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Explaining a Miracle: Intensification and the Transition Towards Sustainable Small-scale Agriculture in Dryland Machakos and Kitui Districts, Kenya

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Summary. — The transition to sustainable agriculture in tropical small-scale farming has been discussed intensively since Boserup published her theory on the role of population pressure as a leading factor. Bosemp's work challenged the Malthusian approach to rural transformation. Recent evidence supports the Boserup theory as applied to Machakos District, Kenya. This paper aims to establish how much of terracing is directly explained by population density increases as opposed to other district and village-level variables by using a retrospective multivariate analysis in Machakos and Kitui Districts, Kenya. The findings suggest that variables such as the distance to major urban markets and the windfall profits from the coffee boom in the late 1970s are at least as important in explaining the investment in the quality of land in Machakos and Kitui Districts.

Key words — Africa, Kenya, agricultural intensification, sustainable agriculture, terracing, transition

1. INTRODUCTION

The discussion on whether the agricultural population in dryland areas in Africa will follow a Malthusian "poverty trapped" or a Boserupean "stepwise innovative" path has been raging for some time now. This debate was fuelled by the publication of a book on the transition that had taken place in Machakos District, Kenya. Fifty years ago, the semi-arid Machakos district in Kenya was a disaster area, characterized by overpopulation, soil erosion and poverty. Since that time the population has tripled, but so has per capita output, while soil erosion has virtually stopped. This "miracle of Machakos" is a massive transition from unsustainable to sustainable agriculture, based on large-scale investment in terracing (Tiffen, Mortimore, & Gichuki, 1994).

The possibilities for transition of farming systems to higher levels of productivity while still maintaining sustainability—defined here as the possibility for present generations to use the natural resources without compromising future levels of productivity—have been a major concern of governments and international and multilateral organizations. Alarming trends of reduced availability of agricultural land and rapid and sustained population growth have appeared. Coupled with a continued reliance

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on agriculture these trends could endanger local agricultural societies and national food security. Declining or increasingly variable rainfall due to global climatic changes further threatens food production systems and food security at national level in many developing regions (Brown & Kane, 1994; van den Born, Schaeffer, & Leemans, 1999; Dietz & Put, 1999; Alexandratos, 1999).

There is growing evidence that agricultural intensification, though by no means equivalent to increased sustainability of small-scale agricultural systems, can occur together with and contribute to it in a context of increasing pressure on lands (Boserup, 1965; Conelly, 1992; Tiffen *et al.*, 1994; Reij, Scoones, & Toulmin, 1996). Indigenous technology development and local testing and implementation of introduced technologies often achieve the limited goal of sustaining nutrient and organic matter contents in soils together with other goals of rural development (Richards, Slikkerveer, & Phillips, 1989; Reij & Waters-Bayer, 2001). Institutional development and economic integration, on the other hand, may also have a positive impact, either directly or indirectly, on the motivation and possibilities of farmers to invest in the quality of their land and on the sustainability of management within the local land use and livelihood system.

In this paper we aim to test the Boserupean Hypothesis proposed by Tiffen *et al.* for the Machakos and Kitui districts by evaluating the role of variables other than population density in the process of intensification. We will be particularly looking at the *dynamics* of terrace adoption at the village level, making use of retrospective information on village-level variables such as population density, rainfall, crop prices (especially coffee) and terrace construction. The analysis will show that variables such as distance to major urban markets and windfall profits from the coffee boom in the late 1970s are at least as important for explaining the historical investments in the quality of land as increasing population pressure in the Machakos and Kitui Districts.

In this paper we will not address another issue which has arisen following the analysis of Tiffen *et al.*, namely whether farmers are experiencing declining welfare amid the improving environment. Murton (1999), using household-level data collected in Machakos district, argues that the aggregate district level data used by Tiffen *et al.* mask differentiation at the household level, with increasing polarization of land holdings, differential trends in agricultural productivity, and a decline in food self-sufficiency within the study areas in Machakos district. These findings suggest that even if agricultural transition is feasible, it might have an adverse distributional impact on the population (López, 1998).

The article is structured as follows. In Section 2 we describe the study and study site on which the analysis of the determinants of agricultural intensification is based, including some of the relevant literature. In Section 3 we describe the historical pattern of adoption for eight villages in Machakos and Kitui. Adoption was not smooth but involved a number of "bursts" or "peaks" during which villages went through rapid phases of agricultural intensification. We describe these periods of heightened intensification activities, and we relate them to certain events. In Section 4 we present the results of a multivariate analysis, where we estimate the determinants of agricultural intensification in Machakos and Kitui for 1966–95. We also present a number of simulations to investigate the cumulative impact of the coffee boom at the end of the 1970s on terrace construction as well as the impact of the development of infrastructure, population density and droughts during this period. Section 5 follows with conclusions and policy recommendations regarding feasible approaches toward sustainable small-scale agricultural development in these dryland areas of Africa.

2. THE STUDY AND STUDY SITE

The focus of the research is the context needed for farmers in drylands to not only increase productivity, but also improve the production environment. These terms are by no means equivalent.

Tiffen *et al.* (1994) focused on the role of population pressures, stressing the relationship between the increasing population density and growing demand, labor availability, infrastructure, and the increased levels of interaction and innovation generation. They and others pointed at the evidence of actual Boserupian processes of population-growth related innovation processes coupled with land quality enhancement (Templeton & Scherr, 1997). Other factors, however, such as market conditions, weather and government activities, may be very important too (Brown & Shrestha, 2000). Equally important may be local social conditions at village level, characteristics of households implementing the innovations (Lapar & Pandey, 1999), and characteristics of the plots on which these innovations are applied (Pender, 1999). All these levels need careful scrutiny before it can be concluded that population pressure is the main driving factor in practice.

