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Institutions, Economic Development, and Deforestation

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Abstract — This paper offers a unified framework linking two important debates: First, the debate about the respective roles of geography and institutions on economic development; Second, the literature on the role of technological change and economic development on agricultural intensification and land use changes. We use this framework to study empirically deforestation patterns at the rainforest margin. To this end we specify an empirical model that can explore the causal chain ranging from geographic conditions via institutional change to economic development and deforestation. We estimate this model using a unique data set of villages at the rainforest margin in Indonesia. Our results show that geography-induced institutional change is the key driver of technological change in our villages. The bad news is that some of these processes along the causal chain seem to promote deforestation. The good news is that economic development, conditional on these effects, appears to reduce deforestation.

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1. Introduction

The majority of the world's poor resides in rural areas and derives a significant share of their incomes from agriculture. As has been demonstrated empirically many times in the literature, sustainable income growth and poverty reduction in rural areas requires improvements in agricultural productivity (e.g. Datt and Ravallion, 1996, 2002; Byerlee, Diao and Jackson, 2005; Ravallion and Chen, 2007; Grimm, Klasen and McKay, 2007; Thurlow and Wobst, 2007, World Bank, 2007). Key to such agricultural productivity improvements are improvements in agricultural production technologies. Thus the critical question arises what are the key drivers of technological change in agriculture. This is of particular relevance in regions where land is still available for conversion to agricultural use, as these are typically the areas where individual property rights are absent or not well defined which might constrain investments in land improvement and new technologies (see e.g. Binswanger, Deininger, and Feder 1995). This situation applies to much of Sub-Saharan Africa, but also significant portions of Latin America and Asia where lowland savannahs and forested areas continue to represent an internal land frontier that is available for conversion to agricultural uses.

At the same time, improving agricultural productivity and incomes at the land frontier inevitably begs the question regarding the environmental impact of such developments. If the land frontier consists of rainforest that provide important local and global ecosystem services, it is important to determine to what extent economic development and poverty reduction at the forest margin will promote or discourage deforestation (e.g. Reardon and Vosti, 1995).

The purpose of this paper is to jointly investigate the determinants of economic development and deforestation at the rainforest margin using a unique data village data set from Indonesia that will allow us to study both drivers of economic development and deforestation in a joint empirical framework.[2] Our results suggest that geography- and demography-induced institutional change, which in our case is the establishment of property rights over agricultural land, are the key drivers of agricultural productivity improvements, which in turn determine economic development outcomes at the rainforest margin. At the same time, several of these drivers of economic development themselves promote deforestation while the conditional effect of economic development (controlling for its drivers) is associated with reduced deforestation.

The paper is organized as follows. The next section discusses the conceptual framework, also in the context of existing literature on the subject. The following section describes the data, the setting, and the econometric method. Section 4 focuses on the results, while section 5 concludes.

2. Conceptual Framework

When studying the literature on determinants of economic development in general, and development in rural settings, seemingly competing hypotheses are invoked. A first strand of the literature has debated the respective roles of geography versus institutions for long-term economic development. One group has argues that geography, such as climate, disease environment, landform, market access, and soil quality of the cultivated land area, is the dominant factor in determining long-term economic development, including particularly agricultural development (see e.g. Diamond, 1997; Gallup, Sachs and Mellinger, 1998). The opposing view is that institutions such as property rights and the rule of law are much more important determinants of long-term economic progress (e.g. Hall and Jones, 1999; Acemoglu *et al.*, 2001; Easterly and Levine, 2003; Rodrik, Subramanian and Trebbi, 2004). Those in the

[2] A related paper by Grimm and Klasen (2008) focuses on the determinants of technological change in agriculture, thereby concentrating on a smaller part of the causal chain investigated here. This paper extends the analysis to economic development and deforestation.

latter camp allow, however, for the fact that institutions have evolved endogenously responding to, among other things, geographic conditions. This is done most explicitly in Acemoglu *et al.* (2001) where geographic conditions, particularly a high disease burden, affected European settlement patterns which in turn led to extractive institutions in non-settler economies and development-friendly institutions in settler economies. Through historical persistence, these institutions still heavily influence the economic fate of nations today.[3]

A closely related but rather independent strand of the literature also emphasizes the role of endogenous institutional change, this time with an explicit focus on improvements in agriculture (North, 1990; Hayami and Ruttan, 1985). In this literature, the role of land rights has received particular emphasis (e.g. Binswanger, Deininger, and Feder, 1995; Deininger, 2003). According to this argument, land rights would provide security to the land owner, would lower the cost of trading land and could be used as collateral for credit. This in turn would have a positive impact on investment in land improvement as well as new and more productive cultivation technologies. However, the literature also emphasizes that land rights have to be considered as endogenous, responding, among others, to past investment decisions in the land, land scarcity, land quality, as well as the differential power of different rural groups (e.g. Binswanger, Deininger, and Feder, 1995; Rozelle and Li, 1998; Besley, 1995; Brasselle, Gaspart and Platteau, 2002). The empirical evidence on the effectiveness of land rights is quite mixed, as will be discussed below.

A third strand of the literature emphasizes population size and density, and associated pressure on land, inducing technological improvements or the adoption of existing technologies (see e.g. Boserup 1981; Kremer, 1993; Klasen and Nestmann, 2006).

These three strands of the literature have evolved quite independently and there are only few studies that explicitly test the relative importance or the inter-relationships between these competing hypotheses. In this paper, we suggest a theoretical argument which links these three potential explanations and then proceed to test these linkages empirically. We argue that migration to a land frontier is driven by a favorable geography, and that high migration and associated population growth in turn intensify land pressure in these areas. Land pressure induces communities to opt for land rights, which in turn increase the incentive of farmers to invest in agricultural technology. Eventually, agricultural technology enhances agricultural growth which in turns drives economic development and poverty reduction. In short, endogenously generated institutional change is the core element of our transmission channel from geography to economic development.

In this sense, our argument is a "micro version" of the "institutions hypothesis" discussed above and focuses on the transmission channels from geography-induced institutional to economic development. As the debates about the "institutions hypothesis" have usually been based on cross-country regressions where questions about parameter heterogeneity, unobserved heterogeneity, and endogeneity cannot easily be controlled for, we believe there is value added to consider these linkages at a micro level, where parameter heterogeneity and endogeneity are likely to be less relevant. In addition, it allows examining in more detail what kind of institutions matter and how in turn these are determined. In this paper we focus on legal government titles for agricultural land and argue that those are a critical driver of agricultural development. We also show that the introduction of land titles at the village level is driven by migration and geography. Thus, similar to Acemoglu *et al.* (2001) and others we

[3] See Grimm and Klasen (2008) for a more detailed exposition of this geography versus institutions argument.

attribute to geography an indirect role on economic development through its effect on institutions.

