is likely to fall, and consequently so are yields. Table 6 illustrates that this is very likely the case with regard to fertilizer and pesticide use. While overall chemical fertilizer use is very low, with fewer than 12 percent of all farming rural households applying it, it is even more so in the two most isolated quintiles, where less than 5 percent use it and on average less than a tenth of a kilogram is applied per are. This is in sharp contrast to the more than 25 percent of rural farming households in the two least isolated quintiles[15] who apply chemical fertilizers (see Figure 4 for a map of the communes by the share of farming households using chemical fertilizers). The differences are even more

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[15] In terms of time to the nearest city, those households within 4.5 hours travel time are in the first two quintiles.

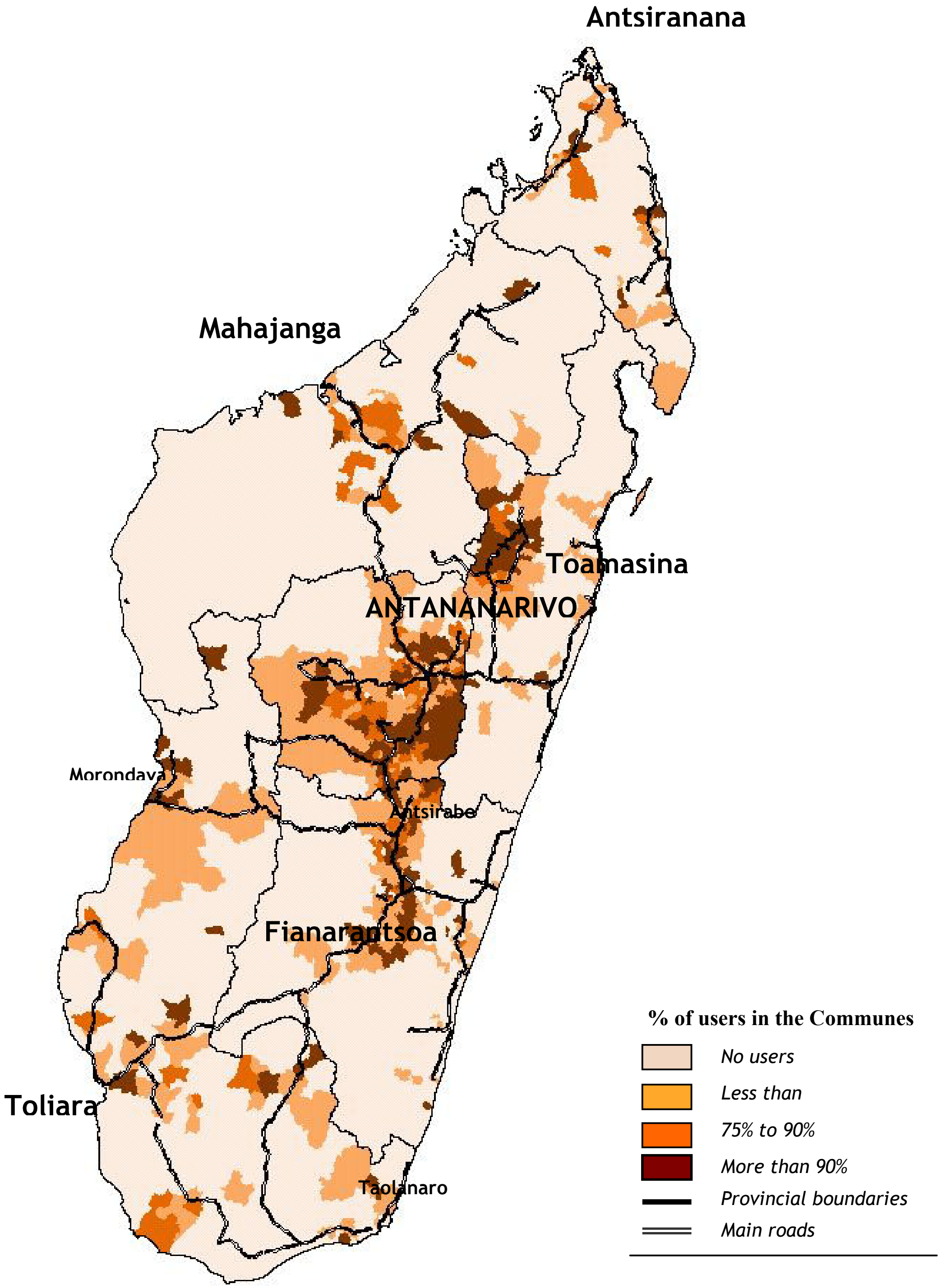
stark for organic fertilizer. Between 67 and 74 percent of farming households in the least isolated quintile apply organic fertilizer depending on the isolation measure used, whereas less than 13 percent and as low as 2 percent in the most isolated quintile use it. In terms of quantities, less than a quarter of a kilogram of organic fertilizer is applied per are in the most isolated areas, while over 7.5 kilograms are applied on average per are in least isolated areas. A very similar picture is portrayed for pesticide/herbicide use.

The pattern of declining organic fertilizer use does not appear to directly follow from lack of access to dung. As Table 7 illustrates, livestock ownership is generally no less prevalent in more isolated areas. In fact, the average number of heads owned and the average total value increase with isolation.

Table 6—Agricultural Input Use by Quintiles of Remoteness

	Percentage of households using…			Average quantity (kg/are)…		Average value (FMG/are)
Quintiles	Chemical Fertilizers	Organic Fertilizers	Pesticides/ Herbicides	Chemical Fertilizers	Organic Fertilizers	Pesticides/ Herbicides
Remoteness Index						
Least Remote	26.6	73.9	18.5	0.36	9.95	1,609
2	27.6	50.8	17.3	0.44	2.19	112
3	6.2	16.8	4.9	0.08	1.29	90
4	5.0	12.0	3.0	0.13	0.44	43
Most Remote	0.9	12.9	2.3	0.04	0.23	14
Travel Time to Nearest City						
Least Remote	28.1	67.0	18.8	0.28	7.59	1,013
2	25.0	55.3	16.0	0.48	3.49	369
3	4.4	11.9	3.3	0.10	0.45	36
4	0.8	18.4	2.9	0.01	0.13	27
Most Remote	3.2	1.5	1.9	0.10	0.19	62
Total	11.3	28.3	7.9	0.21	2.54	319

Figure 4—Map of the communes by the share of farming households using chemical fertilizers



<u>Source :</u> Commune Survey 2001, Programme Ilo, Cornell University

Table 7—Livestock Ownership by Quintiles of Remoteness

All households

	Percent that own…				Average number owned…				Average value…			
Quintiles	Draft zebu	Cattle	Milk Cow	Total	Draft zebu	Cattle	Milk Cow	Total	Draft zebu	Cattle	Milk Cow	Total
Remoteness Index												
Least Remote	2.7	15.2	2.0	18.5	0.1	0.6	0.0	0.8	84,698	675,048	49,730	809,476
2	13.2	23.1	2.3	34.2	0.5	1.0	0.0	1.5	394,465	882,627	34,577	1,311,669
3	12.7	28.3	5.9	35.8	0.5	3.7	0.7	4.9	490,208	2,838,221	561,054	3,889,484
4	7.3	24.9	3.4	30.0	0.3	3.3	0.3	3.9	239,675	2,216,882	120,400	2,576,957
Most Remote	7.2	32.9	4.1	39.1	0.4	6.1	0.2	6.7	255,413	2,909,944	214,560	3,379,917
Travel Time to Nearest City												
Least Remote	6.4	16.2	2.5	21.9	0.2	1.0	0.0	1.2	188,229	863,471	46,030	1,097,730
2	11.6	28.8	2.1	37.7	0.5	1.8	0.1	2.3	431,654	1,238,086	34,303	1,704,042
3	9.3	20.5	1.9	26.9	0.3	2.5	0.2	2.9	242,685	1,891,779	88,982	2,223,446
4	7.7	30.8	6.3	35.9	0.6	4.7	0.8	6.1	408,423	2,880,580	627,726	3,916,728
Most Remote	7.9	29.5	5.4	36.5	0.2	5.0	0.3	5.6	214,735	2,813,763	249,661	3,278,160
Total	8.5	24.8	3.6	31.4	0.4	2.9	0.3	3.6	291,459	1,903,432	197,953	2,392,843

