Geography vs. Institutions at the Village Level

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CESIFO WORKING PAPER NO. 2259
CATEGORY 5: FISCAL POLICY, MACROECONOMICS AND GROWTH
MARCH 2008

CESifo *Working Paper No. 2259*

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Abstract

There is a well-known debate about the roles of geography versus institutions in explaining the long-term development of countries. These debates have usually been based on cross-country regressions where questions about parameter heterogeneity, unobserved heterogeneity, and endogeneity cannot easily be controlled for. The innovation of Acemoglu, Johnson and Robinson (2001) was to address this last point by using settler mortality as an instrument for geography-induced endogenous institutions and found that this supported their line of reasoning. We believe there is value-added to consider this debate at the micro level within a country as particularly questions of parameter heterogeneity and unobserved heterogeneity are likely to be smaller than between countries. Moreover, at the micro level it is possible to identify more precise transmission mechanisms from geography via institutions to economic development outcomes. In particular, we examine the determinants of economic development across villages on the Indonesian Island of Sulawesi and find that geography-induced endogenous emergence of land rights is the critical institutional link between geographic conditions and technological change. We therefore highlight and empirically validate a new transmission channel from endogenously generated institutions on economic development.

JEL Code: K11, O12, Q12.

Keywords: geography, migration, land rights, institutions, technology adoption, agricultural development, Indonesia.

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Version: February 2008
This paper draws on data from the German-Indonesian collaborative research centre referred to as *Collaborative Research Center* 552: STORMA ("Stability of Rainforest Margins"). The project is carried out by the Universities of Göttingen and Kassel in Germany, the Agricultural University of Bogor and the Tadulako University of Palu in Indonesia. Funding by the German Research Foundation (DFG) is greatly acknowledged. We also thank sub-project A3 for kindly granting access to the village survey. The paper benefited from comments by Chairil Anwar, Denis Cogneau, Stefan von Cramon Taubadel, Heiko Faust, Cecilia Garcia- Penalosa, Melanie Grosse, Michael Lipton, Jean-Philippe Platteau, Mark Rosenzweig, Paul Schultz, Stefan Schwarze, Chris Udry, and Walter Zucchini as well as participants at conferences and seminars in Maastricht (UNU-MERIT), Göttingen (VfS Development Economics), IDS Sussex, Berlin (PEGNet), Yale University Development Workshop, ZEF Bonn, ISS The Hague, Paris (EUDN) and at the OECD Development Centre in Paris. Any remaining errors and omissions are, of course, entirely our own.

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 being converted to agricultural uses.

When studying the literature on determinants of agricultural productivity growth, several seemingly competing hypotheses are invoked. A first strand of the literature argues that geography, such as climate, landform and soil quality of the cultivated land area, is the dominant factor in determining agricultural productivity and the techniques to use (see e.g. Diamond, 1997; Gallup, Sachs and Mellinger, 1998). A second strand of the literature emphasizes population size and density, and associated pressure on land, inducing technological improvements or the adoption of new existing technologies (see e.g. Boserup 1981; Kremer, 1993; Klasen and Nestmann, 2006). A third strand of the literature emphasizes the role of endogenous institutional change as critical for improvements in agriculture (North, 1990; Hayami and Ruttan, 1985). Within that 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.

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 and economic development. In short, endogenously generated institutional change is the core element of our transmission channel from geography to technological change.

In this sense, our argument is a "micro version" of the well-known "*Institutions Hypothesis*", which tries to explain long run differences in economic development across countries with lasting differences in the quality of endogenously generated institutions. Acemoglu, Johnson and Robinson (2001), who are some of the principal advocates of this hypothesis, use this argument to explain the differential economic performance of countries. They argue that Europeans adopted very different colonization policies in different colonies, resulting in different institutions across the developing world. In places where Europeans faced high mortality rates (i.e. unfavorable geographic conditions), they could not settle and were more likely to set up extractive institutions. In places where they faced relatively low mortality rates, they settled and set up institutions favorable for individual entrepreneurship. These institutions have persisted to the present, so the argument, and explain to a large extent differences in economic development across countries. In this study, geography has no direct impact on economic development, once geography-induced institutions are taken into account.

Our study shows how exactly geography-induced institutional change could have caused economic development. Our objective is not to rule out completely a direct influence of geography on economic development, but to show a mechanism which might be hidden in the more macro-economic literature supporting the institutions hypothesis. We use an original village level data set, which was collected in 2001 in 80 villages situated close to or in the Lore Lindu National Park on the Indonesian Island of Sulawesi, where land at the rainforest margin has been progressively converted to agricultural land. Although, the villages we analyze share many common features and are spread over a relatively limited area, they also differ significantly with respect to their level and the dynamic of well-being, geography, technology and institutions. Some of these villages stagnate, while others developed fast in the past twenty years. Our analysis will reveal at least one explanation why this was the case.