The causal chain from geography to economic development we have in mind is as follows. We argue that immigration to the villages in our study region is driven by the geographic features of these villages, with favorable geography (such as high quality land, favorable climatic conditions, good accessibility) attracting immigrants. Villages with relatively high immigration in turn experience population pressure on increasingly scarce land resources. Land pressure and associated conflicts induces villages to regulate their land market and to opt for land rights, for which there is a demand-driven system of land rights in place in Indonesia (see below). In line with a large literature on this topic, land rights increase incentives and means for agricultural productivity improvements as farmers are able to capture the returns to long-term investments through higher productivity or higher land values and can use the land as collateral for credit (e.g. Braselle et al. 2002). Tenure security is particularly important in our study area because the main innovation in agriculture is the cultivation of cacao, a perennial crop, which starts to generate returns from the third year onwards. Eventually, agricultural technology enhances agricultural growth and economic development.[4]

The reader might notice some similarity between our hypothesis and the one by Boserup (1981) mentioned above. Boserup (1981) argued convincingly that demographic pressure and associated food shortages would induce technological improvements or the adoption of existing technologies. A rising population density would force individuals to modify the mode of land use and to employ progressively modern agricultural technologies. The argument put forward in our paper is consistent with Boserup's line of reasoning, but the crucial issue is, that we assume that institutional change is the critical intervening variable between population and technology. Without that institutional change investments in new technologies will not take place for the reasons given above.

Regarding the link between this causal chain and possible deforestation, the literature suggests competing influences (see Maertens et al. 2006; Angelson, 1999; Angelsen et al., 2001). On the one hand, deforestation and environmental degradation more generally is seen as a consequence of population pressure, poverty, and poor technologies, where people are pushed onto marginal lands and/or convert forests for agricultural use. Conversely, deforestation can also result from profitable income-earning opportunities in agriculture that induces the expansion of a land frontier, i.e. deforestation is a result of pull factors to the rainforest margin. As has been suggested in the literature (e.g. Maertens et al. 2006, Angelsen et al., 2001), the type of technological change might matter as well, with labor-saving technological improvements favoring forest clearing while land-saving technologies discouraging land conversion. Some of these forces have actually been investigated using the same data from Indonesia. In particular, Maertens et al. (2006) examine the impact of land- and labor-saving technologies in rice production, as well as population pressure on land expansion in a set of Indonesian villages. They find that population pressure and labor-saving technologies promote deforestation while land-saving ones reduce it.[5]

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[4] The details of this causal chain as well as the literature on aspects of this causal chain are discussed in Grimm and Klasen (2008).

[5] Our study differs from their approach by explicitly considering the drivers of technological change, by looking directly at deforestation rates (rather than land use changes as a proxy), by considering more covariates, and by including an explicit panel dimension in the analysis.

This literature thus suggests that many of the determinants along our causal change, including favorable geography, population pressure, land rights, technological change as well as economic development could all have an impact on land-use changes and deforestation rates and that it is therefore important to consider the direct and indirect effects of these determinants in our empirical analysis.

3. Data, study context, and econometric method

3.1. Data

The data used in this analysis consists of a village survey matched to GIS data on forest cover and its changes. The village survey we use was conducted during March to July in 2001 in the Lore Lindu region. This region includes the Lore Lindu National Park and the five surrounding sub-districts. It is situated south of Palu, the provincial capital of Central Sulawesi/Indonesia. The survey is part of an international and interdisciplinary research program known as "Stability of Rain Forest Margins" (STORMA) which studies the determinants of biodiversity and land use in this region and how such biodiversity can be protected through appropriate socioeconomic mechanisms. For the survey 80 of the 119 villages in the region were selected using a stratified random sampling method (Zeller, Schwarze and van Rheenen, 2002). The survey collected data on current and past demographics, land use practices and technology adoption, conservation issues, infrastructure and qualitative information on income and well-being. Additional information on geographic features was taken from secondary data sources and added to the data set by Maertens, Zeller and Birner (2006). It is important to note that the retrospective information on population size, migration, land rights and so on was taken from administrative records available in each village. Therefore this information is very reliable and not based on possibly biased recall information. Interviews were held not only with the village leader but also with other persons who had good knowledge about the surveyed village. This again suggests that the quality of the data is quite high. Therefore, using this data set we can - in contrast to most of the macro-economic studies looking at geography and institutions - use variations in migration flows, institutions and the use of technologies over space *and* time to test our hypothesis. Identification of our proposed causal chain is also facilitated by the fact that variations in the data over time and space are generally very large (see also below).

This data set was complemented by land cover data derived from satellite images for 1981 and 2001 (for details see Erasmi and Priess, 2007). The information on forest cover was extracted from the land cover data, then aggregated from the pixel level with a resolution of 500x500m to the village level, and finally merged with the survey data.

3.2 Study context

3.2.1 The role of agriculture

The Lore Lindu region is rural. 87% of the 33,000 households living in the region depend economically on agriculture. 15% of the total area—excluding the National Park—is used for agricultural production. The rest of the area is mainly grasslands and forests. The principal food crop is sawah rice ('sawah' means wet rice field or paddy). Important cash crops are cocoa and coffee. Households mainly operate as smallholders and with very few exceptions there are almost no large plantations in the region (see Maertens *et al.*, 2006). Logging is mainly done informally (mainly for the conversion of forest land into cacao plots and not for selling the wood) and has then only a marginal importance for the local population.

3.2.2 Migration
During the past decades a significant part of the immigration into the study region has taken place from the south and middle-west of Sulawesi to the north-east of the Lore Lindu region, in particular to the districts of Palolo, Sigi Biromaru and Lore Utara. Some immigration has also taken place within so called 'transmigration programs', organized by the government mainly during the 1960s and 1970s. These programs resettled people in particular from the islands Java, Bali and Lombok in Central-Sulawesi. The places were chosen according to factors such as soil fertility and land availability (Faust, Maertens, Weber *et al*., 2003). Most of these migrants have today returned and the programs are seen as having failed. In our sample only three villages were affected by such migration programs during the period 1990-2001. We excluded these three villages from our sample. No village was affected by these programs during the 1980s.

3.2.3 Land rights
Land rights became more and more widespread over time in the Lore Lindu region. Some villages have had land rights since the early 1980s. Others introduced them only recently and a significant share of the villages is even today without such titles. In the villages where land titles exist they were in most cases established in the framework of the land certification schemes PRONA (*Proyek Operasi Nasional Agraria*) and PRODA (P*rogram Proyek Agraria Daerah*), which can provide ownership rights to land holders. These schemes were created by the Indonesian Government in 1981. However, no central or regional government beyond the village level ever enforced land titling and land redistribution in the study area using these mechanisms. PRONA/PRODA is rather an available scheme which can be used if there is a demand and the willingness to opt for land titling by villagers (Siagian and Neldysavrino, 2007). The costs of land titling under these schemes have to be borne by the villagers. The process of land titling needs collective action by the villagers and usually starts with a proposal to the land administration office. This implies that the process of land titling is - consistent with our hypothesis - demand and not supply driven. In villages where land rights were established outside of PRONA/PRODA-scheme, the titles were usually issued by village leaders, but they also usually provide ownership rights and not only management rights. Finally, it should be emphasized that formal and informal credit is available in the study region and that titled land is frequently used as collateral (Nuryartono, Schwarze and Zeller, 2004).