Table 8—Agricultural Labor by Quintiles of Remoteness

Average number of man-days per crop per are

	All Crops				Rice (Principal Season)				Maize				Cassava			
Quintiles	Total	Household	Reciprocal	Hired	Total	Household	Reciprocal	Hired	Total	Household	Reciprocal	Hired	Total	Household	Reciprocal	Hired
Remoteness Index																
Least Remote	33.8	26.9	1.9	5.0	37.6	27.9	2.0	7.7	28.0	20.3	2.6	5.0	23.8	16.8	2.8	4.2
2	26.7	19.3	3.7	3.7	38.1	25.9	5.1	7.2	13.0	9.8	2.0	1.2	16.9	12.4	3.8	0.7
3	49.6	39.6	7.1	3.0	84.7	67.7	13.9	3.2	23.6	15.0	3.6	5.0	26.5	22.4	3.1	1.0
4	52.7	45.2	4.4	3.1	82.4	72.1	7.0	3.4	29.5	21.9	7.6	0.0	39.7	27.8	3.2	8.7
Most Remote	26.9	21.8	3.8	1.2	46.6	37.8	5.8	3.0	12.6	9.8	2.5	0.4	15.2	13.0	1.5	0.7
Travel Time to Nearest City																
Least Remote	28.1	22.6	2.6	2.9	33.1	24.3	2.9	5.9	13.6	10.1	2.5	1.1	15.5	12.9	2.0	0.6
2	29.3	22.4	3.5	3.4	52.2	39.1	7.8	5.3	21.6	15.9	1.3	4.4	17.6	13.8	1.8	2.0
3	51.9	41.0	6.4	4.5	79.9	65.2	9.6	5.1	30.7	17.3	5.9	7.5	35.5	28.5	6.0	1.1
4	45.5	36.5	5.1	3.9	76.2	62.9	7.5	5.7	22.1	15.4	6.3	0.4	31.2	18.5	1.8	10.9
Most Remote	38.1	33.1	4.0	1.0	58.3	48.6	7.6	2.1	18.4	16.5	1.8	0.2	20.3	17.2	2.6	0.5
Total	38.0	30.6	4.3	3.2	59.0	47.0	7.1	4.9	20.5	14.7	3.4	2.5	24.7	18.6	2.9	3.1

With regard to labor inputs, the bulk of which consists of household labor, there appears to be an inverted-U relationship between man-days per are and isolation (Table 8) for the three primary crops – rice, maize and cassava. This does not follow directly from the generally monotonically increasing agricultural wage rates across isolation quintiles (Table 9). We note, however, that such behavior is not inconsistent with economic theory since *ceteris* are not *paribus* in Table 8. In other words, such confounding factors as soil quality and fertilizer inputs can affect the marginal productivity of labor differently across farms such that farmers optimally choose different levels of labor inputs when faced with the same wage rates.[16]

Table 9—Agricultural Prices by Remoteness Quintile

Commune-Quintile Averages in FMG

	Average over past year		
Quintiles	Male Daily Wage	Female Daily Wage	Price of Paddy (kg)
Remoteness Index			
Least Remote	5,440	4,960	1,418
2	6,027	5,600	1,269
3	6,720	5,830	1,277
4	6,420	6,086	1,368
Most Remote	9,041	4,858	1,196
Travel Time to Nearest City			
Least Remote	5,909	5,078	1,472
2	5,851	5,292	1,179
3	5,914	5,431	1,323
4	5,777	5,590	1,269
Most Remote	10,079	6,139	1,282
Total Rural	6,667	5,482	1,311

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[16] We also note that there is little variation in the commune-level daily wages that appear in the data. As we see later in the labor demand estimates, labor demand is invariant to the price of labor as recorded in these data. We conclude that this is largely due to lack of variability in the prices.

Third, the inverse relationship between yields and isolation could simply follow from differences in soil quality. Based on the premise that cities formed around the most fertile land[17] (Krugman, 1999, Fujita et al, 2001), one might expect soil/plot characteristics to be at least moderately correlated with isolation. This appears not to be the case for the plot characteristics available in the EPM data. Table 10 illustrates theshare of land (plots weighted by area) by various types of land (lowland rice, hill-side rice, etc.) and characteristics of the slope (flat, slight slope, etc.) and of the soil (sandy, clay and muddy). The one apparent message stemming from this table is that there is no clear pattern in the relationship between soil quality and isolation.

Another consequence of remoteness or isolation is the effect of transactions costs on diversification and crop choices. We begin by examining the concentration of crops across the isolation quintiles using the commune-level Herfindahl-Hirschman index, which is defined as

$$HHI = 100 * (s_1^2 + \ldots + s_k^2)$$

where s_i is the share of land devoted to crop i in the commune. A look at the extremes will help to understand the *HHI*. At one extreme, if all land is devoted to the cultivation of one crop, then the *HHI* is equal to 100. At the other extreme, as the number of crops increases and as the shares approach zero, the *HHI* also approaches zero. So a value of one represents perfect crop concentration, while very low values represent crop diversification. It is not clear, *ex ante*, if we should expect the concentration or

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[17] Trading centers and agglomeration effects are clearly important determining factors for the establishment of cities as well.

diversification of crops to increase with isolation. On the one hand, farmers in less isolated areas may rely solely on a few cash crops that are relatively easily marketed. On the other hand, farmers in poorer isolated regions may rely primarily on nontradable staple crops for subsistence purposes. Both scenarios result in high crop concentrations, but for different reasons.

In Table 11, we find that although there do not appear to be systematic differences in the average number of crops grown in the various isolation quintiles, the distribution of these crops over cultivated land is considerably greater in the most isolated quintile than in the less isolated 80 percent of the population. The decline in the *HHI* is monotonic across the remoteness index quintiles, whereas it is much more level across the first four travel time quintiles. In either case, in the most isolated regions, agricultural land is less concentrated on particular crops and more diverse.

The question then is: “Does the choice of crop differ with isolation?” The von Thunen (1966) model suggest that it should. As farmers grow their crops further away from the cities and market centers, we expect them to shift out of perishable cash crops such as vegetables and into such storable crops as staples and pulses.[18] In terms of cultivated land area devoted to various crops, we do find a decline in vegetables corresponding to increased isolation (Table 12). However, contrary to expectations, we find that staples (of which rice is clearly the most important crop) and pulses also decline. This is due to the fact that in more isolated areas more land is devoted to industrial and export crops such as vanilla, cloves and coffee. This in turn could follow from these

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[18] See Minten and Kyle (1999) on Zaire, and Fafchamps and Shilpi (forthcoming) on Nepal.

crops being grown in the humid regions in the East and to the Northeast, which as we see from Figures 1 and 2, are isolated. Whether isolation in this region is a consequence of difficulties in maintaining roads under such ecological conditions is difficult to confirm. Note that when we consider all agricultural land except for industrial crops, we do observe that more land is devoted to staple crops the more isolated the area. Although land devoted to pulses decrease slightly, the von Thunen model is generally confirmed for direct food crops – less valuable crops are cultivated by more isolated farming households. This is one possible link between poverty and isolation.

Table 10—Qualities and Characteristics of Agricultural Land by Quintiles of Remotenes

Remoteness Index	*Type of Land*						
Quintiles	Lowland rice	Hill-side rice	Terraced rice	Base of hill	Hill-side	Hill-top	Total
Least Remote	5.2	1.4	1.3	3.3	3.1	2.5	16.7
2	7.2	1.6	0.8	4.8	5.2	3.5	23.0
3	8.3	2.3	0.3	3.8	4.9	1.4	21.1
4	6.5	1.4	0.7	5.0	4.8	2.3	20.7
Most Remote	5.5	1.9	0.1	4.8	4.1	2.2	18.7
Total	32.7	8.5	3.2	21.7	22.1	11.9	**100**
		Slope of Land					
		Flat	Slight slope	Moderate Slope	Steep	Total	
Least Remote		7.9	4.4	3.2	1.2	16.7	
2		7.3	7.0	7.0	1.7	23.0	
3		10.6	5.7	3.6	1.3	21.2	
4		9.0	5.4	4.2	1.8	20.3	
Most Remote		7.8	6.0	3.5	1.4	18.8	
Total		42.6	28.5	21.6	7.3	**100**	
		Soil Characteristics					
		Sandy	Clay	Muddy	Other	Total	
Least Remote		2.4	5.6	5.1	4.6	17.7	
2		4.4	6.4	5.0	4.7	20.5	
3		4.8	9.7	6.4	2.8	23.6	
4		3.4	8.2	5.7	3.9	21.2	
Most Remote		2.2	6.3	5.6	2.9	17.1	
Total		17.2	36.1	27.7	18.9	**100**	

Table 11—Concentration of Crops by Remoteness Index

Commune-Quintile Averages

Quintiles	Hirfendhal-Hirschman Concentration Index*	Number of Crops
Remoteness Index		
Least Remote	58.0	5.2
2	54.2	6.3
3	53.4	5.1
4	47.6	5.8
Most Remote	39.9	5.6
Travel Time to Nearest City		
Least Remote	56.9	5.5
2	54.1	6.0
3	53.7	4.9
4	55.6	5.2
Most Remote	43.2	6.5
Total Rural	53.1	5.6

* HHI = $s_1^2 + \dots s_k^2$

where s_i = share of crop i in the commune

Table 12—Average Share of Household Cultivated Land Devoted to Various Crops by Remoteness Quintiles

