Preprint of: Vanclay, J.K., 2005. Deforestation: correlations, possible causes and some implications. *International Forestry Review* 7(4):278-293.

Deforestation: correlations, possible causes and some implications

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SUMMARY

Changes in national forest areas during 1990-2000 are contrasted with other variables to illustrate correlations and provoke discussion about possible causes. Twenty-five statistically-significant correlations (including rural population, life expectancy, GDP, literacy, commerce, agriculture, poverty and inflation) are illustrated and a statistical model suggests that good governance, alternative employment opportunities, and payments for environmental services may be effective in combating deforestation. The data suggest that a global forest convention may need to be supported by substantial and carefully-targeted development assistance to foster good governance.

Keywords: deforestation, global forest convention, governance, payments for environmental services

INTRODUCTION

The United Nations Forum on Forests (UNFF) seeks to secure a global forest convention to help curb deforestation. These efforts began in 1990, with calls for such an agreement appearing in the 1990 Sào Paulo Declaration of the Intergovernmental Panel on Climate Change (IPCC 1991), in reviews of the Tropical Forestry Action Plan (Dembner 1991), in a fact sheet of the former US President George Bush (1990), and as a call from the G7 for a “global forest convention ... to curb deforestation, protect biodiversity, stimulate positive forestry actions and address threats to the world's forests” (G7 1990). Agreement could not be reached at the Earth Summit in Rio de Janeiro in 1992 (the compromise was a “Non-binding authoritative statement on forest principles”), and negotiations have continued fruitlessly with progress toward a conclusion appearing imperceptible. The most recent setback was in May 2005, when the United Nations Forum on Forests (UNFF) failed to get agreement on “the parameters of a mandate for developing a legal framework on all types of forests” (UNFF 2000). Advocates argue that a convention would ensure that all of the world's forests are sustainably managed, provide the basis for a common understanding of sustainable forest management, and establish the legal framework for monitoring and compliance (e.g., Roberts 2003). Critics contend that the proposal addresses the wrong issues, and does not provide an adequate means to regulate the private sector (e.g., Jeanrenaud *et al* 1997). There is little reliable evidence to inform this debate. The pursuit of reliable data tends to lead researchers to sub-national or regional-scale studies in a few selected countries (Angelsen and Kaimowitz 1999), but this introduces new problems including the possibility of bias and a reduced ability to generalize. In contrast, this study draws on a global database to offer a broad overview and to stimulate discussion on deforestation.

This paper presents an overview of trends evident in recent global data. It makes no attempt to review the extensive literature on deforestation; instead readers are encouraged to consult the comprehensive reviews by Wibowo and Byron (1997), Kaimowitz and Angelsen (1998), Angelsen and Kaimowitz (1999), Barbier and Burgess (2001), and Geist and Lambin (2002, 2003). In their comprehensive review of 146 economic models of deforestation (and some 200 literature references), Kaimowitz and Angelsen (1998) challenged many conventional hypotheses about deforestation. They found that most researchers agreed that more roads, higher agricultural prices, lower wages, and a shortage of off-farm employment generally led to more deforestation, but that the effects of agricultural input prices, household income levels, tenure security, population growth, poverty reduction, national income, economic growth, and foreign debt were unclear. They criticized the weak methodology and poor data of many models which, they felt, make results questionable. Kaimowitz and Angelsen (1998) were particularly critical of global regression models, because of limited and poor data, inability to distinguish between correlation and causality, inappropriate assumptions regarding the normality of data, and the dilution of micro-level patterns during the aggregation of data. These concerns serve as a caveat on the conclusions that may be drawn from global databases, but should not inhibit such analyses. The Forest Resource Assessment 2000 (FRA 2000) is an improvement on previous global inventories (Mayaux *et al*. 2005), has sufficient degrees of freedom to allow examination of several variables, and is easily transformed to a normal distribution that satisfies statistical assumptions (see Figure 1 below). It is clear that weaknesses remain, both in the FRA 2000 data, and in the assumption that national averages are informative of deforestation trends. Thus this paper draws attention to patterns evident in the data (rather than to estimated parameters), so that readers can judge for themselves the adequacy of the database. This paper is not a comprehensive review, but seeks to complement existing reviews by presenting empirical data at the global scale in an accessible format to stimulate discussion.