The reminder of our paper is organized as follows. In the next section, we develop our theoretical argument. In Section three we present our data and provide the relevant information about our study area. In Section four we lay out our estimation strategy. In Section five we present our results and provide many robustness tests. In Section six we draw some policy implications and conclude.

2. A micro version of the "Institutions Hypothesis"

There is well-known debate about the respective roles of geography versus institutions in explaining the long-term development of countries. While some (e.g. Diamond, 1997; Gallup *et al.*, 1998; Sachs, 2003) argue that geographic factors, such as location in the tropics, being land-locked and distant from markets, or being susceptible to particular diseases have a direct impact on reducing the economic potential or regions, 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 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 developmentfriendly institutions in settler economies. Through historical persistence, these institutions still heavily influence the economic fate of nations today.

These debates have usually been based on cross-country regressions where questions about parameter heterogeneity, unobserved heterogeneity, and endogeneity cannot easily be controlled for. Moreover, these studies cannot say much how exactly institutions shaped the pattern of economic development. Typically used proxies for institutions such as “a measure of social infrastructure” (used in Hall and Jones, 1999), “the risk of expropriation of private foreign investment by government” (used in Acemoglu *et al.*, 2001) or Kaufmann’s institutions index (used in Easterly and Levine, 2003) are rather broad measures and it is difficult to say how they influenced decisions of workers, farmers and entrepreneurs.

Therefore, we believe there is value-added to consider the institutions hypothesis at the micro level within a country as this 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 on the village level is driven by geography. Thus, similar to Acemoglu *et al.* (2001) and others we attribute to geography an indirect role on economic development through its effect on institutions.

The causal chain 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. Villages with relatively high immigration in turn experience population pressure on increasingly scarce land resources. Land pressure induces villages to regulate their land market and to opt for land rights, which in turn increase investments in agricultural technology. Eventually, agricultural technology enhances agricultural growth and economic development. In what follows, we discuss each element of that causal chain in more detail.

In a context in which rural-rural migration is still widespread it is reasonable to believe that prospective migrants select their destination according to its geographic traits. The landform, the soil quality and rainfall are certainly factors which will be considered by the migrant as they may determine the return on agricultural activity. For instance fields on steep slopes require much more labor input for the same return than flat fields. They are also much more difficult to irrigate. Hence, it is very likely that in a highly agrarian economy labor moves, all else equal, to localities where the geography is favorable for agriculture.

In the absence of endogenous institutional and technological change, such a process of migration could lead to an equilibrium where returns are equalized across villages, and thus villages would converge to similar income levels. But we are arguing that the endogenous institutional and technological change creates opposing diverging forces where the places with favorable geography will also experience favorable technological change and slow down or entirely prevent such convergence processes.[1]

Increasing population density and associated land pressure is likely to lead to tensions and conflict about the distribution of land providing an incentive for villagers to opt for land management institutions and in particular for land rights which clarify property relations and reduce tensions and conflicts over land distribution. “Land rights” can take very different forms according to the level of security they promise as discussed in detail by Braselle *et al.*

[1] In this sense our work is also related to the insights from the New Economic Geography literature on the agglomeration versus congestion dynamics (see e.g., Krugman, 1991). Moreover, even if one posits that migration generates long-run convergence processes we would only be observing part of this long-run transition.

(2002). Here we mean transfer rights, which include rights to sell, rent, bequeath, pledge, mortgage and gift the land, which is registered and protected by a legal title.

Once land rights are established, we assume that given this security in the right to use the land durably increases investments in that land. This may happen for three reasons (see e.g. Brasselle *et al*., 2002). First, tenure security increases the return on long-term land improvements and conservation measures and therefore farmers have a higher incentive to undertake investments (the '*assurance effect*'). Second, with land rights it is easier to sell or rent the land and thus to realize improvements made through investments enhancing such investments (the '*realizability effect*'). Third, land titles allow to use land as a collateral, which in turn facilitates access to credit and enables the farmer to finance investments, short-term such as fertilizer and pesticides (which have often to be financed in the pre-harvest period) and long-term such as tree planting, the construction of terraces or an irrigation system (the '*collateralisation effect*').

Despite their theoretical plausibility the empirical evidence regarding the existence of these effects is rather mixed. Besley (1995) for instance, looked at two regions in Ghana and confirmed only for one of them the positive impact of land rights on investment. Braselle *et al.* (2002) analyze a region in Burkina Faso and also do not find any systematic influence of land tenure security on investment. Jacoby and Minten (2007) analyze the case of Madagascar and conclude similar to the former study that having a land title has no significant effect on plot-specific investment. Migot-Adholla, Hazell, Blarel *et al.* (1991) and Place and Hazell (1993) are other pessimistic examples for Sub-Saharan Africa. However, Deiniger (2003, Chapter 2) provides a number of examples in particular, but not only, from Asia and Latin America where land titles increased investment. Broeck, Newman and Tarp (2007) is another recent study which found a positive impact in Vietnam, but the authors emphasise that the positive effect only arises if land titles are exclusive and if they provide also ownership rights and not only user rights. More generally, formalization seems particularly attractive where traditional tenure systems are weak, where the return on investment in land is high and where collaterized lending exists. These conditions are likely to apply in many regions in Latin America and Asia, including our study region, but less so in Sub-Saharan Africa which might explain the lack of effects of land rights on investments there.