All Crops

Quintiles	Staple Crops	Rice	Pulses	Vegetables	Fruits	Industrial and Export Crops
Remoteness Index						
Least Remote	86.2	55.4	7.4	4.6	0.2	1.6
2	82.0	52.2	6.8	5.5	0.3	5.5
3	83.4	56.6	4.5	0.8	1.1	10.2
4	84.7	50.3	4.0	0.3	0.5	10.5
Most Remote	81.0	52.0	6.1	0.6	0.7	11.7
Travel Time to Nearest City						
Least Remote	83.2	50.9	5.9	7.2	0.3	3.5
2	82.2	50.8	9.5	3.0	0	5
3	86.5	60.0	4.0	0.5	1.2	7.9
4	84.3	49.2	4.5	0.7	0.6	10.0
Most Remote	79.6	52.9	4.0	0.3	0.5	15.6
Total Rural	83.2	53.1	5.5	2.0	0.6	8.7

Just Non-Industrial Domestic Food Crops

Quintiles	Staple Crops	Rice	Pulses	Vegetables	Fruits
Remoteness Index					
Least Remote	87.7	56.4	7.6	4.6	0.2
2	87.1	55.6	6.9	5.7	0.3
3	92.8	63.8	4.7	1.1	1.4
4	94.9	58.3	4.2	0.3	0.6
Most Remote	92.3	60.2	6.3	0.6	0.8
Travel Time to Nearest City					
Least Remote	86.3	53.5	6.0	7.2	0.5
2	87.0	53.8	9.6	3.2	0
3	94.0	65.6	4.1	0.5	1.4
4	93.8	56.3	4.8	0.7	0.7
Most Remote	94.6	64.6	4.2	0.5	0.7
Total Rural	91.5	59.3	5.7	2.1	0.7

5. ECONOMETRIC EVIDENCE

Having observed that (a) the incidence of poverty in rural Madagascar increases with isolation; (b) yields of major staple crops are estimated to fall considerably one gets farther from major cities and markets; and (c) the use of agricultural inputs such as fertilizer also decline with isolation, we now ask the question: "Controlling for input use, land quality and other factors, does isolation still affect agricultural productivity?" In other words, are the effects of isolation on productivity indirect ones (i.e. through the impact of transactions costs on input demand), or is there some inherent direct effect.[19] After all, we have seen that fertilizer use dramatically drops once farmers must spend more than 4.5 hours to travel to the nearest major city in the dry season.

The first step in addressing this question is to estimate agricultural production functions and to examine the parameter estimates for the isolation controls. We do this for the predominant crop in Madagascar[20], rice, estimating translog production functions both with and without inputs. The rationale for estimating the model without inputs is to test the difference in the direct and indirect effects of isolation on rice production in the models without inputs, the (admittedly biased) isolation estimates capture the total effect, while the model with inputs captures solely the direct effect. The indirect effect of isolation is transmitted through its effect on the use of inputs. This brings us to the

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[19] The latter is especially difficult to prove, given that it could follow simply from omitted variable bias.

[20] Rice is planted on 65% of cultivated land.

second step in which we estimate input demand functions to verify that indeed isolation has an indirect effect on rice production through input use. In these reduced form demand models, the isolation parameter estimates are found to be significant both in a statistical sense as well as in an economic sense. We take up these two steps in turn.

RICE PRODUCTION FUNCTIONS

To capture the determinants of rice production, and to assess the impact of physical isolation on productivity, we estimate a translog production function. Given lack of variability in the commune-level input and output price data, as well as the degree to which these prices are imperfect substitutes for the shadow prices of inputs, we prefer the estimation of the primal production function to the dual profit function. This further provides us with a means of exploring the direct and indirect impact of isolation on productivity. The dependent variable in the model is the log of the quantity (kg) of principal season rice harvested per plot. The explanatory variables include inputs (land, labor, animal and mechanical traction, and fertilizer) and such shifters as plot characteristics, household characteristics, weather shocks, and province dummies. In addition three measures of isolation are included, (1) log of the distance (km) to the nearest major city, (2) travel time (hours) per kilometer to the nearest major city, and (3) total travel time (hours) to the nearest agricultural extension service. The first two are clearly related to the transaction costs of getting the product to the market, as well as of purchasing marketable inputs. As we saw in Table 2, distance and road quality have independent effects on the cost of transporting a 50 kg sack of rice to the nearest major city. By entering these two measures of isolation into our model, we attempt to isolate the separate effects. This is motivated in large part by policy implications. While government policies can do little about the physical distance between rural areas and major cities (short of building new cities), there is potential for government interventions to improve the quality of the roads and to maintain them. The third measure of isolation – travel time to nearest agricultural extension service – is also a policy variable that has often been advocated.

The means and the parameter estimates of the shifter variables appear in Table 13. We reserve discussion of these results to the more interpretable elasticities that will be analyzed following the discussion of isolation and rice productivity. We also note that although the dependent variable is the quantity of rice produced per plot, the effects of all the explanatory variables represent marginal contributions to both production and yields because we control for the plot size. In other words, the elasticities of production (e.g. percentage change in output per plot) can be interpreted as the elasticities of yields (i.e. percentage change in output per hectare). As such, we use production and productivity interchangeably in this discussion.

Table 13—Means and Coefficient Estimates of Shifters in Rice Production Function Models

	Mean	Std. Dev.	Coef.	t
Hill-side	0.30	0.46	-0.066	-1.53
Terraced	0.06	0.24	0.146	2.00 *
Mod. to steep slope	0.11	0.32	0.008	0.14
Soil - claylike	0.43	0.49	0.042	0.97
Soil - muddy	0.25	0.43	-0.154	-2.87 **
Irrigated field[++]	0.70	0.46	-0.100	-1.83 +
Irrigated field * Drought			0.433	5.59 **
Plot is titled+++	0.37	0.48	-0.256	-1.16
Designated "zone rouge"	0.19	0.40	-0.199	-3.39 **
Dist plot to passable route (minute walk)	21.49	23.48	0.004	5.75 **
Late planting	0.10	0.30	-0.021	-0.37
Flood	0.41	0.49	-0.206	-3.67 **
Drought[++]	0.39	0.49	-0.163	-2.41 *
Agr. is principal activity	0.91	0.29	0.164	2.28 *
HH owns 1 to 5 head of livestock	0.29	0.45	-0.006	-2.73 **
HH owns more than 5 head of livestock	0.13	0.34	0.045	1.16
Female head	0.14	0.35	-0.020	-0.36
Age of head	41.82	13.45	0.001	1.08
No. adults w/ primary educ	1.62	1.44	-0.001	-0.05
No. adults w/ secondary educ	0.49	0.98	0.057	3.00 **
No. adults w/ tertiary educ	0.02	0.19	0.145	1.65 +
Distance to clinic (hours, dry season)	0.09	0.72	-0.032	-1.54
Fianarantsoa	0.23	0.42	0.612	5.42 **
Taomasina	0.19	0.39	0.080	0.79
Mahajanga	0.10	0.30	0.518	3.96 **
Toliara	0.08	0.27	0.319	3.15 **
Anstiranana	0.08	0.27	-0.299	-2.34 *
Constant			2.709	10.72 **
No. observations			2,743	
R^2			0.614	

++ Elasticity calculations and t-statistics include the interaction term

+++ Predicted probability

Isolation

In Table 14, we present the isolation results of estimates of two rice production models. The first model (column one) is designed to capture the total effect of isolation and is simply a reduced form estimate of production on the exogenous shifters that appear in the full structural model. In other words, this is the same as the structural model except that all of the inputs (except plot size) are dropped. The second model (column three) is the structural model (the parameter estimates on the shifters and the estimated input elasticities appear in Tables 13 and 16, respectively), which is designed to capture the indirect effect of isolation on production. The idea is that once we control for input use, which is itself a function of isolation, then the parameter estimates for the isolation variables "explain" the remaining direct effect. In the right-most columns of Table 14, are the differences between these estimates which can be interpreted as the sum of the indirect effects of isolation on rice output through the effect on input use. Test statistics for these differences are also provided to give an indication of the statistical significance of the sum of the indirect effects.

The effects of distance from the city and road quality in both models are negative and significant with a larger total effect in the model without inputs. For example the total elasticity of production with respect to distance is 0.07,[21] while the elasticity net of the effect of inputs is 0.04. Nonetheless, there is enough imprecision in these estimates,

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[21] Note that although the magnitude of this effect is less than half of that found for India in the 1970s (Binswanger et al., 1993), it is only part of the transportation costs picture which is completed with the introduction of road quality which also has a significant negative effect on rice production.

that the difference between them is not statistically significant. The indirect effect of road quality, however, is different. The total effect of a one minute per kilometer decrease in travel time is an extremely large 27 kilogram average increase in production,[22] relative to an direct effect of 10 kilograms per minute reduction. The implications of this result are two-fold. First, the indirect effect of road quality through overall input use is statistically significant and large roughly on the order of 17 kilograms of output per minute reduction in travel time per kilometer. Second, despite controlling for input use, land quality and other factors, there remains a significant effect of isolation on agricultural productivity. This latter implication is the case for distance as well as road quality. This is a point to which we will return.