3.3 Estimation Strategy
First, we show that in the Lore Lindu Region agricultural technology is an important driver of agricultural household income. Although the empirical literature has shown many times that technology drives agricultural development, we think it is important to show that this link is also significant in our case. Therefore, we estimate using ordinary least-squares (OLS) the following equation:

$$Y_i = \mu + A_i^{'}\alpha + X_i^{'}\gamma + \varepsilon_i \,, \qquad (1a)$$

where the index *i* stands for the villages. Since the survey does not provide any information on village mean income or alike, we use the percentage of all houses (used for the purpose of human residence) in each village built from stone, bricks or cement. Throughout the Lore Lindu region having a stone house is seen as sign of prosperity and wealth and therefore that variable should be a good measure of the villager's living standard, *Y*. As can be seen in Table 1, the share of stone houses varies significantly in our data set and therefore should contain enough information about differences in well-being across villages and over time during the period we look at.[6]

As measures of agricultural technology (*A*) we use the existence of technical or semi-technical irrigation systems (usually village schemes), the construction of terraces as well as the use of fertilizer, pesticides, and improved seeds in the villages. Irrigation systems are only reported for villages with sawah rice fields. This concerns 70 out of the 77 villages and only those are included in the respective regressions. Likewise, terraces are only relevant for villages which have fields on steep slopes. This concerns 46 out of the 77 villages and again only those are included in the relevant regressions. One should also note that irrigation and terraces are rather long term investments, whereas fertilizer, pesticides and improved seeds are short term investments. For the latter land rights matter if land can be used as collateral for credit. In the study region this is the case and credits are an important device to finance inputs such as fertilizer in the pre-harvest period.

The vector *X* stands for additional control variables such as the male per agricultural land ratio in the village, the share of the village population between 19 and 45 years old (both measures of labor availability/abundance) and whether the village had connection to drinking water in 1990. We also control for adult education, which we measure by a dummy variable indicating whether the village had a primary school in 1980.[7]

In the basic specification the dependant variable is measured in 2001 and all explanatory variables, including technology, in the mid-nineties to allow for a time lag until these investments translate into higher incomes. Given that we have for most of our variables also retrospective information, we estimate Equation (1a) also with a panel fixed-effects estimator to control for all time-invariant unobserved village effects:

$$Y_{it} = \mu_i + A_{it}^{'}\alpha + X_{it}^{'}\gamma + \varepsilon_{it} \; . \qquad (1b)$$

At this stage, we do not address the issue of a possible simultaneity bias of technology and income, but we will return to this issue below. All we want to show in the estimation of the equation above is that there is, as it has been illustrated in many other contexts a number of times, a clear impact of technology on income. We are however not interested in producing a precise unbiased estimate of this effect, which we will deal with below. Central to our argument is rather to understand the process from geography to endogenous technological change itself.[8]

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[6] It should also be noted that stones and bricks are often made or collected in the surroundings of the villages and hence, no road is necessary to bring them. Also, heavy materials including stones are in the Lore Lindu region traditionally and still frequently transported using buffalos, donkeys, horses or motorcycles. Given that labor is very cheap, transport time plays no important role. In 2001, among the 15 villages without any stone house, 11 are not accessible by car and 4 are accessible. Conversely, 8 villages among the 19 villages which are not accessible by car, have a significant share of stone houses.

[7] We also used a few other control variables but they did not change the results. Due to the relatively small sample size, we cannot include a large set of control variables in a single estimation.

[8] The problem is also partly mitigated by using lagged technology in the income regression.

To identify the drivers of technology adoption and to test for the hypothesis we developed in Section 2, we estimate then step-by-step the impact of geography on migration, the impact of migration on land rights and the impact of land rights on technology.[9]
The causal impact of geography on migration is tested by estimating the following equation:

$$M_i = \lambda_I + G_i^{'}\beta_I + X_i^{'}\gamma_I + \upsilon_{Ii}, \tag{2}$$

Migration (M) is measured alternatively through two variables: first through the net immigration rate to each village over the period 1980 to 1990 and, second, through the logarithm of village population size in 1980. The former is measured as the difference of immigrating and emigrating households over a given period divided by the number of households in the village at the beginning of that period. It should be noted that we take here the household as the observation unit and not the individual, since rural-rural migration is in this context usually household migration. Village population size in 1980 is used as a proxy for immigration prior to 1980, but of course it includes past natural population growth as well. However, the latter should vary much less over the villages in the Lore Lindu region than migration. Therefore, we are confident that we capture with this variable reasonably well the effect of migration. As an additional regressor in the net-migration rate equation we use the population density in each village (population divided by total land area, excluding forest) in 1980 to control for the possibility that denser villages attract more or less migrants. Finally we control whether the village had a connection to drinking water and to electricity in 1980. Both might have an impact on immigration rates.

As measures of the geographic features of the villages (G) we use the share of agricultural land which is on steep slopes,[10] the year of the last drought as a measure of the frequency of droughts, the logarithm of the village altitude above sea level in meters and whether the village was accessible by car in 1980.[11]

To show that migration enhances land titling, we estimate the following equation:

$$R_i = \lambda_R + \beta_R M_i + X_i^{'}\gamma_R + \upsilon_{Ri}, \tag{3a}$$

where *R* is a dichotomous variable which takes the value one if legal government titles for land exist in village *i*. Control variables included in *X* are adult education and the availability

[9] In this paper we only model the causal chain as a series of OLS regressions. In Grimm and Klasen (2008), they are also examined IV estimators in the context of 2SLS and 3SLS estimators.
[10] A slope of more than 30° is considered as ‘steep’.
[11] The accessibility by car variable is not intended to measure current infrastructure access. By using historical road access, it is rather included as a measure of geographical remoteness and as a measure of geographic traits which make the construction of a road more or less easy.[11] The first roads in Central Sulawesi can be traced back to the colonial period and were indeed built where geography made it easy. Roads through rougher areas as for example the road to Barisi in the South-East of the Lore-Lindu region were built after 1980. In our dataset, accessibility by car in 1980 is negatively correlated with the share of agricultural land on steep slopes (correlation coefficient: -0.25), this also supports the view that this variable is a good measure of geography. See Grimm and Klasen (2008) fur further discussion on the relevance of these geographic variables.

of a credit program in the village during the past twenty years. Higher adult education might facilitate the village action needed to submit a proposal for land titling. The availability of a credit program might increase the demand for land titling such that land can be used as collateral. It should be noted that in all equations above and in those which follow, we operate with appropriate time lags that is we use migration prior to land titling, and land titling prior to technology adoption.