Of course the empirical challenge in analyzing this relationship is to control for the possible endogeneity of land rights with respect to investment. This endogeneity can stem from different sources. Farmers may register more often parcels that benefit from relatively high levels of investment, or that more profitable farms make it easier to bear the costs of land registration. It might also be that investments such as tree planting are undertaken to enhance tenure security. However, the latter rather applies in a setting of informal land titling. According to our hypothesized causal chain, we will show that geography induced population pressure is a decisive determinant of land rights and this may also serve as a relevant and exogenous instrument when investments are regressed on the existence of land titles.

Finally we assume, and this is the last element of our hypothesis, that technology plays a crucial role for agricultural productivity and thus economic development of villages inhabited by individuals who draw more or less their total income from agriculture. The importance of technology adoption for productivity improvements has been shown many times in the literature. In Indonesia for instance a growth accounting exercise suggests that over the period 1980 to 1998 11% of the agricultural growth can be attributed to the expansion of irrigated land, 20% to the increase in fertilizer use and 10% to the accumulation of capital (Mundlak, Larson and Butzer, 2002). All these components involve technology adoption.

The reader might notice some similarity between our hypothesis and the one by Boserup (1981). Boserup (1981) argued convincingly that demographic pressure and associated food shortages would induce technological improvements or the adoption of new existing technologies. A rising population density would force individuals to modify the mode of soil use and to employ progressively modern agricultural tools. 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 intermediate variable between population and technology. Without that institutional change investments in new technologies will not take place for the reasons given above.

In our analysis we will not try to show that geography has no direct impact on economic development although we think that its impact through institutional change is much more important.[2] We focus rather, as mentioned above, on one microeconomic mechanisms which may be behind the institutions hypothesis put forward by the macroeconomic literature.

In what follows, we test and illustrate our hypothesized causal chain empirically using village level data for Central Sulawesi. Our results provide strong evidence supporting our arguments.[3]

3. Data and study context

3.1. Data

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 agricultural technology, population and geographic features was collected from secondary data such as village census data and the Global Positioning System (GPS) and added to the data set by Maertens, Zeller and Birner (2006). A further particularity of the data set is that it contains not only detailed information for the survey year, but for selected variables also retrospective information, such that variations over space *and* time can be examined and used to test our hypothesis. Identification is facilitated by the fact that variations in the data over time and space are sizeable (see also below).

[2] In contrast to Acemoglu *et al.* (2001) who argue that settler mortality rates are uncorrelated with the current disease environment and thus current economic performance in these countries we do not have such an instrument at our disposal.

[3] This does not, of course, preclude that other transmission mechanisms might also be relevant. But the empirical results are fully consistent with the argument we advance here.

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 either done informally (mainly for land conversion and not for selling the wood) and has then only a marginal importance for the local population or is done formally but then by companies from outside the Lore Lindu Region and has again no impact on local incomes.

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 decentral 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).

4. 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 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 long term 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.[4]

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 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.[5]

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:

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[4] 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.

[5] 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.

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

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. In general, we are, however, less interested in producing a precise unbiased estimate of the impact of agricultural technology on incomes than in understanding the process of endogenous technological change itself.[6]

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. At the end we also estimate all equations as a simultaneous equation system.

The causal impact of geography on migration is tested by estimating the following equation:

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

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,[7] 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.

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.[8] 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.

[6] The problem is also partly mitigated by using lagged technology in the income regression.
[7] A slope of more than 30° is considered as 'steep'.
[8] Given the long time lag of this variable and the significant changes in accessibility over time, this variable should be relatively independent from accessibility by car today.

Regarding the share of agriculture land on steep slopes one may argue that it is not relevant as long as the total land size is very large. However, we argue that this variable is a good measure of geography, since we look only at agricultural land. If enough land in the plain were available villagers would not convert land on steep slopes to agricultural land, given that it needs much more time to be cultivated and irrigated. One may also question the exogeneity of our "share of agricultural land on steep slopes" variable. One may argue that immigration and economic expansion leads to the conversion of land which is more difficult to cultivate than existing land. We checked this hypothesis by comparing villages where expansion of land was still possible in 1990 and 2001 with villages where expansion was still possible on 1990 but *not* in 2001. Obviously, in the latter villages (10 villages) conversion has taken place. However, in these villages the share of agricultural land on steep slopes was not significantly different from the share observed in the other villages.