A recent inventory of local soil and water conservation technologies showed that population densities do play a role as incentives to invest in land (as land becomes the scarcest resource, not labor). But, cases of low-population densities with high levels of soil and water conservation adoption and cases where the opposite is found are too numerous to be able to say with confidence that it is this factor alone that causes the adoption of innovation (Reij *et al.*, 1996). For example, in Honduras, reverse trends and patchy occurrence of innovation and investments for conservation were found under conditions of increasing densities (Crowley & Carter, 2000). In addition, collective actions, considered by induced innovation theory to be related to high-density areas, were related to lower rather than higher density areas (Pender, 1999). Of course, immediate benefits in the form of significant, recognizably and sustained higher yields from the innovations are very important, and may ultimately be the only incentive for farmers to adopt any innovation (Laman, Sandee, Zaal, Sidikou, & Toe, 1996; Zaal, Laman, & Sourang, 1998; Templeton & Scherr, 1997). Differences in adoption rates occur even within one area. Land fragmentation and unequal distribution may play a role here, making land scarcer for some people than for others. Gender plays an important role in this respect. Lack of credit facilities is often mentioned in relation to low-adoption rates, but it is not so much credit for these highly uncertain investments but rather lack of access to capital in general which is an important hindrance to investments in land. When money is available it may be invested in innovations, but money is not borrowed for this purpose. Regular remittances or windfall profits from high-cash crop prices may therefore be important (Bevan, Collier, & Gunning, 1992; Bigsten, 1996). More fundamentally, cultivation may be only one option in a larger portfolio of options (Ellis, 2000). Other strategies for reaching sustainable livelihoods may be more promising but require other investments (Jambiya, 1998). Thus, people may want to invest in the education of their children, the establishment of businesses, or livestock (Brons, Zaal, Ruben, & Kersbergen, 2000).

Innovation theory holds that the incentive to invest may be higher when the value of output increases, and for this either household demand needs to be high with few available alternatives, or the market prices need be compelling enough. At the same time, transaction costs should be low enough to allow access to the market. A good price, input markets and credit availability, output marketing infrastructure and institutions (including information), institutions to manage resources, social organization in general, and location in relation to markets are all-important for livelihoods based on natural resource use (Fleuret & Fleuret, 1991; Templeton & Scherr, 1997). In this sense the situation of small farmers in Africa is basically similar to any enterprise in the Western world (Reij *et al.*, 1996; Buch-Hansen, 1992). The point is to discover which innovations within intensifying agricultural development pathways are combined with investments in fertility enhancement, erosion control and agro-ecological diversity. The possibilities are often there but their realization depends on local conditions (Pender, 1999; Conelly & Chaiken, 2000).

Finally, certainty in land rights may be a basic condition for sustained and high-level investments in land-based innovations, if not the actual goals of these investments. These investments can be both soil building as well as tenure building (Gray & Kevane, 2001).

The data for our study were collected in 1999 as part of a research project "Agricultural Transition towards Sustainable Tropical Land Use," financed by the Netherlands Organization for Scientific Research (NWO) Programme on Environment and the Economy. Eight villages were included in the survey, with four villages in Machakos district and four villages in Kitui district. The research villages were selected on the basis of population density (from both a densely and sparsely populated sublocation, the administrative level below the district and the lowest level for which data are available) and distance to Nairobi in travel time (both far and nearby, measured in minutes using public transport along the most direct road) as a proxy for transactions costs, so that consequently four categories were distinguished in each district. Table 1 presents the villages, the sublocations, and the scores of the various villages on the selection criteria. The scores are defined as A = (high-density, low-transaction

Table 1. *Village characteristics*

Village name	Sublocation	District	Sublocation density (cap/km^2)	Distance to Nairobi (min)	Category[a]
Ngalalia	Ngiini	Machakos	494	60	A
Kisaki	Kithangaini		179	80	B
Ngumo	Katheka		305	150	C
Musoka	Kyamatula		121	145	D
Range for rural Machakos			30–1061[b]	15–195	
Range for AEZ4 in Machakos			75–500	60–195	
Mwanyani	Misewani	Kitui	436	210	A
Utwiini	Kaluva		64	195	B
Kitungati/Matua	Kitungati		144	270	C
Kyondoni	Kauwi		93	180	D
Range for Kitui			13–447	150–510	
Range for AEZ4 in Kitui			25–447	175–360	

[a] A = (high-density, low-transaction costs), B = (low-density, low-transaction costs), C = (high-density, high-transaction costs), and D = (low-density, high-transaction costs).
[b] This excludes the two urban sublocations of Mjini (1093) and Eastleigh (2825).

costs), B = (low-density, low-transaction costs), C = (high-density, high-transaction costs), and D = (low-density, high-transaction costs).

Ecological conditions were kept constant as far as possible, by selecting villages in agro-ecological zone 4 (AEZ 4) (Jätzold & Schmidt, 1982). AEZ 4 can be characterized as a transitional zone between semi-arid and semi-humid, depending on the altitude. It has between 115 and 145 growing days (medium to medium/short growing season) and mean annual temperatures between 15 and 18 °C in the Lower Highland Zone. The Upper Midland Zone has between 75 and 104 growing days (short to very short growing season) and mean annual temperatures between 21 and 14 °C. Cattle and sheep raising and the growing of barley are recommended in the Lower Highland Zone, while sunflower and maize are recommended in the Upper Midland Zone.

From each village, 25 households were randomly selected. This was done using a complete list of all households in the village, developed with the village elders and the village "headman," the senior elder supposed to be the government representative at this lowest level. The final number of households visited depended on availability of these households and the possibility of finding replacement households for those households that were unwilling to answer the questions or that were not available. Table 2 gives the general information on the survey population size. All household members were enumerated. All plots, owned, rented out, rented in, in ownership, or in use in any other way, were included in the survey and visited while the survey was implemented. GPS recordings were taken to find the same plots in the second year of data collection in 2000.

Table 2. *General information on the survey population size*

Number of Districts	2
Number of Villages	8
Number of Households	193
Number of Household members	1259
Number of Plots	484 (422 valid on terracing)

3. THE DYNAMICS OF AGRICULTURAL INTENSIFICATION IN EIGHT VILLAGES IN MACHAKOS AND KITUI DISTRICTS

(a) *The level of explanation: village*

In this paper we focus on the determinants of agricultural intensification at the level of the village, ignoring differences in adoption levels within the villages across households and plots. In principle this implies that much of the variance in adoption we leave unexplained, as actually most of the variation in the adoption of conservation techniques can be found at the household and plot level, as opposed to the village level. Here we are interested in village-level explanations of agricultural adoption for four reasons. First, much of the literature on agricultural intensification and the spread of innovations stresses explanations at this level of analysis, such as population density (Tiffen *et al.*, 1994; Barbier & Bergeron, 1998), transaction costs (Wadsworth & Swetnam, 1998; Holloway, Nicholson, Delgado, Staal, & Ehui, 2000), location and distance (Haegerstrand, 1967), technological improvement (Barbier & Bergeron, 1998), social structure (Havens, 1975) and crop prices (Barbier & Bergeron, 1998). Second, village-level (and higher-level) analyses are often most relevant for policy-making purposes, as most policies of agricultural intensification are actually policies of regional development. Third, we do not have retrospective data on household and plot characteristics, making a study of household and plot-level determinants of adoption over time infeasible. Fourth, adoption at the plot level may well be affected by (endogenous) village-wide adoption patterns because of copying effects, technological spillovers, and endogenous village prices (Pomp & Burger, 1995; Taylor & Adelman, 1996). By analyzing reduced form patterns at the village level we avoid modeling such interactions, which are difficult to handle in household or plot-level analyses.