To shed further light on the policy implications of isolation, Table 15 breaks down distances and travel times by road type and simulates the effects of investments in these road types on primary season rice production in the various remoteness quintiles. We note first that the average travel time of 11 hours to the nearest primary urban area is broken down into an average of one hour on trails not accessible by vehicles, and five hours each on feeder roads (unpaved) and major highways (paved). As expected, travel on feeder roads is considerably slower at six minutes per kilometer (average of 67 kilometers) relative to three minutes per kilometer (average of 130 kilometers) on major highways. Naturally, this overall characterization differs substantially across the

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[22] Since the dependent variable is in logs, the marginal effect is the average of the parameter estimate multiplied by the output level (i.e. $ME = \frac{1}{n}\sum_{i=1}^{n}\beta_{time/km} * output_i$). Note that the average output level is 904 kg.

remoteness quintiles. For example, in the least remote quintile almost all travel takes place on highways (and none on foot), while for households in the most remote quintile approximately half of travel takes place on feeder roads (approximately a quarter of the average distance traveled) and over 10 percent is on trails.

Table 14—Total and Direct Effects of Remoteness on Rice Production from Production Function Estimates

Parameter Estimates	**Total Effect** (Without Inputs)		**Direct Effect** (With Inputs)		**Implied Indirect Effect**	
	Coef.	t	Coef.	t	Difference	t
Log of distance (km) to major city	-0.066	-3.13 **	-0.036	-1.65 +	-0.030	-0.98
Travel time (hours) per km (*road quality*)	-1.851	-4.65 **	-0.791	-2.10 *	-1.060	-1.93 +
Travel time (hours) to agr. Extension	0.008	2.06 *	0.016	4.30 **	-0.008	-1.40

Interestingly, travel times per kilometer on highways in the least remote quintile (4.0 minutes/km) are not much lower than in the most remote quintile (4.1 minutes/km), and in fact are higher than in the middle quintiles (1.9 to 2.7 minutes/km). This suggests that in the locations closest to the primary urban centers suffer to some degree from congestion effects. With regard to feeder roads, however, average travel times per kilometer are 6.9 minutes/km in the most remote areas where greater distances are traveled on feeder roads, instead of 4.5 minutes/km in the least remote quintile.

To simulate the potential gains of road quality improvements on rice production, we consider three scenarios: investments in (1) major highways, (2) feeder roads, and (3) trails that halve the travel time per kilometer. The simulation for investments in major highways, for example, is done by reducing only the travel time per kilometer on highways for each household in the sample, and calculating the percent reduction in total travel time as well as total travel time per kilometer. The averages of the percent reduction in travel times are reported in the table. Using the travel time per kilometer parameter estimate from Table 14, along with the household-level pre-simulation travel time per kilometer and percent change in travel time due to highway improvements, the potential percent increase in rice production is simulated for each household. These increases are averaged over households and appear at the bottom of Table 15.[23]

We find that investments in major highways leads to a predicted 30 percent decline in total travel time on average, and to a 1.3 percent increase in rice production. Most of these gains can be attributed to increased production in the least remote quintile in large part because almost 90 percent of all travel among these households is on paved roads. Nonetheless, we do find that production in the most remote quintile would also increase by 1.5 percent following such improvements. If we value the total primary season rice production at FMG 1,300 per kilogram (see Table 9), then the value of the simulated increase in production is just over FMG 41,000 million.

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[23] To be precise, the potential gain in rice production from investments in major highways is calculated as

$$\%\Delta prod = \frac{1}{N}\sum_{i=1}^{N} \beta \cdot x_i \cdot \%\Delta x_i \,,$$

where x_i is the pre-simulation travel time per kilometer of household *i*, and $\%\Delta x_i$ is the percent change in total travel time per kilometer for household *i* due to travel time per kilometer on highways falling by half. Note that given the non-linearity in this simulated change in output, this estimate is *not* equivalent to evaluating the output change at the means:

$$\%\Delta prod' = \beta \cdot \left(\frac{1}{N}\sum_{i=1}^{N} x_i \right) \cdot \left(\frac{1}{N}\sum_{i=1}^{N} \%\Delta x_i \right).$$

Table 15—Simulations of Rice Production & Remoteness

	Quintiles of Remoteness (Travel Time to Nearest Primary Urban Center)					Center
	Least Remote	2nd	3rd	4th	Most Remote	National
Rice Production (Primary Season), millions of kg	384.7	565.2	436.2	700.7	365.0	2451.8
Percent of National Rice Production	15.7%	23.1%	17.8%	28.6%	14.9%	100.0%
Median Rice Yields, kg/are	28.0	27.0	16.0	18.6	18.8	22.7
Average Travel Time, hours						
Total	0.9	3.4	8.8	16.2	32.2	11.0
On Major Highways (paved roads)	0.8	1.9	4.0	7.1	13.9	4.8
On Feeder Roads (unpaved, passable)	0.1	1.3	3.2	8.1	15.3	4.8
On Trails (not accessible by vehicle)	0	0	0.6	1.3	4.5	1.0
Average Travel Distance, kms						
Total	18.4	90.2	157.6	319.8	555.7	220.4
On Major Highways (paved roads)	16.3	64.7	89.1	172.3	354.7	129.5
On Feeder Roads (unpaved, passable)	2.1	22.0	50.8	128.6	154.7	66.7
On Trails (not accessible by vehicle)	0	0	3.0	6.4	16.3	5.3
Average[*] Travel Time per Kilometer, minutes/km						
Total	4.0	3.2	5.3	3.5	5.4	4.2
On Major Highways (paved roads)	4.0	1.9	2.7	2.5	4.1	3.1
On Feeder Roads (unpaved, passable)	4.5	5.9	5.6	5.5	6.9	5.9
On Trails (not accessible by vehicle)	..	..	10.9	11.9	13.9	11.8
Percent Reduction in Total Travel Time with Improvement[**] in:						
Major Highways (paved roads)	44.3%	28.0%	27.5%	21.8%	21.0%	29.6%
Feeder Roads (unpaved, passable)	5.7%	19.9%	19.5%	23.7%	21.2%	17.4%
Trails (not accessible by vehicle)	0%	0%	3.0%	4.5%	7.8%	3.1%
Percent Reduction in Total Travel Time per Kilometer with Improvement[**] in:						
Major Highways (paved roads)	44.3%	29.2%	25.4%	21.8%	21.0%	29.3%
Feeder Roads (unpaved, passable)	5.7%	20.8%	18.0%	23.7%	21.2%	17.2%
Trails (not accessible by vehicle)	0%	0%	2.8%	4.5%	7.8%	2.6%
Potential Gain in Rice Production Under Alternative Scenarios:						
Investments in Major Highways	2.3%	0.8%	1.1%	0.9%	1.5%	1.3%
Investments in Feeder Roads	0.3%	1.4%	1.0%	1.1%	1.6%	1.0%
Investments in Trails	0%	0%	0.2%	0.3%	0.5%	0.2%

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[*] Average conditional on using the particular type of road

[**] Improvement defined as reducing the travel time per km by half

Given that the cost of constructing a highway with speeds of up to 60 km/hour (or 1 minute/km – well less than half the average travel time per kilometer on paved roads) is estimated at FMG 1 billion/km (World Bank, 2002), this is equivalent to the cost of constructing some 41 kilometers of paved roads.

Investments in feeder roads are estimated to have the largest impact on the most remote quintile of households. While national rice production is simulated to increase by 1.0 percent, it would increase by 1.6 percent for the most remote. This follows from average travel times falling by over 20 percent for the more remote areas relative to under 6 percent for the least remote areas. In this scenario, the total value of the predicted increase in primary season rice production is just under FMG 32,000 million. This is equivalent to 32 kilometers of new paved roads, or to 106 kilometers of unpaved roads allowing speeds of up to 30 km/hour (FMG 0.3 billion/km; World Bank, 2002).

Finally, investments in trails accessible only to foot traffic and to zebu-drawn carriages stimulate an increase of 0.2 percent in total rice production. This simulation has no affect on the two least remote quintiles as none of these communes report such travel. The greatest effect of the investment would be on the most remote quintile, where total travel time would fall by just under eight percent, and production would increase by 0.5 percent. The value of the increase in rice production (FMG 6,000 million) in this scenario is equivalent to some 600 kilometers of new unpaved roads accessible to zebu-drawn carts (FMG 0.01 billion/km; World Bank, 2002).

While the costs of road construction, improvement and maintenance vary substantially across regions and terrains, these simulations give an indication of the possible effects that improvements may have and the potential costs. The benefits are partial in that they derive solely from increases in principal season rice production for a given year. Total benefits to road construction/rehabilitation will also derive from other sources and will accrue over time. We note further that these partial estimates are based on the direct effect of road improvements, and do not account for the indirect effects of isolation on the use of inputs in rice production. As such, these simulations are conservative by design.