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 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:

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

Moreover, in line with our hypothesis formulated in Section 2, we are interested to see whether geography-induced migration makes land rights more likely. Therefore we re-estimate Equation (3a) using 2SLS and instrument migration with geography:

$$M_i = \pi_{I1} + G_i^{'}\pi_{I2} + \omega_{Ii}$$

and

$$R_i = \lambda_R + \beta_R \hat{M}_i + X_i^{'}\gamma_R + \upsilon_{Ri} \quad \text{with} \quad \hat{M}_i = \hat{\pi}_{I1} + G_i^{'}\hat{\pi}_{I2}. \tag{3c}$$

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:

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

and with 2SLS where we instrument land rights by migration:

$$R_i = \pi_{R1} + \pi_{R2} M_i + \omega_{Ri}$$
and
$$A_i = \lambda_A + \beta_A \hat{R}_i + X_i^{'}\gamma_A + \upsilon_{Ai} \quad \text{with} \quad \hat{R}_i = \hat{\pi}_{R1} + \hat{\pi}_{R2} M_i \quad (4c)$$

Finally we combine IV with fixed-effects given that we have for all variables including the instruments multiple observations over time:

$$R_{it} = \pi_{R1} + \pi_{R2} M_{it} + \omega_{Rit}$$
and
$$A_{it} = \lambda_{Ai} + \beta_A \hat{R}_{it} + X_{it}^{'}\gamma_A + \upsilon_{Ait} \quad \text{with} \quad \hat{R}_{it} = \hat{\pi}_{R1i} + \hat{\pi}_{R2} M_{it}\,. \quad (4d)$$

An obvious way to complete the above analysis is to estimate the Equations (2), (3a) and (4a) as a simultaneous equation system using 3SLS and to check whether the effects identified in the estimation step-by-step still hold. That is what we do at the end of our empirical analysis.

Then, in principle a further and final step could be, in line with the more macro-economic literature, to test whether geography has any impact on income once its effect through migration, land rights and technology is accounted for. Although, below we will briefly discuss results from such estimations, we will focus more on the transmission mechanism and are less interested in a precise estimation of the impact of agricultural technology on rural growth.

Table 1 presents the descriptive statistics of all key and the principal control variables in our analysis. As the statistics show, migration, land rights and technology adoption 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.

[Please insert Table 1]

5. Results

5.1. 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.

[Please insert Table 2]

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[9] - 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 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. Columns (8)–(13) show that all results hold and that most of the technology coefficients have a similar magnitude.

As a further robustness test, in Table A1 in the Appendix we present regressions in which we use as a dependent variable, instead of the level, the average yearly absolute growth of the share of stone houses observed over three alternative periods. All effects hold, i.e. the villages where modern technologies where already used in the beginning of the period, show subsequently higher growth rates. We also tested whether the initial share of stone houses has any impact to capture a possible ‘conditional convergence’ effect, but this variable was not significant in any of these regressions.

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 discuss this possibility below. In fact, we are not interested in generating a precise point estimate of the effect of technology on development. 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.

[9] 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.

5.2 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, which, again, we use as a measure of landform. 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.

[Please insert Table 3]

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 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 due to data limits credit or adult education as time-variant control variables.

[Please insert Table 4]

An implication of our theory is that geography should be a relevant instrument for migration. Geography should also be exogenous to land rights. Hence, we present in columns (5)-(7) 2SLS regressions as specified in Equation (3c), where we instrument migration through geography in the land rights equation. The relevant F-test for the instrumentation of the migration rate is not above ten; hence we cannot be sure that the instrument is strong enough. However, if we instrument population size in 1980 by geography the test statistic is very satisfying. The over-identification tests give us confidence that our instruments are indeed exogenous.

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 Table A2 in the Appendix. 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.

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 agricultural investment. 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 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)). The results do also not change if we define land rights only as land rights if they were established under the PRONA/PRODA framework.[10]

[Please insert Table 5]

In principle many villages have today some support by governmental or non-governmental extension workers which might also play a role in promoting technological progress. Our data do not contain any information when these workers came for the first time to the village. But anecdotal evidence suggests that extension work is rather a demand and not a supply driven process.[11] If we regress technology on land rights and add as a regressor the presence of an

[10] These results are not shown in Table 5, but can be obtained on request by the authors.

[11] Villagers report that these workers, although they are quite well trained, are only rarely able to transmit their knowledge. Usually these workers do not have a car or motorbike to reach the villages and dispose of almost no technical equipment and training material. Hence, the real impact of these workers in the Lore Lindu region is in

extension worker today (columns (12)-(14)), the effects of land rights on technology adoption hold and the coefficient of the extension worker variable is insignificant except for fertilizer use, without however in this case changing very much the coefficient of the land rights variable.

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.

Columns (18)-(23) show estimations as specified in Equation (4c) where we instrument land rights in 1990 with the net migration rate during the period 1980-1990 and the village population size in 1980. In all regressions the effect of land rights persists. The first stage regressions all have an *F*-statistic well above ten and the second stage regressions always pass the over-identification test. The effect does also hold if we combine the instrumental variable approach with the fixed-effect estimator (Equation (4d)). The results are shown in columns (24)-(26). Again, all relevant test-statistics are satisfactory.[12]

Our hypothesis can also be formulated as a simultaneous equation system comprising two equations for geography-induced migration, one equation for migration-induced land rights and one equation for land rights-induced technology. Table 6 shows the results. We use three different technology variables, irrigation, simultaneous use of fertilizer, pesticides and improved seeds and the construction of terraces. All results are qualitatively consistent with the results above and support our line of reasoning, although the coefficients vary in size which is due to the relative small sample size we have to rely on to identify this system of equations.