We are aware that our analysis may be biased because of omitted household and plot characteristics in the analysis. For this reason, we also compare our results with those based on a model of adoption at the *plot level*, instead of at the village level. Although we do not have information on time-varying household and plot characteristics, we include time-invariant household and plot characteristics to test for the importance of household and plot heterogeneity.

In the remainder of this section we describe the history of soil conservation in Machakos and Kitui districts over the past 40 years. The analysis here is descriptive, and focuses on the trends in soil conservation activities over the entire period, as well as of "peaks" or "bursts" in soil conservation investment activities. Most of the intensification took place in these peak years, and therefore we also look at a number of variables which may have played a role here, particularly variations in rainfall, increases in population density, implementation of agricultural development programs, new road construction, and variation in coffee and maize prices over the past 40 years. This descriptive analysis provides the background for a more formal multivariate analysis in Section 4 estimating the impact of each of these factors on soil conservation activity.

(b) *Forty years of soil conservation in Machakos and Kitui: trends, peaks and external factors*

Terracing overwhelmingly features as the most prominent type of investment in land quality. Terraces in this area are of the "Fanya Juu" type, where trenches are dug along the contour and the soil thrown uphill, so forming the start of a terrace. Of the 422 plots for which we have valid data, 318 fields were terraced and 104 were not. For this reason, because of the resources involved and because of the role of terracing in maintaining moisture, nutrient and organic matter content in the soils, terracing was chosen as the indicator of investment in land for both intensification and sustainability.

The adoption process in Machakos and Kitui Districts is presented in Figures 1 and 2, with the fourth order polynomial trend line added in Figure 1.

In the two districts taken together (Figure 1), after a slow start, the adoption of terraces speeded up until some years ago, when growth slowed down. This slowing down of the adoption process is caused by a reduction of new terracing in Machakos, where most plots suitable for terracing have been treated. Kitui is still in the rapid adoption phase. In the case of Machakos, the total number of plots terraced was 214, with 40 plots remaining or 15%. In Kitui, 104 plots were terraced with 64 plots remaining or 38%.

The general trend is that of adoption of terracing on most plots in the districts. This trend may be related to higher-level variables such as population growth and growth in population density. The population density figures are as presented in Figure 3.

The adoption of terracing seems to follow the increasing population density. Comparing Figures 2 and 3, however, we note that the population density of Kitui is still lower in 1998 than that of Machakos in 1960, while terracing in Kitui in 1998 is much higher than terracing in Machakos in 1960. This suggests that population density is not the sole factor in terracing. [1] In addition, in Figure 1, the occurrence of peaks suggests that other factors are at work as

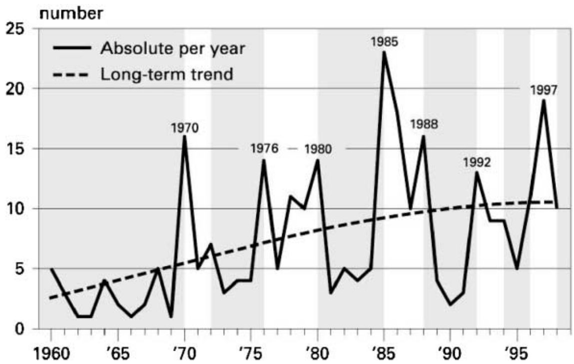

Figure 1. *Number of plots terraced, per year of first terracing on the plot, absolute for both districts, 1960–98.*

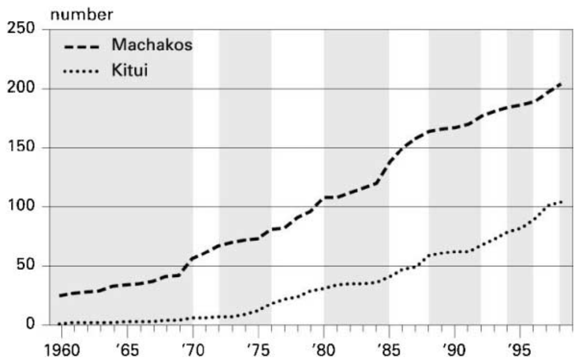

Figure 2. *Number of plots terraced, per year of first terracing on the plot in Machakos and Kitui Districts, cumulative, 1960–98.*

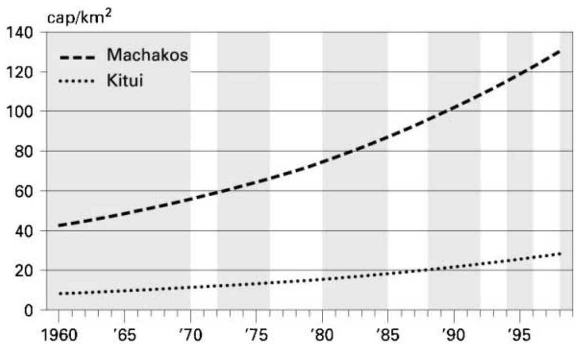

Figure 3. *Development of population density in Machakos and Kitui Districts (cap/km*^{2}*), 1960–98. (Note: the population density figures are from the 1989 and 1963 census, as well as various district development plans (DDP). Interim years have been calculated using the growth percentages as presented in the DDPs.)*

well and these peaks may be linked to certain events. [2] Five of the identifiable peaks are selected. In chronological order these are [3]

—rapid adoption in 1970–72,

—rapid adoption in 1976 and again in 1978–80,

—very rapid adoption in 1985 until 1988,

—rapid adoption in 1992, somewhat less in 1993–94,

—rapid adoption in 1996–98, with a peak in 1997.