Other Productivity Shifters

We now turn to the remaining parameter estimates, starting with the productivity shifters and then proceeding to the inputs. Plot characteristics clearly matter to the level of output. While rice production on non-terraced hill-side plots is marginally lower than on lowland plots (the left-out category), it is statistically higher for terraced plots (Table 16). The full sample elasticity for terraced plots, however, is at less than 0.01. In other words, since these elasticities are calculated for dummy variables, terraced plots are on average less than 1% more productive than lowland plots, *ceteris paribus*. Somewhat surprisingly, we find that muddy soil is less productive that sandy soil, while claylike soil does not differ statistically from sandy soil in its effect on rice production. On average, muddy soil is 4% less productive for the full sample, and over 5% less productive in the most isolated quintile.

Table 16—Elasticities of Productivity Shifters in Rice Production Function Estimates

		Remoteness Quintiles (Time to Nearest CUP)				
	Full Sample	Least Remote	2nd	3rd	4th	Most Remote
Hill-side	-0.020	-0.023	-0.024	-0.022	-0.014	-0.014
Terraced	0.009 *	0.019 *	0.010 *	0.002 *	0.002 *	0.009 *
Mod. to steep slope	0.001	0.001	0.001	0.001	0.001	0.001
Soil - claylike	0.017	0.016	0.019	0.015	0.022	0.016
Soil - muddy	-0.038 **	-0.029 **	-0.030 **	-0.047 **	-0.038 **	-0.052 **
Irrigated field++	0.046 +	0.001	0.070 +	0.073 *	0.048 +	0.037
Irrigated field * Drought						
Plot is titled+++	-0.094	-0.138	-0.115	-0.061	-0.076	-0.068
Designated "zone rouge"	-0.036 **	0	-0.004 **	-0.050 **	-0.105 **	-0.044 **
Dist plot to passable route (minute walk)	0.086 **	0.070 **	0.068 **	0.106 **	0.074 **	0.122 **
Late planting	-0.002	-0.003	-0.002	-0.002	-0.002	-0.002
Flood	-0.085 **	-0.037 **	-0.057 **	-0.131 **	-0.123 **	-0.090 **
Drought++	0.054	0.036 +	0.081 *	0.064	0.046	0.033
Agr. is principal activity	0.149 *	0.137 *	0.154 *	0.153 *	0.148 *	0.155 *
HH owns 1 to 5 head of livestock	-0.002 **	-0.003 **	-0.002 **	-0.001 **	-0.001 **	-0.001 **
HH owns more than 5 head of livestock	0.006	0.004	0.005	0.005	0.011	0.005
Female head	-0.003	-0.002	-0.002	-0.004	-0.003	-0.004
Age of head	0.057	0.056	0.055	0.058	0.057	0.057
No. adults w/ primary educ	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001
No. adults w/ secondary educ	0.028 **	0.039 **	0.021 **	0.027 **	0.034 **	0.022 **
No. adults w/ tertiary educ	0.003 +	0.007 +	0.001 +	0.003 +	0.001 +	0.003 +
Distance to clinic (hours, dry season)	-0.003	0	-0.002	-0.007	-0.002	-0.003
Fianarantsoa	0.150 **	0.013 **	0.089 **	0.276 **	0.188 **	0.219 **
Taomasina	0.015	0.006	0.017	0.020	0.019	0.015
Mahajanga	0.045 **	0.020 **	0.030 **	0.063 **	0.006 **	0.116 **
Toliara	0.024 **	0.032 **	0.022 **	0.020 **	0.032 **	0.018 **
Anstiranana	-0.024 *	-0.009 *	-0.011 *	-0.020 *	-0.043 *	-0.051 *
Constant						
No. observations						
R^2						

++ Elasticity calculations and t-statistics include the interaction term

"+++ Predicted probability

Consistent with other studies on overall agricultural production in Madagascar (Minten, et al., 1998; Randrianarisoa, 2001; and Randrianarisoa and Minten, 2001), we find that the effect of irrigation on rice productivity to be small. While these other studies measure the direct effect, we attempt to capture the indirect effects as well by including an interaction term with droughts. The idea of this interaction term is that by accounting for the effect of irrigation on plots in areas affected by drought, we can control for the indirect effect of irrigation on better water control (Randrianarisoa and Minten, 2001).[24] Interestingly, we find that this indirect effect dominates the direct effect. The parameter estimate on the dummy variable indicating an irrigated field – the direct effect – is in fact negative and significant, while the interaction term – the indirect effect – is positive and strongly significant. The total elasticity is positive and significant, indicating that irrigated plots are 4.6% more productive than rain-fed plots, *ceteris paribus*. Further, the elasticities are largest for the second, third and fourth isolation quintiles (up to 7%), and are insignificant for the least and most isolated quintiles.

We find that land titling has no significant effect on rice production. This result is consistent with the findings of Randrianarisoa and Minten (2001), who used the 1993 EPM data, as well as with other studies of tenure systems in Madagascar. For example, Keck et al (1994) find that traditional tenure systems prevailed in the five villages they studied, and that there was no evidence that these systems created conflict over land.

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[24] We also note that there are other indirect effects. For example, farmers might be more willing to allocate more inputs to rice production when there is better water control. Indeed this is the case in our sample where the quantity of fertilizer applied on irrigated plots is 10 percent larger than on non-irrigate plots (Table 16). As such, the total effect reported in the text here is an underestimate. We thank Jean Claude Randrianarisoa for point this out.

Leisze et al (1995) also find in that contrary to their research sites in which customary tenure systems dominate, there was a general lack of tenure security for the communities where the state tenure systems predominate. Note that when we instrument for titled plots using distance to the nearest court (difficulty in seeking legal redress) and population density (greater pressure on agricultural land) as instruments, there appears to no direct effect of titling a plot (as opposed to increased levels of input use as we will see in the instrumenting equations). Nor does there appear to be an indirect effect as the parameter estimate from the reduced-form model without inputs is also insignificant.

Physical insecurity as measured by living in a commune designated as a *zone rouge*, has a negative effect on production.[25] This is hardly surprising given the incentive to under-invest resources in agricultural land when the benefits are more uncertain in the presence of rural insecurity. Thus we find that, *ceteris paribus*, rice production is 3.6% lower on average in regions with high insecurity than in relatively safe regions. That these elasticities range from zero in the least isolated quintile to 4.4% in the most isolated quintile is consistent with the findings of Fafchamps and Moser (2002) who find that crime in Madagascar increases with distance from urban centers and decreases with population density (i.e. with increases in isolation).

In terms of natural shocks, rice production was on average 8.5% lower in regions affected by flooding. That these effects are higher in the more isolated areas is a result of the higher incidence of flooding reported in these areas. For example, while 18% of the plots in the least isolated quintile were affected by floods, over 60% in the third and

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[25] The national police divide the country into three zones classified by the degree of insecurity. The *red zone* (*zone rouge*) characterizes the most insecure areas.

fourth quintiles were affected, and 44% in the most isolated quintile were subject to floods. The direct effect of droughts on rice production is also negative and significant. However, once the interaction effect with irrigation is accounted for in the estimation of the elasticity, we find a positive effect though it is only significant in the least and second isolation quintiles. This positive overall effect of droughts on rice production in the least isolated areas could be the result of substituting effort between crops from those more susceptible to drought to irrigated rice. This hypothesis, however, cannot be tested with these data.

We turn now to characteristics of the household that may effect productivity. For example, rice production for households in which agriculture was reported to be the principal economic activity for at least on member, is higher than for the nine percent of the households not classified as such. This presumably captures experience effects as well as effort. Similarly, while household human capital limited to primary levels of education has no effect on productivity, the more household members with secondary and tertiary levels of education the larger the output. This is especially the case for secondary levels of education where the elasticity of additional members completing high school is 3%. The returns to education in rice production range from 4% in the least isolated quintile to 2% in the most isolated quintile. A plausible explanation for these returns is that more educated households – negatively correlated with isolation – are more effectively able to apply physical and managerial inputs efficiently. Again, this accounts for unobservables that are not captured in the labor inputs that are measured in man-days.

Finally, we find that neither the gender nor the age of the household head have a significant effect on rice production. The irrelevance of gender and age in the isolated regions is consistent with the findings of Razafindravonona et al (2002) with respect to household consumption using the 1999 EPM.[26]

Inputs

The elasticity and marginal product estimates for land, labor, seed, traction and fertilizer inputs are presented in Table 17 for the full sample and for each quintile of isolation as defined by travel time to the nearest primary urban center. The first result of note is that the land elasticity of rice production, 0.37, is significantly less than one. Thus, despite controlling for soil quality (Bhalla, 1988, Bhalla and Roy, 1988, and Benjamin, 1995) and other possible factors, we find further evidence of the inverse relationship between plot size and productivity consistent with other studies in Madagascar (Barrett, 1996, Randrianarisoa, 2001, and Randrianarisoa and Minten, 2001). This relationship also varies almost statistically across the isolation quintiles with elasticities ranging from 0.39 in the least isolated quintile to 0.34 in the fourth and most isolated quintiles. A simple intuitive explanation for the declining productivity of land across the isolation quintiles is, quite simply, that land is relatively more abundant in the most isolated areas (see bottom of Table 15), and is relatively more constrained in the least isolated areas. Thus in the least isolated areas, with more household labor and

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[26] Razafindravonona et al. (2002), however, do find that female-headed households are at a distinct disadvantage and that households with older heads have higher consumption levels in the *least* remote rural areas.

fertilizer inputs applied for each are of land, the marginal product of land is 7 kg of rice, while it is just under 5 kg in the most isolated areas.