To control for village specific time invariant effects, we estimate Equation (3a) also with a panel fixed-effects estimator:

$$R_{it} = \lambda_{Ri} + \beta_R M_{it} + X_{it}^{'}\gamma_R + \upsilon_{Rit} \,. \tag{3b}$$

The last element in our causal chain is the hypothesized positive impact of land rights on technology adoption. We estimate the following equation:

$$A_i = \lambda_A + \beta_A R_i + X_i^{'}\gamma_A + \upsilon_{Ai} \,, \tag{4a}$$

where *A* stands for the same technology variables than in Equation (1). Again we estimate this equation also with a fixed-effects estimator:

$$A_{it} = \lambda_{Ai} + \beta_A R_{it} + X_{it}^{'}\gamma_A + \upsilon_{Ait} \tag{4b}$$

In the last step on the causal chain from geography to economic development, we revisit equation 1a) and estimate it using 2SLS, this time using geography as an instrument for technological change to deal with the problem of endogeneity. The particular specification we use is

$$Y_i = \mu + \hat{A}_i^{'}\alpha + X_i^{'}\gamma + \varepsilon_i$$

With

$$\hat{A}_i = \hat{\lambda}_G + \hat{\beta}_G G_i + X_i^{'}\hat{\gamma}_G \tag{5}$$

To test the impact of the causal chain on our deforestation rates between 1980 and 2001, we need to consider that some of the drivers of economic development (such as population pressure) have a direct impact on changes in the forest cover (FC) while others will have an indirect effect via economic development. The easiest way to capture this effect is to specify an OLS regression of forest losses at the village level on the drivers of economic development as well as economic development itself. This way one can then later identify (and quantify) direct effects of these factors using the OLS regression and consider indirect effects by examining the earlier regressions and the impact of economic development on deforestation.[12]

$$\Delta FC_i = \mu + G_i^{'}\alpha + \Delta M_i^{'}\beta + \Delta A(ld)_i^{'}\gamma + \Delta A(lb)_i^{'}\delta + \Delta Y_i^{'}\phi + \varepsilon_i \tag{6}$$

Where the delta-signs stand for change over time and A(ld) and A(lb) distinguish between land-saving (A(ld)) and labor-saving (A(lb)) technological change. We use the use of hand-

[12] See Klasen (2002) for an example of such a path analysis.

tractors as an indicator or labor-saving technological change and consider the changes in the package of modern seeds, fertilizer and pesticide use as one indicator of land-saving technological change, and the implementation of terraces as another one.[13] We will consider both the effect of economic growth (as shown in the equation) and, alternatively, the level of economic development as a factor influencing deforestation.

Table 1 presents the descriptive statistics of all key and the principal control variables in our analysis. As the statistics show, migration, land rights, technology adoption, and income growth show a sizable variation across villages and over time. Both should help to identify the parameters we are interested in. This spatial and intertemporal variation also shows that our region of analysis is a region under substantial transformation. Regarding forest loss, the forest cover in the villages is reduced by about 7 percentage points between 1980 and 2001 (from about 77% forest cover to 70%). This is somewhat smaller than the average for Indonesia and might also be affected by the protective function of the national park (see Schwarze et al. 2008). But also here there is significant variation and thus it is very interesting and important to understand the drivers of this differential in deforestation rates.

4. Results

4.1. Technology and economic development

Table 2 reports regressions of Equation (1a), i.e. of the share of houses built from stone, bricks or cement, our measure of economic development, on various variables of agricultural technology.

Columns (1)–(5) show that all used technology variables have a positive and highly significant impact on economic performance. Note that technology is measured in 1995 and the share of houses in 2001, taking into account the time it takes until new technologies can translate into durably higher incomes. Column (6) shows a regression in which we use irrigation and a dummy variable as technology variables - the latter taking the value one if the village used fertilizer, pesticides and improved seeds simultaneously[14] - and, as an additional control variable, the average share of households who emigrated from the village between 1995 and 2001. This latter variable is insignificant and thus makes it unlikely that the share of stone houses is strongly related to remittances coming from former villagers who migrated to the city.

Column (7) introduces as additional controls the ratio between the male population and the total size of agricultural land in 1995, the share of villagers between 19 and 45 years old, adult education approximated by the availability of a primary school in the village in 1980, and a dummy variable whether the village had in 1990 a drinking water system. Using the results of that regression we find that on average in a village with irrigation the share of stone houses is higher by almost 20 percentage points than in a village without irrigation. Using fertilizer, pesticides and improved seeds simultaneously increases this share again by 23 percentage points. This model explains more than 62% of the total variance in the data. We also estimated the models presented in columns (1)-(7) with maximum likelihood using a generalized linear model which might be more appropriate given that our dependant variable

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[13] As terraces are only relevant in some of the villages, we include a variable “terraces not relevant” as an additional regressor in order to be able to use the full data set. Please note also that regression (6) is focused on those villages where there was some forest cover in 1980; this led to the exclusion of three villages from the analysis.

[14] Note that these techniques are often adopted in a sequence, starting with irrigation, followed first by fertilizer, second by pesticides and last by improved seeds.

is a ratio bounded between 0 and 1. It turned out that the standard errors were nearly identical and hence we decided to stick to the simpler OLS model.

Given the relatively small sample size we are of course constrained by the number of control variables we can introduce in the model. However, given that we have for the relevant variables observations over at least four different points in time (usually 1980, 1990, 1995 and 2001), we can estimate our model also using fixed effects as specified in Equation (1b) and thus at least control for the influence of all time-invariant village effects (including the potential role played by geography). Columns (8)–(13) show that all results hold and that most of the technology coefficients have a similar magnitude.[15]

Of course all these results might be affected by a possible endogeneity of technology to income, although we mitigate this problem by using appropriate lags. In principle proper instruments are needed to solve the endogeneity problem satisfactory. We implement this below. At this stage of the analysis we simply conclude, as many other empirical studies have done before, that agricultural technology enhances rural development. This motivates us to look now at the determinants of technology adoption. We will show that technology is driven by migration-induced land rights.

4.2 The transmission channel from geography to technological change

As discussed in our theoretical part, we assume that technology can be traced back to geography, migration and land rights. Table 3 shows the results we obtain if we regress, according to Equation (2), migration on our four geographic variables. As mentioned above, migration is captured alternatively through two variables: first through the net immigration rate to each village over the period 1980 to 1990 and, second, through village population size in 1980. The latter is used as a proxy for settlements and immigration prior to 1980.

Regressions (1)-(4) in Table 3 show the effect of each single geographic variable on the net immigration rate at the destination. We control for population density in 1980. The regressions show that all geographic variables, except village altitude, have a significant impact on migration. The signs are always as expected. This also holds if we control for infrastructure in 1980, such as the availability of a drinking water system and electricity supply, which are both not significant (column (5)). An increase of the share of fields on steep slopes by 10 percentage points increases the net immigration rate by 1.2 percentage point. This seems to be a reasonable order of magnitude. If we use all geographic variables together only the share of agricultural land on steep slopes comes out as significant (column (6)). As columns (7)-(11) show, migration prior to 1980 seems in particular to be related to village altitude and to accessibility by car in 1980. It should be emphasized that these results are not affected by transmigration programs, since we excluded from our analysis, as mentioned above, the three villages which received immigrants through these programs during the observation period.