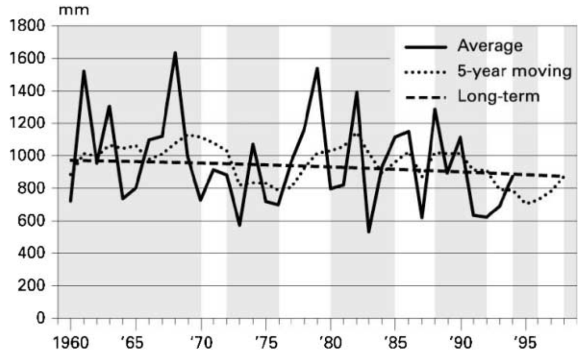

Figure 4. *Rainfall figures, long-term and five-year average trends, for both districts, 1960–98.*

Chronologically, the first peak occurred in 1970–72, with three subsequent years of slightly lower adoption figures. This peak followed after a year of relatively low rainfall (Figure 4), though no critical conditions seem to have been experienced that seriously affected crops and or created food shortages. As rainfall reappears again as a factor during a later period of adoption (see below), it therefore is indicated as one of the variables for inclusion in the model. Rainfall figures (average per year for the two districts, five-year moving average and fourth-order polynomial trend line) are presented in Figure 4.

A more appreciable and sustained period of adoption of terracing is found 1976–80. In fact, there are two peaks of which one may be the direct reaction to drought conditions in 1972–76 with rainfall figures around normal in 1974, but with shortages of between 20% and 35% in the other years. There may have been an urgent need for soil moisture control.

During this time however terracing was also stimulated by the Machakos integrated development programme (MIDP), which was set up in 1978 after a long period of absence of any coordinated effort to initiate development on a program or project basis. [4] MIDP lasted until 1988 when it ran out of funds and was followed up by the so-called arid and semi-arid lands (ASAL) programmes in Makueni. But, only 6% of the MIDP budget of 17.25 million Kenyan pounds for both the first period and the next one of 1989–91 (as an ASAL program) was spent on conservation activities directly. In Kitui, no similar program existed to supplement the efforts of the local population until 1982, when a USAID-funded ASAL programme was set up in the district. This lasted until 1997, with the Danish Development Agency DANIDA taking up funding after 1990. In itself, however, the presence of development programs and projects is not a very useful independent variable. Much depends on the actual activities and interventions. Road construction as far as it was funded by MIDP (1978–82) may have been important for example (Tiffen *et al.*, 1994).

Probably more important than the financial support of MIDP and ASAL was that the local population itself started to invest in terracing, following the rapid rise of world market coffee prices. [5] Prices of this cash crop soared during 1972–78, as is shown in Figure 5. This may have made it possible for farmers to fund their own terracing efforts by hiring in extra labor (Bevan *et al.*, 1992). Farmers started investing in terraces in areas normally considered unsuitable for coffee (AEZ 4), to concentrate water on this crop. The variable as presented in Figure 5 is deflated using the low-income consumers' price index.

Included in Figure 5 is a similar price of maize as a food crop. The consideration is that a price hike of maize as the main staple crop may cause farmers to at least harvest the minimum food requirement of the household, and invest accordingly. Fafchamps has noted that this food security motive for investment may be strong for poor farmers, especially if higher prices lead to higher (perceived) price risks (Fafchamps, 1992). Considerable price increases may therefore incite them to invest in terracing, as the productivity of terraced land is higher than of nonterraced land (Zaal, 1999).

A third peak occurred in 1985–88, and followed the drought in the early 1980s (Figure 4) and the drought year of 1987. Again, the main

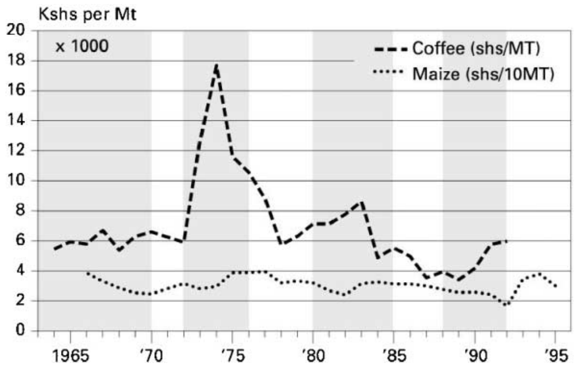

Figure 5. *National coffee and maize prices in KShs per Mt of green coffee and white maize (indexed at 1964 price levels), 1964–95.*

motivation to adopt may have come from moisture control rather than erosion as such, though the National Soil and Water Conservation Programme, supported by SIDA from 1978 onward, may have played a role as well. Though the SWC Programme started in the high-potential areas (AEZ 2 and 3), it extended its activities to the dryer areas later on. From our evidence it does not appear however, to have been active in the villages in our study. In addition, this period witnessed the construction of the Machakos–Kitui road (Tiffen *et al.*, 1994). Transport possibilities between these places therefore improved considerably and this may have stimulated market gardening and terrace building.

The fourth peak of the early 1990s followed the bad rainfall situation in 1990 and 1991, particularly in Kitui district. By this time, there was no longer a Machakos district development project to support terracing, [6] but in Kitui the earlier established Kitui integrated development programme (KIDP) had been renamed Kitui agricultural project (KAP) and had started to focus on agriculture exclusively. Still, with diminishing funds both through KAP and the Ministry of Agriculture and Livestock Development, the effects of external interventions were probably minimal. This peak and the last one in the second half of the 1990s may again have occurred in reaction to low-rainfall figures and the need for better moisture control, not a generally felt need for erosion control *per se*. Moreover, maize prices went up with unprecedented percentages. Most of the terraces in these two last peaks were built in Kitui as by this time the majority of the plots in Machakos District had already been terraced.

4. MULTIVARIATE ANALYSIS

The above analysis of the dynamics of terrace construction suggests a number of possible explanations for the observed increase in soil and water conservation in Machakos and Kitui. Population density has been increasing steadily, but there have also been strong variations in rainfall, coffee and maize prices, government interventions, and improvements in infrastructure. In order to disentangle the relative weight of each of these variables, we discuss in this section the results from a number of multivariate analyses, which explain the timing of terrace construction at the village level. Before doing so, there are a number of issues to consider, namely the role of (omitted) plot and household-level characteristics; time-variation in the effects of explanatory variables; sample selection bias; and specification of the models. We discuss these four issues in turn before we move to a discussion of the empirical results.