[Please insert Table 6]

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 some 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. The results are shown in Table A3 in the Appendix. It turns out that the migration rate is never significant in these regressions.

6. Concluding Remarks

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

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most cases, according to the villagers, very limited, or needs at least explicit village action to bring these workers to the village.

[12] Only in the case of terraces building the coefficient takes an unrealistic value, but one should note that terraces building concerns only the smaller sample with fields on steep slopes and therefore the estimates are definitely less precise.

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. We tested this hypothesis empirically using data on villages situated on the Indonesian Island Sulawesi. Employing a system of nested equations and controlling for potential endogeneity problems and unobserved heterogeneity, we found strong empirical support for our hypothesis. We think this finding has at least three important implications.

First, at least in this context, land rights have a significant and positive impact on agricultural investment, even if we control for their endogeneity. This positive impact which is at odds in particular with the results from many studies on Africa, as discussed in Section 2, might be attributable to two aspects: (i) The existence of the necessary pre-conditions which allow to make use of the potential functions of land rights such as using land as collateral; (ii) the fact that land rights are in our context demand driven and not enforced from some higher state authority. Put differently in our context, the process of land titling is endogenous and therefore land rights are more likely to develop their potential favorable effects.

Second, the transmission channel we identify in our analysis is similar to the one emphasized by Boserup (1981), but extends it in the sense that we show that the effect from population on technology is not direct, but acts through its effect on the implementation of land rights, which is endogenous in this process. Hence, we provide a link between Boserupian theory and the theory of institutional change as formulated by North (1987) and Hayami and Ruttan (1985).

Third, we complement the more macro-economic literature, which puts forward the role of institutions for the explanation of long run differences in economic development, in highlighting one possible channel which may underlie the institutions hypothesis. If we wanted to follow this literature even more closely, i.e. not only providing an argument for the institutions hypothesis, but also rejecting the geography hypothesis, we would have to instrument technology through geography. With this instrumentation we would then have to show that geography has no direct impact on development once its indirect impact via institutions is accounted for. While we can indeed show that geography-induced technology drives development, we do not have a geographic instrument at hand of which we can be sure that it drives migration, but has no direct impact on development, i.e. an instrument which satisfies convincingly the necessary exclusion restriction.[13] Acemoglu *et al.* (2001) use, as mentioned above, settler mortality, which was, so the argument, mainly driven by malaria and yellow fever diseases which had only a limited effect on indigenous adults and thus it can reasonably be assumed that settler mortality has no direct impact on economic performance today.

However, we think that the microeconomic mechanism we have identified might be an important part of the link between institutions and development identified by the cross-country literature. Acemoglu *et al.* (2001) use the 'Average protection against expropriation risk index' and expects that a high value of this index is associated with "the tradition of rule

[13] In fact using our data, we can show that (i) geography is correlated with the share of stone houses, (ii) that geography is a relevant instrument for technology, (iii) geography-induced technology has a significant impact on the share of stone houses with technology coefficients slightly higher than under OLS, and (iv) geography has no direct impact on the share of stone houses once its impact through technology is accounted for. In the latter case, we use a sub-set of our geographic variables as instrumental variables (excluded from the main equation) and add one or several alternative geographic variables in the main equation. However, as emphasized above, this test is not sufficient to claim that geography has no direct impact at all. All results are available on request.

of law and well-enforced property rights" (p. 1378). In this sense we use in our study a notion of institutions which is very close to the one in mind by Acemoglu *et al.* (2001). In fact, one natural extension of our work would be to look at land rights as a critical institution that affected economic performance in settler versus non-settler colonies and under different colonial regimes.

For the reasons given, we will not reject the geography hypothesis per se, but think that the channel from geography to migration, land rights, technology and development we have shown is the dominating force, that is this channel is much more important than the possible direct impact of geography. For our study context it would imply that geography might matter for agricultural development but that good institutions and in particular well defined and secure land property rights and investment in modern technology can easily compensate geographic disadvantages. Moreover if geography is favorable, land rights arise endogenously. If in contrast geographic conditions are unfavorable there is room for policy to initiate the process exogenously.