DATA

This study draws on data from the Forest Resource Assessment 2000 (FRA 2000) of the United Nations Food and Agriculture Organization (2002). The FRA 2000 documents the change in forest area in over 200 countries during the decade 1990-2000. Note that the FRA 2000 is concerned with the area forested land, and may not reveal situations where primary forest has been replaced with forest plantations. The reported rate of change varies from -9% per year in Burundi to +9% per year in Cape Verde. These rates of change are over-dispersed (with many values close to zero, and few values exceeding ±5%) and violate the conventional statistical assumption of normally-distributed residuals. Thus the data were normalized using a square-root transformation (or $-\sqrt{|x|}$ where rate of change was negative). The resulting data distribution is close to normal (Figure 1), and was used as the response variable in this study, here abbreviated as *afforestation*. It can be converted to a rate of change simply by squaring and restoring the sign. Thus a response of -3 corresponds to a -9% annual change in forest area and a deforestation rate of 9% per year.

[Figure 1 near here]

Transformations are also appropriate for some of the predictor variables (sometimes called 'independent' variables). For instance, with the untransformed population density data (Figure 2), one nation with a high population density (Singapore) has a huge influence on the assumed trend (statistically, it has strong leverage), and the use of a logarithm transformation allows all the data to have a more equal influence on the trend. Such a transformation is also appropriate because a few additional people will have a greater effect in an area with low density than in an area with an already high density. Notice that the transformation has a dramatic effect on the apparent correlation with tropical afforestation (Figure 2, solid line), changing it from +10% to +1%.

[Figure 2 near here]

The area associated with each datum varies greatly, ranging from about 1000 ha in the Maldives to 850 million ha in the Russian Federation. If the objective was to establish an unbiased estimate of the rate of deforestation, it would be appropriate to weight data according to the area represented. However, the present study is concerned with potential causes of deforestation, so each country was treated equally, and no weights were used.

There is a strong correlation between the response and latitude ($r = 55\%$, $P<0.0001$[1]), with much of the reported deforestation occurring in the tropics (Figure 3). A similar correlation ($r = -56\%$) is obtained with a binary variable that denotes tropical countries as those for which the geographical centroid lies within ±25º of the equator. Since many other variables of interest are correlated with both the response and with latitude, both global and tropical trends are reported and illustrated.

[Figure 3 near here]

Inferences drawn from the FRA 2000 data should be tempered by the realization that these data reflect observations of forest change during a single period (1990-2000) in many different places. When a correlation (e.g., between rural population and

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[1] The correlation coefficient r indicates how well a trend fits the data (0 indicates that there is no trend and a simple average suffices; ±100% indicates a perfect fit; the sign indicates whether the trend increases or decreases), and the probability P indicates the likelihood that the trend is due to chance. A good result has a large r (ignoring the sign) and a small P. It is conventional that P should be less than 0.05, which signifies a 1 in 20 chance of attributing a correlation when one does not really exist.

afforestation) is noted, one is tempted to infer causality (e.g., that an increase in the rural population will lead to more deforestation), but this does not necessarily follow. The FRA 2000 data certainly show that many nations which experienced a reduction in forest area during 1990-2000 also have a relatively high proportion of their population in rural areas. However, the rural population need not be the cause, and need not be associated with the deforestation. Indonesia is one of the nations with a deforestation rate exceeding 1% and with a rural population of 60%. However, most of Indonesia's rural population live on the island of Java (which has 60% of Indonesia's population on 7% of the land area), and most of the deforestation occurred on other islands (e.g., Kalimantan; Fuller *et al* 2004), so it is unlikely that the rural Javanese were a direct cause of Indonesia's deforestation. Clearly, caution is required in drawing inferences from the FRA 2000 data, especially regarding possible causes of deforestation, and in speculating whether similar trends may arise in other situations.

There are other limitations of the FRA 2000 data. The reliability of deforestation estimates varies by countries; the estimates for some countries are based on repeated inventories, whereas for other countries, estimates were inferred indirectly and are less reliable. Such weaknesses in the data may inflate error estimates (and thus weaken any tests of significance), but have relatively little influence on the trends, because the data illustrated in Figures 3-17 did not contain points with high leverage.

RESULTS

Key results are summarized in Table 1, which is divided into two parts to show the correlation of selected indicators with afforestation (square root of the rate of change in forest area) worldwide, and in the tropics. This distinction between global and tropical trends is drawn partly because latitude is the variable with the strongest correlation with afforestation, and partly because many researchers are concerned primarily with tropical deforestation.