In a manner consistent with the changes in land elasticities of rice production and the relative abundance of land, the labor elasticities are also positive and significant. The elasticities of household labor increase across the isolation quintiles, while they decrease for hired labor (though marginally and not statistically). While the elasticity of household labor is 0.11 in the least isolated quintile, it is not much different in the most isolated quintile at 0.08. This difference, however, is more so reflected in the higher marginal product of labor in less isolated areas. For example, an additional day of household labor results in 2.9 kilograms more rice output on average in the least isolated areas. Whereas an additional day of household labor leads to 1.5 kilograms more output in the most isolated areas. A plausible explanation for higher marginal products of household labor in less isolated areas is that the opportunity cost of working on the farm is higher in these areas where there are more employment opportunities.[27]

Consistent with our prior understanding that household labor and hired labor are not perfect substitutes, the elasticity of hired/reciprocal labor (0.03) is 63% lower than that of household labor. Further, this relationship holds significantly across the isolation quintiles. Though, it is reversed when we compare the marginal products. For example, the marginal product of hired/reciprocal labor is 2.3 kilograms, while an additional day of household labor increases rice production by only 1.8 kilograms. Technically, this

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[27] Optimizing agricultural households making separable production and consumption decisions will allocate their labor resources to own agricultural production until the value of the marginal product of household labor is equal to the opportunity wage (e.g. wages earned from other employment opportunities).

follows directly from the fact that the average number of man days of household labor is four to five times greater than the a average number of man days of hired/reciprocal labor. In terms of an intuitive rationale, this could plausibly result from timing of the use of hired or reciprocal labor. Since household labor is applied throughout the year, the estimated marginal product is actually the average of the marginal products over the course of the year. Hired and reciprocal labor is typically employed during peak labor demand periods such as planting and harvesting. As such, the marginal product for this type of labor is averaged over periods for which we might expect the marginal products to be higher. Unfortunately, since our data do not include information on the types of labor employed during different phases of the agricultural cycle, we cannot test this hypothesis. We can only suggest that this may explain the pattern of marginal products of hired/reciprocal labor that are higher than those of household labor.

In terms of non-labor inputs, the signs and magnitudes of the elasticities are generally as expected. For example, given the seed elasticity of output equal to 0.3, a 10% increase in the quantity of seed applied to the field leads on average to a 3% increase in rice production. When this is converted to marginal product quantities, we find that a 1 kilogram increase in seed use leads to a 7 kilogram increase in rice output. Although the seed elasticities and marginal products do not differ statistically across the isolation quintiles, the marginal products do differ substantively. The marginal product of 1 kilogram of seeds equal to 7.7 kilograms of rice production in the least isolated quintile is significantly higher than the marginal products of 5.8 and 6.0 kilograms in the third and fourth quintiles, though it is higher at 9.1 kg in the most isolated quintile.[28]

We find positive returns to tractor use by rice farmers that are robust across the isolation quintiles. The average tractor elasticity of output for each of the quintiles does not differ statistically from the estimate of 0.3 for the entire sample. Similarly, although the magnitudes of the marginal products of tractor use vary somewhat by isolation quintile, they are statistically no different from the return of just under 10 kilograms of rice for an additional hour of tractor use (except for the third quintile where the marginal product is exceptionally high at 195 kg because average use for plots in this quintile is one day). Considering that tractors are used in just over 7% of the plots, it is not too surprising that the estimates of the elasticities and marginal products are noisy enough to not differ across the isolation quintiles. What is of note is that the estimates of the levels of return to tractor use are sufficiently large to outweigh the large standard errors. Quite simply put, the returns to tractor use are high for those with access, *ceteris paribus*. The returns to animal traction, however, are surprisingly negative. In fact we find that for this result for the full sample the negative and significant average elasticities of approximately 0.06 for the middle and most isolated quintiles.

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[28] The quantity of seeds is admittedly an extremely rough proxy for seed inputs given quality differentials. More importantly, however, these elasticity estimates may be biased due to omitted variables such as production technologies. For example, we would expect *ceteris paribus* smaller levels of output for given quantities of similar quality seeds when direct seedling technologies are employed relative to when *System of Rice Intensification* (SRI) methods are employed. Nonetheless, we consider this variable to be an important control variable in the estimation.

Our estimates of the fertilizer elasticities are positive, yet insignificant. This insignificance is unsurprising given the general lack of fertilizer use in Madagascar. Nonetheless, we note that the elasticity estimates are approximately 0.05 and close to significant at the 90 percent level of confidence for the two least remote quintiles. Further, it is in these two quintiles that the bulk of fertilizer use takes place, with 13 and 4 kg applied per plot on average, respectively. More fertilizer use in these quintiles could follow from the higher value returns in the least remote quintiles, despite that the estimated marginal products in the most isolated quintiles are substantively higher (following also in part from the extremely small quantities used there). Finally, while noisily estimated, the marginal product of 5 kg increase in rice production for a 1 kg increase in use of fertilizer is consistent with Bockel's (2002) estimate.

To gain further insight into the question of why so little fertilizer is used, and to further explore the line of reasoning that the indirect effect of high transaction costs on rice productivity is transmitted through the choice of the levels of input use, we now turn to the results of our reduced-form estimates of the demand for inputs.

INPUT DEMAND MODELS

The results presented in this section are those from the first-stage estimates of the variable inputs in the rice production estimates, which as discussed in the methodology section, can be interpreted as input demands. In Tables 18 and 19, we present the average elasticities of the explanatory variables for nonlabor and labor inputs used in rice production, respectively. As in the production function estimates, we control for isolation using three variables. The first two, distance and travel time per kilometer to the nearest major city, represent access to markets (both input and output), while the third, travel time to agricultural extension services, represents access to services. The one measure of isolation that is consistently significant (or close) in all of the input demand functions is travel time per kilometer, or road quality. The road quality elasticities of demand for non-labor inputs are all negative, and range from –0.08 for fertilizer, to –0.83 for daily tractor use.[29] Fertilizer use, for example, would increase on average by 4% if investments in the quality of rural roads halved the average travel time per kilometer from 4.2 hours to 2.1 hours. Note that these negative effects exist once we control for the distance to the nearest major city, and can thus be thought of separately from distance. Nonetheless, taking the two effects into account together gives some interesting insights. While fertilizer use also decreases significantly with distance, we find that both animal and mechanical traction demand increases with distance once we control for the cost of traveling the given distance measured in terms of the time per kilometer. A plausible interpretation of these simultaneous opposite effects on traction use is that while road quality accounts for the difficulty in transporting the zebu or tractors, and the consequently higher (nonpecuniary) transaction costs at a given distance, the distance measure could be capturing the substitution between agricultural labor and traction on more isolated and larger plots.[30]

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[29] This is consistent with the findings of Ahmed and Hossain (1990) with regard to fertilizer use in Bangladesh.

[30] Note that the effect of distance on hired labor is negative, though not significant.

With regard to labor inputs, distances from major cities have no statistical effects on demand for either household or hired/reciprocal labor, while road quality has positive effects on both. It is worth noting that the effects of road quality on labor demand (and supply in the case of household labor) are the opposite of the effects on non-labor demand, suggesting that in the in more isolated areas labor is substituted for the relatively more scarce non-labor inputs.

6. CONCLUDING REMARKS

This paper examines mechanisms that transmit isolation into poverty in Madagascar using rich household survey data combined with a census of administrative communes. The motivation for this analysis stems from Razafindravonona et al.'s (2001) observation that isolation and poverty in 1999 are positively correlated, a finding that is corroborated here. We recognize that isolation can also be ascribed to lack of access to public and private services. But given the importance of agriculture to the rural poor, where nine out of ten poor persons is engaged in farming, we concentrate on isolation manifesting itself in the form of high transaction costs such as the cost of transporting agricultural commodities to major market centers. Such costs, further, are independently affected by distance to markets as well as road quality (travel time per kilometer). While little can be done about the distance of communities from urban centers, road quality can be addressed through public sector interventions.

A surprising result of this analysis is the degree to which crop yields for the three major staple items in Madagascar (rice, maize and cassava) are lower in isolated relative to non-isolated areas. In fact, we find that yields fall by half between the least and most isolated quintiles. While the slightly lower average market output prices in more isolated areas might lead us to expect lower total output levels, the substantive differences in yields were not expected *ex ante*. We note that the use of agricultural inputs such as fertilizer is also strongly negatively correlated with isolation, and that households devote more effort to growing staple crops such as rice in more isolated areas.