First, because we do not have retrospective data on household and plot characteristics other than on the adoption of conservation and intensification measures, our analysis focuses primarily (but not exclusively) on explanatory factors at the village level. This implies a possible *omitted variable bias*, if the omitted plot and household-level variables are correlated with the village-level explanatory variables. For instance, if villages that are located further from the market also have poorer households, and if poorer households are less likely to invest because of imperfect credit markets, then in our analysis the effect of distance to market on investment will also pick up this wealth effect. To control for this we also include in our analysis village dummies reflecting village differences in household and plot characteristics. Still this may not be sufficient if the relevant village-level household and plot characteristics vary over time, for instance, because plots which are easier to terrace are terraced first or because wealthier households are more likely to terrace earlier. This would imply that the relevant village-level household and plot characteristics will change over time, as the remaining plots may be the most difficult to terrace or owned by households who are least inclined to invest. We will test for the importance of such changes in the relevant household and plot characteristics by comparing the results of our village-level analyses with a plot-level analysis, where we allow for household and plot heterogeneity. The results show that our conclusions are unaffected in the sense that the same village-level variables explain plot-level adoption, although the results are less robust to the inclusion of year effects.

The second issue is the time-variant effect of the explanatory variables, as the number of terraces is reduced with each new terrace constructed. The various explanatory variables may place a different weight on terracing on the remaining plots, and as the plots that are easier to terrace are the first, each new plot terraced represents a greater effort as well. In our analysis we allow for this possibility by testing for the presence of *structural breaks* between different time periods in the model.

Third, our analysis may suffer from sample selection bias because we only include in our analysis the plots that were not already terraced in 1965 or before. The reason for this limitation is that in our data set we only have information on a number of village-level variables for the period after 1965. It is plausible, however, that any sample selection bias will be small given that only 7.9% of the plots had terraces by 1965.

The fourth issue is the precise specification of the different models that we estimate. We estimate three village-level models. The first is a logit model for the probability that a plot has been terraced in a village in a given year, not having been terraced before. The second is a linear regression model (OLS) for the number of plots that has been terraced for the first time in a village in a given year. The number of plots is expressed as a percentage of the total number of surveyed plots in the village. The third is a logit model for the probability that a peak in terracing has occurred in a village in a given year. The first model analyses the factors that explain the presence of agricultural intensification, the second model analyses the factors which explain the intensity of agricultural intensification, while the third model looks at the factors which explain the occurrence of a period of rapid intensification. Understanding the factors underlying these peak periods is important because more than half of the intensification took place in these peak periods (51%). A peak period is defined as having more than 4% of the village plots terraced for the first time in any given year (the average per year is 1.5% for the regression period). This rule identifies the peak years discussed in Section 3, as well as two other years in which a peak occurred in one village only. [7] Table 3 reports the specifications for these three models.

Density (of the sublocation in which the village is located) and travel time (minutes to Nairobi by public transport) are included as village characteristics. Market-related variables are the national producer price of green coffee and white maize in Shs/Mt (in 1965 prices) and GDP per capita (in constant market prices) in Kenya. In our regressions we will include the ratio of the coffee and maize prices as a proxy for the relative attractiveness of the cash crop (coffee). The results would not change if both the price of coffee and maize are included, as only the coffee price turned out to be (positively) significant in each of the specifications. The GDP per capita variable is included as agricultural intensification may follow from increases in the demand for agricultural outputs as well as the availability of off-farm opportunities. Climate-related variables are included through variables indicating that a drought year has occurred within the last three years in either Machakos or Kitui. Because there are two rainy seasons, and farmers may be able to survive one bad season, we have defined a drought year as a year in which there is a rainy season with a severe drought and a *preceding* rainy season also with a severe drought. [8] A severe drought is defined as a rainy season with a drought index less than or equal to -0.8 ($DI \leqslant -0.8$, see Tiffen *et al.*, 1994, chapter 3). [9] We have also investigated the possibility of including interventions in the area in the analysis through a dummy variable indicating the presence in the past three years of a project that focuses on soil and water conservation and terracing. Unfortunately, because the intervention dummy shows very little variation across time it was not possible to identify the intervention effect. All variables are

Table 3. *Model specifications*

Category	Model 1	Model 2	Model 3	Unit
Dependent variable	Any of the plots are terraced (dummy)	Number of plots terraced if any terracing takes place (%)	Peak year terracing (dummy)	
Explanatory variables				
Village related	Density	Density	Density	persons/km
	Travel time to market	Travel time to market	Travel time to market	min
Market related	Price of coffee	Price of coffee	Price of coffee	Shs/Mt
	Price of maize	Price of maize	Price of maize	Shs/Mt
	GDP per capita	GDP per capita	GDP per capita	Current Shs
Climate related	Drought year in Machakos in past 3 years	Drought year in Machakos in past 3 years	Drought year in Machakos in past 3 years	DI ⩽ − 0.8[a]
	Drought in Kitui in past 3 years	Drought in Kitui in past 3 years	Drought in Kitui in past 3 years	DI ⩽ − 0.8[a]
Unit of analysis	Village/year	Village/year	Village/year	
Estimation technique	Logit	OLS	Logit	

[a] DI = drought index (see Tiffen *et al.*, 1994, chapter 3). A drought year is defined as a year in which there is a rainy season with a severe drought (DI ⩽ − 0.8) and a *preceding* rainy season with also a severe drought.

time-variant except for the distance variable, which was only measured for 1998.

(a) *Results*

Tables 4–6 give the result of the analysis. Table 4 presents the result of a logit analysis of the adoption of terracing in any given year. The regression in column (1) shows that the probability that any of the plots are terraced in any given year is significantly correlated with the population density, GDP per capita, the distance (travel time) to Nairobi and the relative price of coffee. There is also evidence that droughts in the preceding three years do motivate farmers to invest in agricultural intensification, but this effect is only found for Kitui. One explanation for this finding is that in

Table 4. *Logit regression analysis of whether any plot in a village is terraced in any given year (t-values in parentheses)*

Variable	(1)	(2)	(3)	(4)
Density	0.002[a]	0.004	0.002[a]	0.003
	(2.11)	(1.18)	(2.04)	(0.86)
GDP per capita	0.001[a]	0.001	0.001[a]	0.001
	(1.81)	(1.12)	(1.74)	(1.19)
Travel time to market	−0.007[a]		−0.007[a]	
	(2.63)		(2.63)	
Price coffee/maize	0.043[a]	0.048[a]	0.044[a]	0.048[a]
	(2.09)	(2.17)	(1.94)	(1.94)
Drought in Machakos	0.171	0.147	0.174	0.160
	(0.39)	(0.32)	(0.38)	(0.33)
Drought in Kitui	0.767[a]	0.831[a]	0.757[a]	0.823[a]
	(1.90)	(1.89)	(1.78)	(1.77)
Constant	−3.001[a]	−3.479[a]	−3.097[a]	−3.682[a]
	(2.03)	(2.05)	(1.94)	(1.98)
Village effects	No	Yes	No	Yes
(*p*-value)		(0.20)		(0.20)
Year effects	No	No	Yes	Yes
(*p*-value)			(0.26)	(0.25)
Number of observations	240	240	240	240
Goodness of fit (*p*-value)[b]	0.00	0.00	0.00	0.00

[a] Significant at 10% or lower level.