Treaties

Ruis (2001) identified ten international treaties that should contribute towards conservation outcomes, but there is no evidence that these treaties have been effective (Table 1, Figure 4). There is no indication that afforestation increases amongst nations that sign more of these treaties; on the contrary, a significant correlation ($r = -18\%$, $P = 0.04$, Table 1) points to that fact that some parties to the treaties are amongst the countries that lost most forest during 1990-2000.

The ten treaties identified by Ruis (2001) are the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, 1971), Convention concerning the Protection of the World Cultural and Natural Heritage (1972), Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES, 1973), Vienna Convention for the Protection of the Ozone Layer (1985), Convention Concerning Indigenous and Tribal Peoples in Independent Countries (1989), *Convention on Biological Diversity* (1992), *United Nations Framework*

Convention on Climate Change (1992), International Tropical Timber Agreement (1994), *United Nations Convention to Combat Desertification in those Countries experiencing Serious Drought and/or Desertification, particularly in Africa* (1994), and the Agreement Establishing the World Trade Organization, (1994).

Ruis (2001; see also Sayer *et al*. 2000, Innes and Er 2002) argued that three of these treaties (those in *italics*, namely Biodiversity, Climate Change, and Desertification) should impose a particular obligation to conserve forest, but a test of the efficacy of these treaties (collectively or individually) is meaningless (and as expected, not statistically significant at P=0.7), because the test hinges on afforestation trends in a handful of countries that did not sign (mainly those that did not sign the Desertification treaty). The test of the ten treaties collectively is fraught with the same difficulty: the test result hinges largely on whether or not nations signed the Convention on Wetlands of International Importance (Ramsar, 1971) and the International Tropical Timber Agreement (1994). While the former is concerned with wetlands (and waterfowl) and may not impinge on forests, the latter is clearly pertinent to tropical forests.

[Figure 4 near here]

Figure 4 is thought-provoking, but is not unambiguous. Proponents of a forest convention may draw on Figure 4 to argue that existing treaties do not protect forest, and that a specific forest convention is needed. Skeptics can argue that existing treaties (such as the International Tropical Timber Agreement 1994) have not reduced deforestation, so it is fanciful to assume that a forest convention will be more successful. Proponents may counter that it is premature to judge conventions which came into force in the middle of the monitored period (1990-2000). Skeptics may respond that negotiations commenced well before the 1990 baseline, and that serious a commitment by signatories and ratifiers should have become evident in the FRA 2000. The reality may be that many other factors mask any effect of the treaties considered here. While one cannot, and should not, assert that the treaties are making things worse, it is clear that the FRA 2000 offers no evidence that these treaties are helping to reduce deforestation. That lack of evidence may arise because of limitations in the FRA 2000 data, because of insufficient time for the effect of treaties to become evident, or because of the scope and implementation of the treaties.

Development assistance

It is often assumed that development assistance can be influential in halting deforestation, but the evidence for this is equivocal. Estimates of official development assistance reported in the CIA World Factbook (2004; reflecting net official development assistance in ±1999 from OECD nations to less developed nations, that is concessional in character, seeks to promote economic development, and contains a grant element of at least 25%) suggest a positive correlation between aid (per capita) and tropical afforestation (r = 23%, n=114, P=0.01), whereas 1998 estimates reported by the World Bank (2000) suggest a weak negative correlation (r = -17%, n=90, P=0.1). The different trends reflect different kinds and sources of assistance, different time-frames, and different nations. A standardized set of nations common to both data sets is too small to offer meaningful insights (n=77, P>0.2). The pooled data set indicates a positive relationship in the tropics (r = 18%, n=158, P=0.04, Figure 5), but a negligible relationship at the global scale (P=0.2). Clearly, cash is no panacea, and context is critical if development assistance is to be effective (e.g., Easterly 2001).

[Figure 5 near here]

Correlations with deforestation

Vanclay and Nichols (2005) commented on the strong relationship between gross national product, rural population and afforestation, and illustrated that both rural population (%) and Log(GNP/capita) exhibit a linear trend with afforestation. The trend holds when both variables are fitted simultaneously to the FRA 2000 data:

$$\text{Response} = 0.09\ \text{Log(GNP/capita)} - 0.02\ \text{RuralPop} \qquad (1)$$

While prediction of the rate of forest area change is imperfect, the equation offers a reasonable ability to classify nations as afforesting or deforesting (Figure 6).