Given the observation that (a) the incidence of poverty in rural Madagascar increases with remoteness; (b) yields of major staple crops fall considerably as one gets farther away from major cities and markets; and (c) the use of such agricultural inputs as fertilizer decline with isolation, we then ask the question: “Controlling for input use, land quality and other factors, does isolation still affect agricultural productivity?” Estimation of production functions for rice (Madagascar’s most important food crop), and corresponding input demand functions, confirm that there are both direct and indirect effects of isolation on productivity. This is particularly the case for road quality, where both the indirect effect on rice productivity through the impact of transactions costs on input use, and the direct effect are large, at 17 kg and 10 kg, respectively. We note that, although few of the input elasticities of rice production vary significantly across the isolation quintiles individually, the indirect effect of isolation on rice productivity through input use is jointly significant.

An implication of this analysis is that, although little can be done with regard to distances to markets, effective policy interventions can come in the form of improving road quality (i.e. building new road and maintaining existing ones). Our simulation results suggest that halving travel times per kilometer on major highways will increase primary season rice output by 1.3 percent, and similar investments in feeder roads will boost production by 1.0 percent. While we make no claim that infrastructure investment is a panacea. We note that with regard to reducing transaction costs (and if traders marketing margins fall with improvements in roads; Minten & Kyle, 1999), such an intervention is likely to have a positive effect on market integration, agricultural productivity, and poverty.

Finally, the combination of lower yields in the most remote regions, lower average rice output levels despite larger land holdings (see Table 15), and no statistical difference in household labor productivity as measured by labor elasticities of rice production (though marginal products of labor are significantly lower), it is not entirely surprising that poorer households are found in the more remote areas. In this analysis, we approach the isolation-poverty relationship through but one possible mechanism – agricultural productivity and output – and find a strong link. Nonetheless, we ignore the possible interactions between non-farm income earning activities and isolation. This is fertile ground for further research which we intend to undertake given the importance of the issue as well as the availability of the rich set of data used in this analysis.

Table 17— Input Elasticities and Marginal Products in Rice Production

Estimated from Translog Production Functions

Input elasticities of output	Quintiles of Remoteness (Dry Season Travel Time to Nearest Primary Urban Center)													
	Full Sample		*Least Remote*		*Quintile 2*		*Quintile 3*		*Quintile 4*		*Most Remote*		*Difference*	
	ε	t	*ε*	t	*ε*	t	*ε*	t	*ε*	t	*ε*	t	*Most-Least*	t
Area under cultivation (are)	0.366	18.56 **	0.392	15.28 **	0.400	16.65 **	0.348	16.22 **	0.338	13.76 **	0.337	15.02 **	-0.055	-1.61
Household labor (days)	0.087	5.12 **	0.110	5.64 **	0.088	4.91 **	0.077	3.84 **	0.055	2.77 **	0.097	4.76 **	-0.014	-0.48
Hired/reciprocal labor (days)	0.032	2.12 *	0.007	0.35	0.025	1.24	0.054	3.55 **	0.041	2.51 *	0.039	2.40 *	0.032	1.23
Seed (kg)	0.308	14.77 **	0.316	13.66 **	0.300	12.48 **	0.285	13.49 **	0.300	10.84 **	0.346	13.52 **	0.030	0.86
Animal traction (hours)	-0.039	-1.71 +	-0.016	-0.67	-0.039	-1.58	-0.057	-2.06 *	-0.026	-1.26	-0.058	-2.31 *	-0.043	-1.23
Tractor use (hours)	0.274	4.22 **	0.282	4.24 **	0.240	4.11 **	0.311	4.28 **	0.273	4.26 **	0.260	3.93 **	-0.022	-0.23
Fertilizer (kg)	0.038	0.94	0.044	1.54	0.055	1.49	0.014	0.29	0.045	1.00	0.029	0.56	-0.015	-0.26

Marginal Products														
	Full Sample		*Least Remote*		*Quintile 2*		*Quintile 3*		*Quintile 4*		*Most Remote*		*Difference*	
	MP	t	*MP*	t	*MP*	t	*MP*	t	*MP*	t	*MP*	t	*Most-Least*	t
ı under cultivation (are)	6.09	12.67 **	7.21	9.09 **	6.70	10.45 **	4.34	13.73 **	7.16	6.76 **	4.78	5.56 **	-2.43	-2.08 *
Household labor (days)	1.68	4.96 **	2.88	4.80 **	1.73	4.78 **	0.96	3.74 **	1.44	2.54 *	1.51	3.89 **	-1.37	-1.92 +
Hired/reciprocal labor (days)	2.27	2.11 *	0.48	0.35	1.37	1.25	2.82	3.41 **	4.66	2.41 *	2.86	2.34 *	2.38	1.29
Seed (kg)	6.79	11.45 **	7.72	11.82 **	6.91	8.01 **	5.77	11.84 **	5.96	6.68 **	9.12	6.69 **	1.40	0.92
Animal traction (hours)	-1.82	-1.67 +	-1.37	-0.67	-2.08	-1.53	-5.37	-1.94 +	-0.70	-1.17	-4.64	-2.02 *	-3.27	-1.06
Tractor use (hours)	9.90	3.49 **	9.90	2.49 *	4.73	2.85 **	194.91	4.08 **	10.51	2.44 *	14.22	1.97 *	4.32	0.52
Fertilizer (kg)	5.43	0.94	2.05	1.47	8.57	1.45	2.13	0.25	25.22	0.97	14.67	0.56	12.62	0.48

Sample Means

	Full Sample		*Least Remote*		*Quintile 2*		*Quintile 3*		*Quintile 4*		*Most Remote*	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Output per household (kg)	1,425	3,076	1,366	2,335	1,331	3,800	1,078	1,269	2,560	4,510	1,064	2,589
Area under cultivation (are)	54.1	84.8	35.4	72.0	50.2	77.8	56.0	63.8	77.6	107.9	59.5	102.2
Household labor (days)	48.0	77.9	24.9	31.4	40.3	78.3	66.8	105.9	63.1	85.3	49.7	56.9
Hired/reciprocal labor (days)	13.0	32.6	9.7	15.0	14.2	42.3	15.8	40.4	14.4	31.8	10.7	20.4
Seed (kg)	48.4	252.4	26.6	44.9	35.6	64.9	37.7	55.3	130.8	617.2	30.9	33.6
Animal traction (hours)	17.9	101.1	8.1	27.9	12.8	62.1	6.7	19.6	62.5	231.7	10.4	35.5
Tractor use (hours)	23.5	138.1	20.0	130.9	37.2	165.3	1.0	0.8	45.7	208.7	18.0	105.7
Fertilizer (kg)	5.0	23.1	13.1	39.0	4.2	15.6	3.0	21.8	2.1	5.1	0.7	6.6
No. observations	2,743		489		709		678		411		456	

Note: 1,500 bootstrap replications

Table 18—Reduced Form Nonlabor-Input Demand Estimates in Rice Production in Madagascar

	Fertilizer		Animal Traction		Tractor	
	Elasticity	t	Elasticity	t	Elasticity	t
Size of plot (are)	-0.002	-2.39 *	0.033	4.42 **	0.004	0.67
Price of rice (kg)	-0.007	-0.13	1.304	2.54 *	1.334	2.68 **
Agric. wage rate	-0.047	-1.52	0.290	1.38	-1.208	-6.26 **
Price of seed (kg)	0.010	2.42 *	-0.016	-0.66	-0.109	-3.10 **
Price of zebu (head)	0.011	2.00 *	-0.069	-2.50 *	0.079	2.56 *
Price of tractor (day rental)	-0.004	-0.27	0.540	5.91 **	-0.174	-1.70 +
Price of NPK (kg)	0.097	0.48	-2.000	-1.71 +	4.013	2.38 *
Price of Urea (kg)	0.100	1.79 +	0.305	1.64	-0.935	-6.42 **
Price of organic fertilizer (kg)	-0.039	-1.79 +	0.297	2.95 **	-0.718	-6.07 **
Number of kids 6-14 in HH	-0.038	-0.62	-0.201	-0.58	0.246	0.57
Number of adult women in HH	0.059	2.07 *	0.020	0.49	0.159	3.86 **
Number of adult men in HH	0.060	2.58 **	-0.107	-3.75 **	-0.018	-0.63
Female head	0.084	1.78 +	-0.007	-0.10	0.299	3.58 **
Problem: Access to land	-0.128	-1.36	0.526	3.24 **	-0.337	-3.37 **
Problem: Financial insecurity	-0.140	-1.54	0.610	3.08 **	0.140	1.28
Problem: Access to animal traction	0.319	3.48 **	0.058	0.42	0.149	1.54
Problem: Access to labor	0.020	0.18	2.333	6.37 **	-0.278	-2.22 *
Problem: Access to equipment	-0.159	-1.45	-0.763	-8.53 **	-0.351	-3.13 **
Problem: Access to credit	0.196	2.00 *	0.095	0.71	0.450	3.42 **
Maximum credit available	0.000	-0.84	0.001	1.22	0.001	2.67 **
Hill-side	0.032	0.77	-0.068	-1.08	0.570	6.52 **
Terraced	0.168	1.82 +	0.194	1.67 +	-0.092	-0.75
Mod. to steep slope	-0.024	-0.38	-0.136	-1.96 *	-0.256	-4.35 **
Soil - claylike	0.204	4.26 **	-0.147	-2.76 **	-0.071	-1.32
Soil - muddy	-0.032	-0.71	-0.095	-1.50	-0.202	-3.54 **
Irrigated field	0.107	2.78 **	0.057	0.94	0.045	0.79