[b] Indicates the significance level of the chi-square test that none of the slope parameters are significantly different from zero.

Table 5. *OLS regression analysis of percentage of village plots terraced if any terracing takes place in a village in any given year (t-values in parentheses)*

Variable	(1)	(2)
Density	−0.001	−0.004
	(0.49)	(0.57)
GDP per capita	−0.0006	−0.002
	(1.00)	(0.70)
Travel time to market	−0.003	0.011
	(0.07)	(0.45)
Price coffee/maize	0.033	−0.037
	(0.95)	(0.24)
Drought in Machakos	−0.759	1.047
	(1.07)	(1.11)
Drought in Kitui	0.606	−0.713
	(0.89)	(0.24)
Sample selectivity term		−2.443
		(0.47)
Constant	5.24[a]	13.87
	(1.98)	(0.74)
Number of observations	107	107
Goodness of fit (*p*-value)[b]	0.43	0.52

[a] Significant at 10% or lower level.
[b] Indicates the significance level of the chi-square test that none of the slope parameters are significantly different from zero.

Table 6. *Logit regression analysis of whether there is a peak in the number of plots terraced in a village in any given year (t-values in parentheses)*

Variable	
Density	0.001
	(0.51)
GDP per capita	−0.00003
	(0.05)
Travel time to market	−0.010[a]
	(2.44)
Price coffee/maize	0.037
	(1.30)
Drought in Machakos	−1.152
	(1.41)
Drought in Kitui	1.019[a]
	(1.64)
Constant	−3.095
	(1.44)
Number of observations	240
Goodness of fit (*p*-vale)[b]	0.04

[a] Significant at 10% or lower level.
[b] Indicates the significance level of the chi-square test that none of the slope parameters are significantly different from zero.

periods of drought, farmers in Machakos have better outside options in terms of off-farm employment than farmers situated in Kitui, and they are therefore less motivated to improve their farms in periods of drought.

Column (2) presents the results if village dummies are included to control for any unobserved village effects. With village dummies the cross-section patterns are subsumed and the focus is on changes within a village over time. Because our measure of distance in this model is time-invariant, we are unable to include both the village dummies and the distance variable in column (2). The coefficients do not change much from column (1) to column (2), although the significance level of the estimated coefficients suffers. We tested specification (2) against specification (1) by testing the significance of the village dummies if we also include the distance variable. [10] This test shows that specification (1) is not rejected against specification (2) (*p*-value 0.20). In column (3) we have included a random year variable to control for unobserved year effects and because a Hausman test did not reject random effects in favor of fixed effects. [11] Once again, the coefficients are unaffected, and the year effects are not significant (*p*-value 0.26). In column (4) both village and year effects are included but both are insignificant. Hence, we can accept the specification in column (1).

We tested whether lagged values of the relative coffee price were significant, but we did not find evidence for lagged price responses. [12] We also tested whether the 1970s was an exceptional period and therefore an explanation for the observed significant effect of the relative coffee price. If we interact the price variable with a dummy variable for the 1970s, we do not find that adoption reacted significantly different to relative coffee prices in the 1970s compared to the other periods. In other words, we do not detect a structural break in the model.

Table 5 presents the results of a linear regression (OLS) analysis explaining the intensity of terracing in any given village and year. The intensity of terracing is measured as the percentage of plots that have been terraced. None of the population density, the relative price of coffee, distance and drought variables appear as significant. In column (2) we have also included a sample selectivity term to control for the fact that the regression only includes positive observations. [13] This does not change the results. We have also tried to include village and year effects but they were insignificant and did not change the results. Hence, the results show that although the population density, the relative price of coffee, distance and drought variables can explain the probability that any terracing takes place in the village (Table 4), they are unable to explain the intensity of terracing.

The fact that we do not find any significant effect of the village-level variables on the intensity of terracing may be due to a nonlinear relationship between these variables. If there are any fixed costs to terracing, then farmers may prefer to terrace in "bunches" or peak periods. For instance, if terracing involves the mobilization of exchange labor groups, then it is easier to concentrate terracing activity in those years in which these exchange groups are most active. Hence, although we may not find any effect of the village-level variables on terracing intensity in general, we may find an effect if we concentrate on those peak periods.

Table 6 presents the results of a logit analysis of the occurrence of peaks in terracing in any given village and year. A peak in terracing is observed if at least 4% of the plots in the village are terraced in a given year (the average percentage is 1.5%). We have also tried to include village and year effects but they were insignificant and did not change the results. Travel time to the market and drought in Kitui are the only significant explanatory factors for the occurrence of peaks. The effect of the coffee price is positive but not significant. But, if we define a drought year as any calendar year in which there is less than 800 mm, then the coffee price also significantly explains the historical peaks in terrace construction. Villages that were lying further from the market were less likely to experience any peaks in terracing. The latter result may be explained by the presence of transaction costs—villages that were further from the market could not benefit as much from the boom in coffee prices because of higher transportation and/or information costs. Drought in Machakos does not appear as a significant variable, presumably because farmers in Machakos have better outside options in terms of off-farm employment than farmers in Kitui.

(b) *Do omitted household and plot characteristics bias our results?*

One may question the above results because we have not controlled for household and plot characteristics. The reason for this omission is that we do not have retrospective data on household and plot characteristics other than terrace construction. We have however included village dummies to control for time-invariant village-level differences in household and plot characteristics, and we have seen that the results remain unaffected. We also saw that the results are robust to the inclusion of year effects. Here we will test for the significance of household and/or plot heterogeneity by estimating a model of adoption at the *plot level*, instead of at the village level. If the results of this analysis are similar to those found earlier, we may conclude that omitted household and plot characteristics do not drive the earlier results. It should be pointed out, however, that the plot-level analysis itself also suffers from a number of weaknesses. It does not include the effects of village interactions such as copying effects, technological spillovers, and endogenous village prices, because there is no simple way to model them. Moreover, time-varying household and plot characteristics are omitted because of lack of data. Hence, we use the results of the plot-level analysis to see whether the earlier results are robust to the inclusion of time-invariant household and plot characteristics, but not necessarily as a superior model of terrace adoption.