In a next step we first analyze using Equation (3a) whether, according to our hypothesis, migration has an impact on land rights. Columns (1)-(3) in Table 4 show that this is the case, whether we use only the two migration variables, whether we estimate the model with a linear probability model or a non-linear model and whether we include additional controls, such as our proxy for adult education and the availability of any credit program (governmental or not) in the village during the past 20 years. The results imply that an increase in the immigration

[15] In Grimm and Klasen (2008) we also estimate growth rather than level regressions with very similar results.

rate between 1980 and 1990 by 10% is associated with an increase in the probability of having land rights in the village by 1990 by 9.4%. An increase in the village population size in 1980 by 1% is in turn associated with 0.3% higher probability of having land rights in the village. The model explains almost 32% of the total variance in the data. Here again, we can estimate the same model with village fixed effects, as specified in Equation (3b). The results are shown in column (4). With respect to the OLS estimation the size of the coefficients changes a bit, but the signs remain the same and both coefficients of interest are significant. However, while this equation controls for all village-specific time-invariant determinants, we are not able to include credit or adult education as time-variant control variables, as these variables are only available for one time period.[16]

An implication of our theory is that geography should be a relevant instrument for migration. This is implemented in Grimm and Klasen (2008) confirming the results shown here.[17] The anecdotal evidence also supports the chain of causation we just examined. Villagers told us that prospective migrants looking for better living conditions select their destination according to geographic characteristics which are *a priori* favorable for agricultural productivity. In most cases migrants then buy or simply get land or a piece of forest to clear from the village leader. If this happens too frequently local villagers feel disadvantaged, possibly fear expropriation, also claim additional land or believe that the land given to the migrants belonged to them. This eventually initiates the process of land titling. Some villagers also reported that migrants come with forged land rights 'bought' from some higher 'state authority' and get possibly some land by bribing a local village leader. Again, such a process leads communities to demand land security and leads to a demand-driven implementation of land rights.

Now we deal with the question whether land rights enhance investment agricultural technologies. The results are presented in Table 5. The coefficients in columns (1)-(5) which are obtained by estimating Equation (4a) show that land rights in 1990 have a significant and positive impact on all technologies we consider. The impact is the highest in the case of irrigation systems, which is on average probably the most costly investment and with the construction of terraces the only long term investment we look at. The existence of land rights increases the probability of investing in an irrigation system by roughly 45%. The impact of land rights on the probabilities of finding one of the other investments is between 30% and 40%. We obtain similar results when we use a probit model for estimation (columns (6)-(8)) or when we add further control variables, such as our proxy for adult education, the

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[16] In additional specifications (available on request) we also add a dummy variable for villages planting cocoa as an additional regressor affecting land rights. As cocoa is a perennial cash crop requiring sizable upfront investments, the spread of cocoa might be an additional factor affecting land rights. Indeed this variable has a positive impact but does not reduce size and significance of the influence of the migration and population variables on land rights; thus our proposed causal chain is not driven by the expansion of cocoa in the area.

[17] To further underpin the causal direction from migration to land rights, we also estimate for different periods the reverse relationship, i.e. the impact of land rights on migration. In this case we use land rights status at the beginning of the period over which migration is observed. The results are shown in Grimm and Klasen (2008). All regressions show, whether we take the absolute or the net immigration rate, whether we look at the eighties or the nineties and whether we add further controls or not, land rights have never a significant impact on migration in the subsequent period. Hence, we conclude that migration and the induced population pressure on land resources enhance land rights and not the other way around.

availability of any credit program (governmental or not) in the village during the past 10 years or whether one can buy in the village any newspaper (columns (9)-(11)). That the availability of credit has a significant impact on technology underlines that one of the positive effect associated with land rights and technology use might be better access to financial resources if land can be used as collateral.[18]

The effect of land rights on technology adoption does also hold if we use a fixed-effect estimator (Equation (4b)) and thus control again for all time invariant village effects. Although as columns (15)-(17) show the coefficients of land rights are a bit smaller than with the OLS estimator, they remain all significant.

One might argue that migration has a direct (and not indirect) impact on technology adoption. Such a link could exist if migrants bring new technologies to the villages. For example, there is evidence that Bugis (or Buginese, an ethnically Malay, nomadic tribe from the south-western 'leg' of Sulawesi) are well experienced in growing coffee. While we do not deny this link — in fact it is complementary to our approach — we claim that this is not the dominating force. We tested this link also empirically by estimating a regression of technology use in 1995 on the net migration rate between 1980 and 1990.[19]

4.3 Revisiting the technology-growth link

Now that we have demonstrated the causal link from geography via migration and land rights to technological change, we can use this insight to control for the endogeneity of the regressions shown in Table 2 by using geography as an instrument for technological change. This is done in Table 6 where we consider regressions investigating the level of income in 2001 as well as the growth of incomes between 1995 and 2001 (both proxied by our housing variable). The first stage regression shows that geographic factors indeed have a significant influence on technological change and thus are clearly relevant instruments. The second stage regression continues to show a large and significant influence of technological change on economic development in the villages, regardless of whether we consider levels or growth rates. While we cannot conclusively show that our instruments fulfill the exclusion restriction, an overidentification restriction test supports the validity of the instruments and the geographical variables no longer have a separate significant influence on economic growth if included in addition in the second stage regression.[20]

4.4 Modeling the determinants of deforestation

We now turn to investigating the determinants of deforestation in our village data set. In Table 7 we show two specifications which only differ in their use of economic growth (column 1) or income levels in 2001 (column 2) as a covariate. The results show that many of the drivers of economic development indeed also promote deforestation. Among the geography variables, good early infrastructure access (access to car in 1980) and low elevation not only help induce economic development, but they also have a direct effect of promoting deforestation. It thus appears that in locations that are accessible and in the

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[18] Our data does not allow testing the direct impact of land rights on credit use, since only credit availability in the village is known and not the percentage of households which actually used a credit. However, as mentioned above, Nuryartono, Schwarze and Zeller (2004) report that land is frequently used as collateral in the study area.

[19] The results are available on request.

[20] Results are available on request.

lowlands, forest conversion is accelerated. Similar observations relate to population pressure which also helped promote technological change but also has a direct and sizable effect in promoting deforestation. In contrast to these trade-offs, infrequent droughts appear to both promote technological change *and* are associated with reduced deforestation. Here two effects might play a role. First, it could be the case that the absence of severe drought shocks reduce encroachment into the rainforest during such shocks to make up for lower yields.[21] Second, lower drought frequency might alter crop choice and favor irrigated rice over the more drought-resistant but extensively farmed cocoa (see Maertens et al. 2006).

The effects of technology also present some trade-offs. While labor-saving (and thus land-using) technology is, as expected associated with higher deforestation, the package of modern seeds, fertilizers, and pesticides also is associated with higher levels deforestation in the villages. It appears that the processes that generate better technologies and higher incomes encourage further encroachment. Only the implementation of terracing leads to lower deforestation rates. This shows that more labor-intensive paddy rice production indeed has a forest preserving effect, which is in line with Maertens et al. (2006).

Lastly, it is most interesting to see that, conditional on all other included variables, income growth is associated with significantly lower deforestation rates. Thus a 'pure' development effect in the sense of rising prosperity appears to lower deforestation. This might be related to a falling dependence on the forest encroachment, and agriculture in general, for a livelihood, thus reducing the need to convert forest land. Interestingly, this effect is only true for economic growth, but not income levels in 2001 (or earlier).[22] Thus it is not a pure 'prosperity' effect, but rather an effect of rising prosperity.