Agr. is principal activity	-0.235	-4.17 **	-0.091	-1.04	-0.316	-3.63 **
Plot is titled+++	3.831	5.80 **	-0.557	-2.42 *	4.840	6.00 **
Livestock - 1 head owned	0.219	2.25 *	0.053	0.48	0.358	2.41 *
Livestock - 2 heads owned	0.232	3.33 **	0.682	6.43 **	0.077	0.94
Livestock - 3 heads owned	0.269	2.46 *	0.677	5.06 **	-0.234	-5.32 **
Livestock - 4 heads owned	0.106	1.11	0.564	3.48 **	0.350	2.67 **
Livestock - 5 heads owned	0.188	1.56	0.532	2.80 **	0.013	0.08
Livestock - more than 5 heads	-0.075	-1.31	0.863	6.26 **	0.184	2.13 *
Age of head	-0.016	-2.46 *	-0.055	-1.60	-0.172	-4.17 **
No. adults w/ primary educ	0.033	0.39	0.825	1.85 +	-0.844	-1.60
No. adults w/ secondary educ	-0.111	-0.86	2.095	3.39 **	-3.926	-4.68 **
No. adults w/ tertiary educ	-0.165	-0.33	4.993	1.97 *	9.622	1.71 +
Distance to clinic	-0.218	-2.38 *	1.771	2.36 *	-1.436	-1.34
Designated "zone rouge"	-0.136	-2.83 **	0.580	4.98 **	0.021	0.26
Dist plot to passable route	-0.011	-3.70 **	-0.026	-1.38	-0.007	-0.32
Late planting	-0.055	-1.12	0.235	2.56 *	-0.135	-2.18 *
Flood	0.397	7.28 **	-0.053	-0.78	-0.092	-1.30
Drought	0.055	1.39	0.054	0.90	0.150	2.76 **
Fianarantsoa	-0.264	-3.22 **	-0.453	-5.65 **	-0.557	-8.05 **
Taomasina	-0.185	-2.12 *	-0.458	-4.91 **	-0.254	-3.47 **
Mahajanga	-0.137	-1.27	-0.363	-2.65 **	-0.414	-4.42 **
Toliara	-0.124	-0.89	-0.446	-3.08 **	0.307	1.54
Anstiranana	-0.100	-0.59	-0.688	-4.51 **	-0.326	-1.59
Log of distance (km) to major city	-0.076	-3.44 **	0.079	2.67 **	0.201	6.16 **
Travel time (hours) per km (*road quality*)	-0.081	-2.79 **	-0.210	-1.46	-0.829	-5.91 **
Travel time (hours) to agr. Extension	0.021	1.36	-0.227	-2.16 *	0.177	2.05 *
No. observations	2,743		2,743		2,743	
R2	0.156		0.261		0.166	

Note: All prices are in terms of thousands of FMG

"+++ Predicted probability

Table 19—Reduced Form Labor Demand Estimates in Rice Production in Madagascar

Dependent Variables in Logs

	Household Labor		Hired/Reciprocal Labor		Total Labor	
	Elasticity	t	Elasticity	t	Elasticity	t
Size of plot (are)	0.054	3.83 **	0.023	5.54 **	0.085	4.89 **
Price of rice (kg)	0.421	0.45	-0.145	-0.69	0.745	0.81
Agric. wage rate	-0.813	-1.82 +	0.037	0.31	-1.034	-1.99 *
Price of seed (kg)	0.198	4.90 **	0.024	2.07 *	0.196	3.99 **
Price of zebu (head)	-0.094	-1.79 +	-0.055	-3.99 **	-0.139	-2.15 *
Price of tractor (day rental)	-0.038	-0.19	-0.100	-1.68 +	-0.191	-0.80
Price of NPK (kg)	-6.630	-2.62 **	-2.028	-3.35 **	-8.611	-3.13 **
Price of Urea (kg)	-0.669	-1.41	0.294	2.47 *	0.451	0.90
Price of organic fertilizer (kg)	0.620	2.88 **	0.033	0.53	0.601	2.34 *
Number of kids 6-14 in HH	1.526	2.07 *	-0.079	-0.39	1.745	1.94 +
Number of adult women in HH	-0.050	-1.48	-0.150	-4.42 **	-0.094	-2.85 **
Number of adult men in HH	-0.012	-0.40	-0.116	-3.85 **	-0.039	-1.39
Female head	-0.073	-1.17	0.045	0.63	-0.047	-0.79
Problem: Access to land	-0.508	-5.73 **	0.290	1.90 +	-0.425	-4.72 **
Problem: Financial insecurity	0.267	1.64	-0.489	-4.33 **	0.029	0.20
Problem: Access to animal traction	0.044	0.30	-0.198	-1.36	0.096	0.67
Problem: Access to labor	1.051	4.47 **	0.108	0.56	0.733	3.57 **
Problem: Access to equipment	-0.300	-2.36 *	-0.101	-0.60	-0.318	-2.60 **
Problem: Access to credit	0.225	1.77 +	0.479	2.96 **	0.329	2.61 **
Maximum credit available	0.002	2.24 *	0.001	3.39 **	0.003	2.61 **

Hill-side	-0.160	-3.04 **	-0.006	-0.10	-0.154	-3.02 **
Terraced	0.311	3.02 **	0.242	2.26 *	0.302	3.07 **
Mod. to steep slope	0.365	4.23 **	-0.088	-1.18	0.218	2.86 **
Soil - claylike	-0.080	-1.57	-0.121	-2.29 *	-0.088	-1.81 +
Soil - muddy	0.113	1.67 +	-0.146	-2.26 *	0.037	0.60
Irrigated field	0.028	0.50	-0.065	-1.17	0.015	0.28
Agr. is principal activity	0.218	2.21 *	-0.169	-2.21 *	0.046	0.56
Plot is titled+++	-0.209	-0.76	0.074	0.22	-0.106	-0.40
Livestock - 1 head owned	0.073	0.70	0.141	1.43	0.048	0.49
Livestock - 2 heads owned	0.116	1.67 +	0.108	1.34	0.116	1.64
Livestock - 3 heads owned	-0.121	-1.39	-0.141	-1.52	-0.159	-1.92 +
Livestock - 4 heads owned	-0.053	-0.57	0.041	0.38	-0.068	-0.74
Livestock - 5 heads owned	-0.180	-1.54	0.148	0.91	-0.144	-1.26
Livestock - more than 5 heads	-0.253	-3.34 **	0.103	1.07	-0.226	-3.04 **
Age of head	0.139	1.77 +	-0.020	-0.92	0.087	0.90
No. adults w/ primary educ	4.460	4.24 **	0.886	3.06 **	6.334	4.85 **
No. adults w/ secondary educ	1.532	1.08	2.084	5.18 **	4.490	2.62 **
No. adults w/ tertiary educ	-5.060	-0.91	4.416	3.19 **	7.839	1.24
Distance to clinic	-0.690	-0.51	0.318	0.67	0.313	0.20
Designated "zone rouge"	0.408	4.49 **	0.529	5.33 **	0.397	4.68 **
Dist plot to passable route	0.017	0.44	-0.011	-0.92	-0.012	-0.26
Late planting	0.275	2.93 **	0.223	2.49 *	0.290	3.43 **
Flood	-0.053	-0.93	0.016	0.25	-0.053	-0.97
Drought	0.010	0.20	-0.025	-0.46	-0.002	-0.05

Fianarantsoa	0.171	1.54	0.069	0.62	0.098	0.97
Taomasina	2.531	11.47 **	-0.018	-0.16	1.974	10.87 **
Mahajanga	4.039	11.11 **	1.423	5.57 **	3.502	10.82 **
Toliara	0.201	1.15	0.080	0.47	0.268	1.66 +
Anstiranana	3.672	6.70 **	-0.174	-0.82	2.901	6.46 **
Log of distance (km) to major city	-0.037	-1.28	-0.030	-1.01	-0.017	-0.59
Travel time (hours) per km (*road quality*)	0.775	2.26 *	0.349	3.53 **	0.939	2.31 *
Travel time (hours) to agr. Extension	-0.217	-0.97	-0.313	-5.50 **	-0.440	-1.78 +
No. observations	2,743		2,743		2,743	
R2	0.366		0.157		0.330	

"+++ Predicted probability

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