However, regarding the villages we observed, it should be noted that this process of endogenous land rights has mixed effects on the local population and on rainforest conversion. While many villagers appear to benefit from the intensification and technological change that the land rights have helped bring about, some villagers are marginalized in the process. In our study region, it was reported that some villagers behave myopically when land markets arise. They sell land to migrants to make fast money. The land is usually fallow land, which has been kept, e.g. as reserve for heritage. Later, they recognize their mistake, but there is no more free land available. This process leads in some villages to a marginalization of local inhabitants relative to migrants and also accelerates deforestation (Faust *et al.*, 2003; Weber and Faust, 2006). Regarding rainforest conversion, it appears that agricultural intensification not only promotes income growth at the rainforest margin but also reduces conversion so that promotion of land rights not only increases incomes but also helps stabilize the rainforest margin (Maertens *et al.*, 2006).

Appendix

[Please insert Table A1]

[Please insert Table A2]

[Please insert Table A3]

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Tables

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)
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)
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

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 1995 [a)]	0.379 (0.066)***					0.303 (0.097)***	0.191 (0.069)***
Fertilizer 1995		0.395 (0.046)***					
Pesticides 1995			0.313 (0.050)***				
Improved seeds 1995				0.304 (0.060)***			
F., P. & S. 1995 [c)]						0.204 (0.097)**	0.234 (0.069)***
Terraces 1995 [b)]					0.265 (0.087)***		
Emigration 1990-2001						0.364 (1.463)	
Male pop. per ha. 1995							0.039 (0.027)
Population share 19-45							0.361 (0.261)
Prim. school 1980							0.080 (0.083)
Drink. water conn. 1990							0.171 (0.060)***
Constant	0.185 (0.036)***	0.062 (0.022)***	0.082 (0.028)***	0.149 (0.038)***	0.194 (0.044)***	0.101 (0.045)***	-0.181 (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 (0.031)***					0.143 (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 (0.013)***	0.040 (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				-0.114	-0.124
	(0.058)*				(0.063)*	(0.060)**
Years to last drought		0.002			0.002	
		(0.001)*			(0.001)	
Ln altitude above sea			0.004		0.024	
			(0.011)		(0.021)	
Access. by car in 1980				0.059	0.045	
				(0.032)*	(0.038)	
Pop. density 1980	-0.006	-0.004	0.000	-0.011	-0.002	-0.007
	(0.017)	(0.015)	(0.016)	(0.017)	(0.019	(0.017)
Drink. water conn. 1990						-0.026
						(0.032)
Electricity conn. 1990						0.068
						(0.049)
Constant	0.047	0.009	-0.008	-0.001		0.053
	(0.028)*	(0.039)	(0.073)	(0.029)		(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				0.166
	(0.339)				(0.313)
Years to last drought		0.003			-0.004
		(0.008)			(0.007)
Ln altitude above sea			-0.470		-0.382
			(0.089)***		(0.099)***
Access. by car in 1980				0.668	0.392
				(0.163)***	(0.186)**
Constant	6.335	6.267	9.230	5.891	8.457
	(0.103)***	(0.118)***	(0.556)***	(0.126)***	(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

	Dependent variable						
	Land rights in 1990			Land rights	Land rights in 1990		
	OLS regressions	Probit regression	OLS regressions	FE regressions[a)]		IV regressions	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Immigration (1980-1990)	0.988	4.003	0.936	0.584	0.590	2.296	
	(0.334)***	(1.664)**	(0.353)**	(0.280)**	(1.820)	(1.411)*	
Ln pop. (1980)	0.304	1.019	0.314	0.596	0.369	0.421	0.455
	(0.055)***	(0.278)***	(0.059)***	(0.144)***	(0.111)***	(0.097)***	(0.094)***
Prim. school 1980			-0.165		-0.235	-0.160	-0.320
			(0.125)		(0.153)	(0.146)	(0.108)***
Credit avail. past 20 y.			0.143		0.101	0.115	0.060
			(0.180)		(0.178)	(0.197)	(0.176)
Constant	-1.564	-6.973	-1.613	-3.471	-1.875	-2.309	-2.300
	(0.338)***	(1.799)***	(0.374)***	(0.958)***	(0.672)***	(0.589)***	(0.555)***
R^2	0.295		0.316	0.185			
N	77	77	77	231	77	77	77
					First-stage regression: Migration[b)]		
Share steep slopes					-0.112	-0.102	
					(0.089)	(0.080)	
Years to last drought						0.002	
						(0.001)	
Ln altitude above sea					0.009	0.022	
					(0.016)	(0.019)	
Access. by car in 1980						0.053	
						(0.045)	
F-Stat.					0.8	1.3	
					First-stage regression: Ln pop 1980[b)]		
Share steep slopes					-0.051	0.171	0.165
					(0.411)	(0.380)	(0.376)
Years to last drought						-0.003	-0.003
						(0.008)	(0.008)
Ln altitude above sea					-0.454	-0.363	-0.362
					(0.096)***	(0.113)***	(0.113)***
Access. by car in 1980						0.473	0.469
						(0.215)**	(0.212)**
F-Stat.					13.1	10.1	10.3
Hansen J *p*							0.145

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.
4. [b)] Only the coefficients of the excluded instruments are presented.

Table 5
The effect of land rights on technology
OLS, Probit, FE, IV and FE-IV regressions

	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 5 continues on next page.