The specification of the plot-level model follows the adoption model developed in Pomp and Burger (1995). The logit model gives the probability of adoption in a given year for a given plot. Each year, any plot that has not been terraced before has a probability of being terraced. If terracing occurs, then the plot drops out of the model. If terracing does not occur, then the plot gets another chance in the next year. The logit model includes the same village-level explanatory variables as in the earlier analyses, as well as a number of other variables to control for household and slope heterogeneity: dummies for slope and soil type, a variable measuring the distance from plot to home in meters and household fixed effects. [14] Note that with our data we can only estimate a model for adoption at the plot level, and not for plot-level adoption intensity or the presence of peaks in adoption activity. In addition, the travel time to the market cannot be included because of the presence of household fixed effects. Table 7 presents the results of the analysis.

Initially we included several slope and soil type dummies, but none of the soil type dummies turned out to be significant, and for the slope dummies we did not find a significantly different effect between lower, medium and upper slope. Hence, in the above regressions we have combined these three slope types. The most important result from Table 7 is that each of the significant village-level variables in Table 4 is also significant in Table 7, except the drought variable (column 1). The plot slope variable is also significant and positive, as

Table 7. *Logit regression analysis of whether any plot in a village is terraced in any given year, controlling for household and plot heterogeneity (t-values in parentheses)*

Variable	(1)	(2)
Density	0.011[a]	0.001
	(5.81)	(0.05)
GDP per capita	0.001[a]	0.003[a]
	(4.29)	(7.14)
Price coffee/maize	0.028[a]	0.028
	(2.50)	(1.04)
Drought in Machakos	−0.216	−0.599[a]
	(0.87)	(1.83)
Drought in Kitui	0.936[a]	0.116
	(3.39)	(0.34)
Distance plot to home	−0.0001	−0.00004
	(1.37)	(0.69)
Lower/medium/upper slope	1.191[a]	1.700[a]
	(2.44)	(3.31)
Household effects	Yes	Yes
Year effects (*p*-value)	No	Yes
		(0.00)
Number of observations	5752	5752
Goodness of fit (*p*-value)[b]	0.00	0.00

[a] Significant at 10% or lower level.

[b] Indicates the significance level of the chi-square test that none of the slope parameters are significantly different from zero.

expected. This result would suggest that the omission of household and plot characteristics does not bias the results in any serious way as we can still conclude that density, GDP per capita, and the coffee price are significant factors in the adoption of terracing. The size of the coefficients is not directly comparable, however, because of the aggregation problem. If year effects are included (column 2) then the coefficient on the density variable becomes much smaller and strongly insignificant. [15] These year effects also turn out to be strongly significant in this case. In the village-level model (Table 4) we did not find that the density variable became insignificant if year effects were included. This suggests that the village-level density variable is a good proxy for population pressure in the village-level model, but not in the plot-level model. Population pressure felt at the plot-level depends as much on village-level population pressure as on household characteristics (land ownership and household size), and therefore may vary strongly between households and plots.

(c) *Population pressure or other factors?*

How much of the Machakos miracle can be attributed to increases in population pressure over the sample period? The above analysis shows that besides population pressure, coffee prices, droughts, and travel distance to the capital city also play a role in explaining the Machakos miracle. In fact, the above analysis allows us to analyze the relative importance of population pressure against these other factors.

We have used the village-level model to simulate what would have happened to the *cumulative rate of adoption* over 1966–95 if population density had remained at the level observed in 1966 in each of the villages. [16] As a contrast, we also have simulated what would have happened if there had been no droughts, no coffee boom (the relative coffee price would have stayed at levels observed for 1966), or if the travel times to the villages had been twice as long as currently observed. [17] Figure 6 shows the cumulative patterns of adoption under each of these scenarios, using the village-level results from column (1) in Table 4. [18]

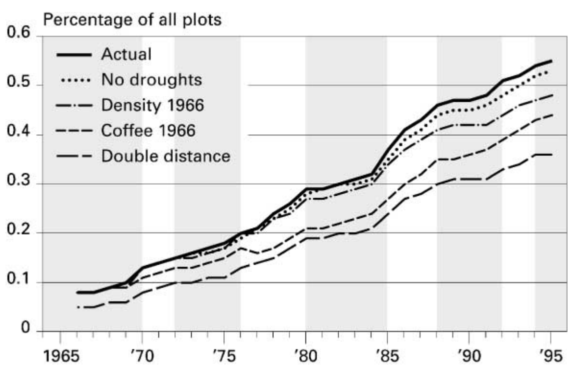

Figure 6. *Model simulations of cumulative adoption rates for all villages using village-level model, 1966–95.*

The simulations for population density, coffee price boom and especially the reduction in travel time to Nairobi show the largest effect on agricultural intensification in Machakos and Kitui. If travel time from Machakos and Kitui had been double, then the models predict that the cumulative rate of adoption would be at most 32% in 1995, as opposed to the observed 55%. The coffee boom appears to have been the second strongest factor in the model. If coffee prices had stayed at their 1966 (real) price level, then the cumulative adoption rate would have been 39%. For density, we find that if the population density had remained at the level observed in 1966, then the cumulative adoption rate would have been 42%. The effect of droughts is found to be of relatively minor importance in the model simulation, explaining 8% of the cumulative terracing rate in 1995. [19]

Summarizing, the model simulation in Figure 6 suggests that the improvement in infrastructure was a driving force behind the Machakos/Kitui miracle. The rise in population density and the coffee boom also played a role but their effect appears to have been weaker. Of course, here we have analyzed the direct impact of population density, but not the indirect impact. For instance, development of transportation infrastructure may itself be a function of population density and as such we may have underestimated the role of population pressure for agricultural development. This might indeed be true, but the opposite might also hold—population pressure may itself be affected by other factors, such as transportation infrastructure, and we might even have overestimated the role of population pressure. In addition, a positive correlation between population and road density should not be taken for granted either (Pender, 1999). A much more elaborate model would be necessary to study all these linkages, to assess the ultimate role of population pressure, and, to our knowledge, no such study has been undertaken as of yet. It is clear, however, that other factors besides population pressure may have had at least as strong a *direct* impact on agricultural intensification as population pressure.