Given the fact that many drivers of economic development seem to promote deforestation while economic development itself has a forest conserving effect, one can use the regressions in tables 3-7 to quantify the net effect of these drivers. This has to be done with some caution as such a quantitative assessment is focused on the point estimates (without considering the sizable standard errors) and it neglects the fact that these point estimates are quite sensitive to included and excluded control variables and thus depend on the specification used. It turns out that the forest-clearing direct effect is always larger than the forest-conserving indirect effect of promoting economic development. Thus, on net, population growth, the modern technology package, better accessibility and lower elevation all end up furthering deforestation despite their forest-conserving impact on economic development; but the size of the net effect various considerably and is particularly large in the case of population growth and road access, while much smaller it the case of low elevation and the modern technology package. Thus for these factors, a trade-off remains between clearing the forest and promoting economic development; in contrast this is not the case for terracing and lower drought frequency, where a win-win situation appears to be feasible.

6. Concluding remarks

As we argued in the beginning of our paper there is considerable debate about the main drivers of technological change and economic development in a poor rural economy. The

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[21] In the time period under investigation, the role of the severe El Nino Southern Oscillation event in 1998 which led to a severe drought in Indonesia might have played a significant role.

[22] We also tried specifications with income levels in 1980, 1990 and 1995. It was never a significant determinant of deforestation.

literature emphasizes among other things geography, population pressure and institutional change as the important determinants without however establishing links between these factors. Our hypothesis was that a favorable geography, such as easily cultivable land and a low frequency of droughts attract migration, which in turn creates pressure on land. This provides an incentive for villagers and village leaders to opt for land rights which in turn provide an incentive to invest in agricultural technology, which in turn promotes economic development. We tested this hypothesis empirically using longitudinal data on villages situated on the Indonesian Island Sulawesi. Employing a system of nested equations and controlling for potential endogeneity problems and village fixed effects, we found strong empirical support for our hypothesis.

We also find, however, that the many of the factors that promote economic development also appear to promote deforestation.. These trade-offs, as well as the identified win-win situations, require more careful scrutiny in future work where we hope to integrate another round of the village surveys with more recent data on deforestation in our analysis.

References

Acemoglu D., S. Johnson and J.A. Robinson (2001), The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91 (5): 1369-1401.

Angelsen, A. 1999. Agricultural expansion and deforestation: Modeling the impact of population, market forces, and property rights. Journal of Development Economics 58: 195-218.

Besley T. (1995), Property Rights and Investment Incentives: Theory and Evidence from Ghana. *Journal of Political Economy*, 103 (5): 903-937.

Binswanger, H., K. Deininger, and G. Feder (1995), Power, Distortions, Revolt and Reform in Agricultural Land Relations. In J. Behrman and T. Srinivasan. (eds.) *Handbook of Development Economics,* Volume Ill.: Elsevier North Holland: Amsterdam.

Boserup E. (1981), *Population and technological change: a study of long term trends*. University of Chicago Press: Chicago.

Brassselle A.-S., F. Gaspart and J.-P. Platteau (2002), Land tenure security and investment incentives: puzzling evidence from Burkina Faso. *Journal of Development Economics*, 67: 373-418.

Broeck, K. vd., C. Newman and F. Tarp (2007) Land Titles and Rice Production in Vietnam. Trinity Economic Papers No. 1207, Trinity College Dublin.

Byerlee, D., X. Diao and C. Jackson (2005), Agriculture, Rural Development, and Pro-poor Growth. Country Experiences in the Post-Reform Era. Agriculture and Rural Development Discussion Paper 21, World Bank, Washington D.C.

Datt, G. and M. Ravallion (1996), How important to India's poor is the sectoral composition of economic growth? *World Bank Economic Review*, 10 (1): 1-25.

Datt, G. and M. Ravallion (2002), Why has economic growth been more pro-poor in some states of India than others? *Journal of Development Economics*, 68: 381-400.

Deininger, K. (2003), *Land Policies for Growth and Poverty Reduction*. World Bank Policy Research Report. World Bank/Oxford University Press: Washington.

Diamond, J. (1997), *Guns, Germs and Steel: The Fates of Human Societies*. W. W. Norton & Company: New York.

Easterly W. and R. Levine (2003), Tropics, Germs, and Crops: How Endowments influence economic development. *Journal of Monetary Economics*, 50 (1): 3-39.

Faust, H, M. Maertens, R. Weber, N. Nuryartono, T. van Rheenen, and R. Birner (2003), Does Migration lead to Destabilization of Forest Margins? STORMA Discussion Paper Series No. 11, STORMA, University of Göttingen.

Gallup J.L., J.D. Sachs and A.D. Mellinger (1998), Geography and Economic Development. NBER Working Paper 6849, NBER Cambridge, MA.

Grimm, M., S. Klasen and A. McKay (2007), *Determinants of Pro-Poor Growth*. London: Palgrave-Macmillan.

Grimm, M. and S. Klasen (2008) Geography versus Institutions at the Village Level. *CESifo Working Paper* No. 2259.

Hall R.E. and C.I. Jones (1999), Why Do Some Countries Produce So Much More Output Per Worker Than Others? *Quarterly Journal of Economics*, 114 (1): 83-116.

Hayami Y. and V.W. Ruttan (1985), *Agricultural Development*. 2nd ed. Johns Hopkins University Press: Baltimore.

Jacoby H.G. and B. Minten (2007), Is Land Titling in Sub-Saharan Africa Cost-Effective? Evidence from Madagascar. *World Bank Economic Review*, 21 (3): 461-485.

Klasen, S. (2002). Low schooling for girls, slower growth for all? *World Bank Economic Review* 16: 345-373.

Klasen S. and T. Nestmann (2006), Population, Population Density and Technological Change. *Journal of Population Economics*, 19: 611-626.

Kremer, M. (1993), Population Growth and Technological Change: 1,000,000 B.C. to 1990. *Quarterly Journal of Economics*, 108 (3): 681-716.

Krugman, P. (1991), *Geography and Trade*. Leuven University Press: Leuven/Cambridge MA.

Maertens M., M. Zeller and R. Birner (2006), Sustainable agricultural intensification in forest frontier areas. *Agricultural Economics*, 34: 197-2006.

Migot-Adholla, S., P. Hazell and B. Blarel and F. Place (1991), Indigenous Land Rights Systems in Sub-Saharan Africa: A Constraint on Productivity? *World Bank Economic Review*, 5 (1): 155-175.

Mundlak, Y., D.F. Larson and R. Butzer (2002), Determinants of Agricultural Growth in Indonesia, the Philippines, and Thailand. Mimeo, University of Chicago and World Bank.

North, D.C. (1990), Institutions, Institutional Change and Economic Performance. Cambridge University Press: New York.

Nuryartono, N., S. Schwarze and M. Zeller (2004), Smallholders access to credit and its impact on the adoption of agricultural technology: Evidence and lessons from agriculture practices in the Vicinity of the Lore Lindu National Park, Central Sulawesi, Indonesia. Mimeo, Institute of Rural Development, University of Göttingen.

Place, F. and P. Hazell (1993), Productivity Effects of Indigenous Land Tenure Systems in Sub-Saharan Africa. *American Journal of Agricultural Economics*, 75 (1): 10-19.

Ravallion, M. and S. Chen (2007), China's (uneven) progress against poverty. *Journal of Development Economics*, 82 (1): 1-42

Rodrik, D., A. Subramanian and F. Trebbi (2004), Institutions Rule: The Primacy of Institutions over Geography and Integration in Economic Development. *Journal of Economic Growth*, 9: 131-165.