Table 5 (… *continued*)
The effect of land rights on technology
OLS, Probit, FE, IV and FE-IV regressions

	Dependant variables: Technology use FE regressions[c)]			Dependant variables: Technology use in 1995 IV regressions		
	Irrigation[a)]	**Fertilizer**	**Terraces[b)]**	**Irrigation [a)]**	**Fertilizer**	**Terraces [b)]**
	(15)	**(16)**	**(17)**	**(18)**	**(19)**	**(20)**
Land rights	0.249	0.208	0.957	0.817	0.824	0.692
(1990)	(0.057)***	(0.051)***	(0.128)***	(0.170)***	(0.200)***	(0.214)***
Constant	0.262	0.514	0.215	0.071	0.334	0.082
	(0.029)***	(0.027)***	(0.053)***	(0.084)	(0.107)***	(0.055)
R^2	0.177	0.176	0.090			
N	280	308	184	70	77	46
				First-stage regression: Land rights [e)]		
Immigration				0.943	0.988	0.617
1980-1990				(0.359)**	(0.334)***	(0.329)**
Ln pop.				0.307	0.304	0.360
1980				(0.057)***	(0.055)***	(0.054)***
F-Stat.				17.7	19.6	24.4
Hansen J *p*				0.342	0.391	0.936

	Dependant variables: Technology use in 1995 IV regressions			Dependant variables: Technology use FE-IV regressions [d)]		
	Irrigation [a)]	**Fertilizer**	**Terraces [b)]**	**Irrigation [a)]**	**Fertilizer**	**Terraces [b)]**
	(21)	**(22)**	**(23)**	**(24)**	**(25)**	**(26)**
Land rights	0.659	0.795	0.815	0.379	0.568	4.193
(1990)	(0.182)***	(0.216)***	(0.234)	(0.201)*	(0.193)***	(0.951)***
Prim. school	0.108	0.067	0.028			
1980	(0.174)	(0.142)	(0.094)			
Credit avail.	0.259	0.346	0.074			
past 10 y.	(0.125)**	(0.237)	(0.062)			
Newspaper	0.357	0.024	-0.389			
available	(0.176)**	(0.197)	(0.428)			
Constant	-0.218	-0.033	-0.028	0.205	0.371	-1.372
	(0.205)	(0.250)	(0.094)	(0.102)**	(0.098)***	(0.484)***
N	70	77	46	210	231	138
			First-stage regression: Land rights [e)]			
Immigration	0.906	0.944	0.574	0.584	0.584	0.584
1980-1990	(0.383)**	(0.362)**	(0.352)	(0.280)**	(0.280)**	(0.280)**
Ln pop.	0.325	0.320	0.350	0.596	0.596	0.596
1980	(0.070)***	(0.068)***	(0.066)***	(0.144)***	(0.144)***	(0.144)***
F-Stat.	13.1	14.9	15.1	10.5	10.5	10.5
Hansen J *p*	0.455	0.461	0.962			

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)] In the FE regressions technology and land rights status in 1980, 1990, 1995 and 2001 are used.
6. [d)] In the FE-IV regressions technology, 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.
7. [e)] Only the coefficients of the excluded instruments are presented.

Table 6
Migration, Land rights and Technology,
Simultaneous Equation system

	Dependant variables: Technology use in 1995		
	Irrigation [a]	**Fertilizer**	**Terraces** [b]
	(1)	**(2)**	**(3)**
Technology			
Land rights 1995	1.164	1.287	0.867
	(0.258)***	(0.268)***	(0.294)***
Primary school 1980	0.219	0.329	-0.029
	(0.178)	(0.195)*	(0.233)
Credit available past	0.125	0.083	0.056
10 years	(0.217)	(0.236)	(0.277)
Newspaper available	0.115	-0.092	-0.420
	(0.220)	(0.231)	(0.342)
Constant	-0.355	-0.318	0.008
	(0.275)	(0.303)	(0.346)
Land rights 1990			
Immigration rate	1.267	1.638	2.076
1980-1990	(0.918)	(0.950)*	(0.942)**
Ln population 1980	0.438	0.430	0.532
	(0.097)***	(0.100)***	(0.114)***
Primary school 1980	-0.214	0.010	-0.074
	(0.152)	(0.167)	(0.197)
Credit available	0.042	-0.214	0.254
past 20 years	(0.169)	(0.153)	(0.203)
Constant	-2.286	-2.211	-3.209
	(0.586)***	(0.601)***	(0.700)
Immigration 1980-1990			
Share of fields on	-0.121	-0.065	-0.113
steep slopes	(0.063)*	(0.052)	(0.073)
Number of years to	0.002	0.003	0.003
last drought	(0.001)*	(0.001)**	(0.002)*
Ln altitude	0.018	0.013	0.026
above sea	(0.020)	(0.018)	(0.036)
Access. by	0.052	0.052	0.026
car in 1980	(0.036)	(0.032)	(0.048)
Population	-0.010	-0.012	0.006
density 1980	(0.017)	(0.015)	(0.023)
Constant	-0.107	-0.098	-0.179
	(0.140)	(0.124)	(0.248)
Ln population 1980			
Share of fields on	0.108	0.262	0.539
steep slopes	(0.336)	(0.300)	(0.328)*
Number of years to	-0.001	-0.002	-0.012
last drought	(0.007)	(0.007)	(0.009)
Ln altitude	-0.433	-0.393	-0.323
above sea	(0.099)***	(0.095)***	(0.153)**
Access. by	0.363	0.404	0.530
car in 1980	(0.191)*	(0.179)**	(0.214)**
Constant	8.773	8.486***	7.938
	0.679***	0.650	1.015
N	70	77	46