5. DISCUSSION AND RESEARCH AND POLICY IMPLICATIONS

Even though the earlier work by Tiffen, Mortimore and Gichuki and their team focused on the district's trend in population density in particular, attention was also paid to other factors conducive to the adoption of natural resource enhancing technologies. But, no retrospective data set was available at the time to test rigorously the proposition that population density was paramount among the variables explaining the adoption of these techniques, as this needed a study at the combined plot, household and village level. Of course, even with peaks in adoption made possible by high-cash crop prices, ultimately the correlation between population density and terracing would have ended up high. The present research offers the first opportunity to test the hypotheses against the evidence.

The result of this test points at the direct impact of low-transaction costs, as operationalized by the time it takes to arrive at the major market, next to population density itself. Both the regular and easy flow of people (farmers, researchers and extension officers alike) and the resultant information flow, and the reduced costs of the transport of inputs and output may have stimulated the construction of terraces. The fact that the windfall profits of the coffee boom seem to have been used extensively for this purpose points at the direct link between cash crop needs (in terms of moisture and nutrient management) and profitability (resulting in the necessary financial resources for the actual implementation of terraces). This link is strengthened through reduced transaction costs. Continued work is now being done to further test this idea through an analysis of crop choice and profitability of the terracing technique. It is interesting to note that using a different methodology and studying another part of Africa, Mazzucato and Niemeijer (2002) reach the same conclusion, that population pressure is not the single nor the most important factor affecting environment. Another impact of transaction costs reduction may be the facilitation of seasonal work in the major cities of Kenya. Much of the explanatory force of this argument focuses on the level of the household, as adoption depends partly on labor availability and wealth. For this reason, another analysis is now being done to determine the factors explaining the variance at the household level. In addition the plot level is considered, as much of the explanation is at that level as well.

Interestingly, droughts do not appear to be the prominent forces of change as they were assumed to be beforehand. The finding that in Machakos, this variable is even less significant as it is in Kitui further corroborates this. The hypothesis is that the relatively low cost of seasonal migration and the higher level of economic activity generally facilitate alternative ways to secure a livelihood apart from further investments in agriculture. This in itself could indirectly lead to higher levels of adoption of inputs and terracing in Machakos, as market opportunities could be seized independently of drought conditions.

In terms of policy, the results point at the need to consider transaction costs and in particular infrastructure development, in relation to policies on direct transmission of benefits from cash cropping and any credit facilities that would further enhance the proper use of these profits for investments in the quality of land by small farmers. The construction boom noticed by Bevan *et al.* (1992) partly found its expression in investments in land quality through terrace construction, but the timing of these investments would have, if deferred to a later date, facilitated the choice of a period with lower labor costs. Consequently, more terraces would have been constructed. On the other hand, this boom certainly caused a take-off phase, accelerating the process of agricultural intensification in Machakos and Kitui.

NOTES

1. We thank one of the anonymous referees for making this point.

2. The accuracy of linking the peaks in terrace adoption with certain events depends on the accuracy of the memories of the respondents, a unreliable source of information generally. In this case, however, the problem may not be the actual year so much as the fact that the memories of people will link the terracing with the year the event occurred instead of with the year after when they reacted to the event by starting terracing. The year people said they acquired the plots does not have a tendency to be linked to five and 10 year periods.

3. Earlier peaks are much smaller and very difficult to relate to any events due to a lack of precise data. Generally, this was a period in which terracing was prescribed by the colonial government and implemented using various approaches including forced labor (IFAD, 1992).

4. The last effort was the African land development fund (ALDEV), which started as a colonial land development program in 1946 and lasted until 1962. Initially, the attention was mostly on land conservation and grazing control in African areas severely eroded, after 1951 the goals were broader defined (Tiffen *et al.*, 1994, p. 254).

5. It is estimated for Machakos that the ALDEV contribution formed about 35% of total investment in terracing until 1985, while private investment from 1985 onward added 15% to the total invested sum per year with little new contribution from project or government sources (Tiffen *et al.*, 1994, p. 259).

6. Nor was it very much needed for this purpose any longer. The Machakos ASAL project had been terminated in 1991, while in the early 1990s the KIDP was in turmoil due to changes in donor agency responsible and many other internal developments.

7. These peaks occurred in 1975 (Mwanyani) and 1983 (Ngumo).

8. The two rain seasons are the short rains (October–December) and long rains (March–May).

9. An anonymous referee suggested this definition of drought to us.

10. More precisely, we included six of the eight village dummies. One village dummy was dropped due to the combined constraints and another dummy the (village-specific) distance variable is included.

11. See Greene (2000, chapter 14).

12. We included three lags for coffee and maize prices, but they turned out to be insignificant in a joint χ^2-test.

13. Heckman and MaCurdy (1986, Table 1) show that if the probability that terracing occurs is specified as a logit model, that the sample selectivity term is given by $-[\ln F(X\beta) - X\beta F(-X\beta)]/F(X\beta)$, where F is the cumulative logistic distribution, X the vector of explanatory variables, and β the corresponding vector of coefficients. The sample selectivity term is calculated by using the estimated vector of coefficients from the logit model (Table 4, column 1).

14. A Hausman test clearly rejected random effects in favor of fixed effects.

15. We have included random year effects because the Hausman test does not reject random year effects against fixed-year effects.

16. For the village-level model the cumulative rate of adoption is calculated as the weighted average of the rate of village-level adoption with weights equal to the share of plots found in each of the villages.

17. A halving of the travel times during 1966–95 appears to be a conservative estimate of the improvement in transportation infrastructure over this period, and the effect of this may have been more dramatic for Kitui than for Machakos due to the relatively recent tarring of the Machakos–Kitui road.

18. The terracing intensity in a given village and year is predicted by the probability that any terracing took place (from Table 4, column 1) times the average reported terracing intensity for villages and years that any terracing was reported (3.4%). The results for the travel time and coffee price simulations barely change if we use the model for peak years instead. In that case the terracing intensity in a given village and year is predicted by the weighted average of the average reported terracing intensities in peak (6.7%) and off-peak years (2.2%) for villages and years that any terracing was reported, with weights equal to the predicted probabilities that a peak or off-peak period occurred (from Table 6).

19. Without any droughts the cumulative adoption rate would be 47%.

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