Rozelle, S. and G. Li. (1998), Village Leaders and Land-Rights Formation in China. *American Economic Review*, 88: 433-438.

Sachs, J.D. (2003), Institutions don’t role: The effects of Geography on Per Capita Income. NBER Working Paper 9490, NBER, Cambridge.

Siagian Y. and Y. Neldysavrino (2007), Collective Action to Secure Land Management Rights for Poor Communities. Governance Brief, May, No. 35, Center for International Forestry Research, Bogor, Indonesia.

Stock, J.H. and M. Yogo (2004), Testing for Weak Instruments in Linear IV Regression. Mimeo, Department of Economics, Harvard University.

Thurlow, J. and P. Wobst (2007), The Role of Agriculture in Pro-Poor Growth: Lessons from Zambia. In Grimm, M., S. Klasen and A. McKay (eds.), *Determinants of Pro-Poor Growth*. London: Palgrave-Macmillan.

Weber, R. and H. Faust (2006), Kulturelle Aspekte der Landnutzung in Indonesien. Einflüsse von Migration, Ethnizität und Wissen auf bäuerliche Entscheidungsprozesse im Hochland Zentralsulawesis. *Geographica Helvetica*, 61 (4): 237-245.

World Bank (2007), *World Development Report 2008. Agriculture for Development.* World Bank, Washington D.C.

Zeller M., S. Schwarze and T. van Rheenen (2002), Statistical Sampling Frame and Methods Used for the Selection of Villages and Households in the Scope of the Research Program on Stability of Rainforest Margins in Indonesia. STORMA Discussion Paper Series No. 1, STORMA, University of Göttingen.

Table 1
Descriptive statistics of used variables

	Invariant	1980	1990	1995	2001
Development					
Share of houses built from stone		0.054	0.125	0.214	0.317
		(0.107)	(0.180)	(0.235)	(0.303)
Deforestation Rate (% 1981-2001)	0.073				
	(0.056)				
Geography					
Share of agr. land on steep slopes	0.156				
	(0.259)				
Number of years to last drought	9.299				
	(10.664)				
Village accessible by car		0.597	0.714	0.727	0.753
Altitude in m (level above sea)	647.3				
	(339.9)				
Demography					
Net immigration rate of housh.[a)]		0.021	0.021	0.014	
		(0.131)	(0.066)	(0.100)	
Village population size		713.5	913.8	987.2	1101.9
		(694.1)	(821.1)	(857.3)	(876.4)
Change in Household Number (%)	1.34				
	(1.65)				
Land rights		0.091	0.351	0.403	0.636
Technology use					
Irrigation system available [b)]		0.200	0.329	0.371	0.514
Fertilizer use		0.403	0.584	0.649	0.727
Pesticides use		0.455	0.636	0.753	0.948
Improved seeds use		0.286	0.416	0.545	0.870
Terraces building [c)]		0.065	0.217	0.283	0.523
Other control variables					
Male population per ha land			0.971	1.053	
			(0.583)	(0.636)	
Share of population 19-45 years					0.380
					(0.088)
Population density (pop per ha)		1.205	1.484	1.652	1.829
		(0.919)	(1.041)	(1.173)	(1.187)
Primary school in village		0.857	0.961		0.987
Newspaper in village					0.052
Drinking water connection		0.416	0.455		0.896
Electricity connection		0.104	0.247		0.922
Doctor available		0.169	0.338		0.442
Credit available [d).]		0.901	0.922		0.909

Kommentar [l1]: Add hand tractors

Source: CRC STORMA A3 Village Survey.
Notes:
1. Standard deviations in parentheses where appropriate.
2. [a)] The net immigration rate relates to the periods 1980-1990, 1990-1995 and 1995-2001.
3. [b)] Information about irrigation is only available in villages cultivating sawah rice (mean computed over those villages, i.e. 70 out of 77).
4. [c)] Terraces are only relevant for villages with steep slopes (mean computed over those villages, i.e. 46 out of 77).
5. [d)] The 'credit available' variable is here shown for the periods 'past 20 years', 'past 10 years' and in 2001.

Table 2
The effect of technology on development
OLS and FE regressions

	OLS regressions. Dependent Variable: Share of stone houses in 2001						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Irrigation	0.379					0.303	0.191
1995 [a)]	(0.066)***					(0.097)***	(0.069)***
Fertilizer		0.395					
1995		(0.046)***					
Pesticides			0.313				
1995			(0.050)***				
Improved				0.304			
seeds 1995				(0.060)***			
F., P. & S.						0.204	0.234
1995 [c)]						(0.097)**	(0.069)***
Terraces					0.265		
1995 [b)]					(0.087)***		
Emigration						0.364	
1990-2001						(1.463)	
Male pop.							0.039
per ha. 1995							(0.027)
Population							0.361
share 19-45							(0.261)
Prim. school							0.080
1980							(0.083)
Drink. water							0.171
conn. 1990							(0.060)***
Constant	0.185	0.062	0.082	0.149	0.194	0.101	-0.181
	(0.036)***	(0.022)***	(0.028)***	(0.038)***	(0.044)***	(0.045)***	(0.147)
R^2	0.356	0.394	0.204	0.252	0.185	0.536	0.620
N	70	77	77	77	46	46	70

	FE regressions. Dependent Variable: Share of stone houses [d)]					
	(8)	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**
Irrigation [a)]	0.190					0.143
	(0.031)***					(0.127)***
Fertilizer		0.139				
		(0.026)***				
Pesticides			0.097			
			(0.018)***			
Improved seeds				0.145		
				(0.019)***		
F., P. & S.						0.127
						(0.029)***
Terraces [b)]					0.072	0.040
					(0.013)***	(0.016)**
R^2	0.238	0.256	0.167	0.236	0.076	0.425
N	280	308	308	308	184	160

Source: CRC STORMA A3 Village Survey.
Notes:
1. Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%.
2. Variable explanations see Section 4.
3. [a)] Information about irrigation is only available in villages cultivating sawah rice.
4. [b)] Terraces are only relevant for villages with steep slopes.
5. [c)] ‘F., P. & S.’ stands for the simultaneous use of fertilizer, pesticides and improved seeds.
6. [d)] In the FE regressions stone houses and technology in 1980, 1990, 1995 and 2001 are used.