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.

Table A1
The effect of technology on economic growth
OLS regressions

	Dependant variable: Absolute growth in share of stone houses		
	Period 1995-2001 **(1)**	**Period 1990-2001** **(2)**	**Period 1980-2001** **(3)**
Irrigation	0.012	0.010	0.012
(1) 1995 (2) 1990 (3) 1980[a)]	(0.004)***	(0.004)**	(0.004)***
F., P. & S.	0.010	0.011	0.003
(1) 1995 (2) 1990 (3) 1980	(0.004)***	(0.005)**	(0.004)
Male pop.	0.001	0.001	
per ha. 1995	(0.003)	(0.002)	
Population	0.022		
share 19-45	(0.018)		
Prim. school	-0.001	0.003	0.003
1980	(0.004)	(0.004)	(0.002)
Drink. water connection	0.009	0.010	0.010
(1-2) 1990 (3) 1980	(0.004)**	(0.004)**	(0.003)***
Constant	-0.004	0.003	0.003
	(0.009)	(0.005)	(0.002)
R^2	0.459	0.440	0.509
N	70	70	70

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.

Table A2
Robustness Check – No effect of land rights on migration
OLS regressions

	Dependent Variable: Net immigration rate of households, various periods					
	1980-1990	**1980-1990**	**1990-1995**	**1990-1995**	**1995-2001**	**1995-2001**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Land rights (1-2) 1980	0.057	0.077	-0.010	-0.026	-0.034	-0.047
(3-4) 1990 (5-6) 1995	(0.052)	(0.056)	(0.019)	(0.024)	(0.023)	(0.031)
Prim. School		-0.042		-0.002		0.036
1980		(0.051)		(0.030)		(0.039)
Drink. water		-0.055		0.036		0.001
(1-2) 1980 (3-6) 1990		(0.042)		(0.027)		(0.031)
Electricity		0.021		-0.019		0.050
(1-2) 1980 (3-6) 1990		(0.056)		(0.035)		(0.037)
Doctor		0.004		0.021		-0.023
(1-2) 1980 (3-6) 1990		(0.045)		(0.026)		(0.028)
Pop. Den. (1-2) 1980		-0.003		-0.001		0.007
(3-4) 1990 (5-6) 1995		(0.020)		(0.012)		(0.012)
Share of fields on		-0.131		0.017		-0.036
steep slopes		(0.065)*		(0.111)		(0.052)
Number of years to		0.001		0.002		0.001
last drought		(0.002)		(0.001)		(0.001)
Ln altitude		0.012		0.001		0.014
above sea		(0.024)		(0.019)		(0.022)
Access. by		0.050		-0.003		-0.003
car in 1980		(0.041)		(0.028)		(0.032)
Constant	0.015	-0.028	0.024	-0.010	0.028	-0.097
	(0.016)	(0.188)	(0.012)***	(0.151)	(0.015)*	(0.171)
R^2	0.017	0.172	0.006	0.176	0.009	0.074
N	77	77	77	77	77	77

Source: CRC STORMA A3 Village Survey.
Notes:
1. Robust standard errors in parentheses.
2. Variable explanations see Section 4.

Table A3

Robustness Check – No effect of migration on technology

OLS regressions

	Dependent Variable: Technology use in 1990				
	Irrigation [a)]	**Fertilizer**	**Pesticides**	**Imp. Seeds**	**Terraces** [b)]
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Migration	0.118	0.215	0.255	-0.531	0.076
1980-1990	(0.432)	(0.439)	(0.441)	(0.436)	(0.445)
Primary school	0.005	0.057	0.096	0.071	0.255
1980	(0.165)	(0.176)	(0.177)	(0.175)	(0.218)
Credit available	0.334	0.437	0.141	0.261	0.252
past 10 years	(0.196)*	(0.208)**	(0.210)	(0.207)	(0.247)
Newspaper	0.662	0.389	0.351	0.591	-0.255
available	(0.236)***	(0.252)	(0.253)	(0.250)	(0.300)
Constant	-0.008	0.104	0.397	0.109	-0.257
	(0.249)	(0.266)	(0.268)	(0.265)	(0.324)
R^2	0.162	0.101	0.045	0.118	0.063
N	70	77	77	77	46

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.

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