Table 3
The effect of geography on population
OLS regressions

	Dependent Variable: Net immigration rate of households between 1980 and 1990					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Share steep slopes	-0.114 (0.058)*				-0.114 (0.063)*	-0.124 (0.060)**
Years to last drought		0.002 (0.001)*			0.002 (0.001)	
Ln altitude above sea			0.004 (0.011)		0.024 (0.021)	
Access. by car in 1980				0.059 (0.032)*	0.045 (0.038)	
Pop. density 1980	-0.006 (0.017)	-0.004 (0.015)	0.000 (0.016)	-0.011 (0.017)	-0.002 (0.019	-0.007 (0.017)
Drink. water conn. 1990						-0.026 (0.032)
Electricity conn. 1990						0.068 (0.049)
Constant	0.047 (0.028)*	0.009 (0.039)	-0.008 (0.073)	-0.001 (0.029)		0.053 (0.030)*
R^2	0.053	0.020	0.001	0.048	0.111	0.087
N	77	77	77	77	77	77

	Dependent Variable: Ln village population size in 1980				
	(7)	**(8)**	**(9)**	**(10)**	**(11)**
Share steep slopes	-0.268 (0.339)				0.166 (0.313)
Years to last drought		0.003 (0.008)			-0.004 (0.007)
Ln altitude above sea			-0.470 (0.089)***		-0.382 (0.099)***
Access. by car in 1980				0.668 (0.163)***	0.392 (0.186)**
Constant	6.335 (0.103)***	6.267 (0.118)***	9.230 (0.556)***	5.891 (0.126)***	8.457 (0.677)***
R^2	0.009	0.001	0.286	0.188	0.331
N	77	77	77	77	77

Source: CRC STORMA A3 Village Survey.
Notes:
1. Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%.
2. Variable explanations see Section 4.

Table 4
The effect of migration on land rights
OLS, Probit, FE and IV regressions

	Land rights in 1990			Land rights
	OLS regression (1)	**Probit regression (2)**	**OLS regression (3)**	**FE regression[a)] (4)**
Immigration (1980-1990)	0.988 (0.334)***	4.003 (1.664)**	0.936 (0.353)**	0.584 (0.280)**
Ln pop. (1980)	0.304 (0.055)***	1.019 (0.278)***	0.314 (0.059)***	0.596 (0.144)***
Prim. school 1980			-0.165 (0.125)	
Credit avail. past 20 y.			0.143 (0.180)	
Constant	-1.564 (0.338)***	-6.973 (1.799)***	-1.613 (0.374)***	-3.471 (0.958)***
R^2	0.295		0.316	0.185
N	77	77	77	231

Source: CRC STORMA A3 Village Survey.
Notes:
1. Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%.
2. Variable explanations see Section 4.
3. [a)] In the FE regressions land rights status and population in 1990, 1995 and 2001 are used. The net migration rate relates to the periods 1980-1990, 1990-1995, 1995-2001.

Table 5
The effect of land rights on technology
OLS, Probit, and Fixed Effects Regression

	Dependant variables: Technology use in 1995						
	OLS regression					Probit regression	
	Irrigation[a)]	**Fertilizer**	**Pesticides**	**Imp. Seed.**	**Terraces[b)]**	**Irrigation [a)]**	**Fertilizer**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Land rights	0.445	0.369	0.323	0.244	0.294	1.205	1.170
1990	(0.114)***	(0.094)***	(0.078)***	(0.114)**	(0.164)*	(0.335)***	(0.368)***
Constant	0.209	0.520	0.640	0.460	0.206	-0.809	0.050
	(0.063)***	(0.072)***	(0.069)***	(0.071)***	(0.071)***	(0.217)***	(0.178)
R^2	0.198	0.136	0.128	0.055	0.082		
N	70	77	77	77	46	70	77

	Dependant variables: Technology use in 1995				Dep. Variables: Technology use in 2001		
	Probit	OLS regression			OLS regression		
	Terraces [b)]	**Irrigation [a)]**	**Fertilizer**	**Terraces [b)]**	**Irrigation [a)]**	**Fertilizer**	**Terraces [b)]**
	(8)	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**
Land rights	0.821	0.376	0.322	0.274	0.309	0.321	0.293
1990	(0.441)*	(0.116)***	(0.093)***	(0.187)	(0.133)**	(0.110)***	(0.172)*
Prim. School		0.119	-0.059	0.049			
1980		(0.145)	(0.139)	(0.184)			
Credit avail.		0.317	0.438	0.231			
past 10 y.		(0.093)***	(0.188)**	(0.086)**			
Newspaper		0.463	0.207	-0.005			
available		(0.121)***	(0.095)**	(0.411)			
Extension w.					0.224	0.270	0.023
2001					(0.136)	(0.117)**	(0.180)
Constant	-0.821	-0.182	0.172	-0.049		0.320	0.340
	(0.246)	(0.155)	(0.225)	(0.184)		(0.098)***	(0.130)**
R^2		0.291	0.211	0.098	0.157	0.258	0.091
N	46	70	77	46	70	77	46

Table 6
Geography, Technology and Economic Development: IV Regression

	Growth (95-01) **(1)**	**Income Level (2001)** **(2)**
Second Stage		
Technology: Seeds,	0.038	0.745
Fert., Pest. 1995	(0.008)***	(0.134)***
Primary school 1980	-0.002	0.016
	(0.007)	(0.153)
Water access 1980	0.007	0.099
	(0.005)	(0.087)
Constant	-0.003	-0.116
	(0.008)	(0.150)
First Stage: Technology		
Primary school 1980	0.061	0.061
	(0.154)	(0.154)
Water access 1980	0.078	0.077
	(0.143)	(0.143)
Ln altitude	-0.0003	-0.0003
above sea	(0.0002)*	(0.0002)*
Number of years to	0.010	0.010
last drought	(0.006)**	(0.006)**
Access. by	0.271	0.271
car in 1980	(0.133)**	(0.133)**
Share of fields on	0.167	0.167
steep slopes	(0.218)	(0.218)
Constant	0.432	0.432
	(0.301)*	(0.301)*
N	73	73

Source: CRC STORMA A3 Village Survey.
Notes:
1. Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%.
2. Variable explanations see Section 4.
3. Technology in the first stage refers to the share of villages having adopted the package of improved seeds, fertilizers, and pesticides in 1995.

Table 7
Determinants of Deforestation

	Forest Loss (80-01)* (1)	Forest Loss (80-01) (2)
Geography		
Ln. altitude above sea	-0.00008	-0.00007
	(0.00003)***	(0.00003)***
Years to last drought	-0.0010	-0.0011
	(0.0004)**	(0.0004)***
Access by car in 1980	0.0426	0.0388
	(0.0130)***	(0.0125)***
Demography		
Growth of # of households	0.0123	0.0130
	(0.0018)***	(0.0023)***
Technology		
Labor-Saving: Hand-tractors per hh in 1980	0.0436	0.0407
	(0.0155)***	(0.0154)***
Land-Saving: Change in seeds, Fert. Pest. (80-01)	0.0155	0.1466
	(0.0101)*	(0.0109)*
Land-Saving: Change in Terraces (80-01)	-0.0209	-0.0189
	(0.0113)**	(0.0145)*
Terracing not relevant	-0.0077	-0.0123
	(0.0135)	(0.0145)
Economic Development		
Economic Growth (81-01)	-1.1214	
	(0.6391)**	
Income (2001)		-0.0211
		(0.0246)
Constant	0.1624	0.1486
	(0.0335)***	(0.0362)***
N	70	70
R2	0.50	0.49

Source: CRC STORMA A3 Village Survey.
Notes:
4. Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%.
5. Variable explanations see Section 4.
6. A positive coefficient means that this factor contributed to higher rates of deforestation.

Kommentar [I2]: These effects are very small, is that really in ln.

Kommentar [I3]: There are only three villages with a hand tractor in 1980, this is a bit problematic. Is it possible to use "plough". This would still be labor-saving compared to a hoe.