[Figure 6 near here]

Equation 1 and Figure 6 correctly classify 132 of 152 nations. It is interesting to examine the mis-classified nations more closely. Nine nations deforest during 1990-2000, even though their GNP and rural population anticipate afforestation. All of these nations have problems with corruption (Chile is the least corrupt, with a corruption perception index of 6.9; Transparency International 2000), and the level of corruption is correlated with the distance from the break-even line (r = -19%, P = 0.3), suggesting that corruption may play some role in explaining the departure from the expected trend. It is more difficult to explain the 21 nations that afforest during 1990-2000 despite indications to the contrary. These nations include Bangladesh, India, Vanuatu, Vietnam, etc. Of several variables examined (including relative area of forest, energy consumption and literacy), the most informative appeared to be energy consumption (kg/capita oil equivalent; World Bank 2000), with 11 of the 21 nations for which data are available exhibiting a strong correlation (r = -80%, P = 0.001) between energy use and departure from the break-even line. It is conceivable that these exceptional 21 nations may rely on wood for fuel (e.g., cooking, heating, sterilizing water), and their citizens may have a personal interest in maintaining the fuelwood resource and in increasing the area of forest. These and other observations suggest that the FRA 2000 data offer some utility for testing hypotheses concerning causes of and solutions to deforestation. Thus a more detailed examination of deforestation trends was undertaken.

Easterly (2001) argues that incentives are necessary for development. They are also necessary to halt deforestation, but they are not sufficient. Halting deforestation also requires the creation of opportunities (e.g., in the form of employment more attractive than cultivating crops and harvesting timber), and fostering the ability to realize those opportunities (e.g., provision of basic services including education, health and transport; in short, good governance; Vanclay 1993, Vanclay and Prabhu 1997). What follows is not an exhaustive search for correlations, but an attempt to shed light on the hypothesis that afforestation is related to these opportunities and services.

Alternatives to deforestation

Table 1 summarizes key results. Entries in Table 1 can be grouped into several categories encompassing concepts of alternatives (to primary agriculture and timber-getting), governance, health, wealth and information. The correlation between afforestation and rural population may well reflect alternatives to agricultural pursuits. This possibility is also reflected in many other variables in Table 1, including internet access, CO_2 emissions, international reserves, commercial services, electricity consumption and industrial value-adding, all of which are significant in the tropics ($P \leq 0.05$), and most of which are significant at the global scale. The ability to use the internet (Figure 7) does not imply that people are deforesting in simulation games rather than in reality; rather, it reflects the capacity and skill available for employment outside the agriculture and lumber sectors. Similarly, higher CO_2 emissions do not imply that people are burning fossil fuel rather than forests, but reflect the job opportunities available in the industrial sector.

[Figure 7 near here]

Other, more direct indicators of alternative employment include exports of commercial services and industrial value-adding (both $P \leq 0.05$, Table 1 and Figure 8).

[Figure 8 near here]

It is interesting that the national unemployment rate (%) is not well correlated with afforestation in the tropics ($r = -10\%$, $P=0.2$), even though it is significant at the global scale ($r = -27\%$, $P=0.0006$, Table 1). This may be because urban and rural unemployment rates may be quite different, and may reflect that it is rural underemployment (and lack of other income-producing alternatives) rather than urban unemployment that contributes to deforestation. The correlation may also be confounded by different definitions of unemployment in different countries.

Intensifying agriculture

Some deforestation is caused by agricultural expansion, and intensification of agriculture rather than expansion of agricultural lands may help to reduce deforestation. As Angelsen and Kaimowitz (2000) have pointed out, making agriculture more profitable can be a two-edged sword, as it may simply allow agriculture to encroach onto still more remote and more marginal forest lands. However, there is some evidence that increasing agricultural productivity by fostering more value-adding per worker, can help to reduce deforestation ($r = 31\%$, $P = 0.01$, Table 1 and Figure 9). However, simply expanding the agricultural sector without commensurate investment in other areas is likely to be counterproductive, as afforestation tends to decrease as the agricultural share of GDP increases ($r = -33\%$, $P = 0.005$, Table 1 and Figure 9).

[Figure 9 near here]

Health

Table 1 shows that life expectancy and infant mortality are significant ($P<0.001$), both in the tropics and globally (Figure 10). It is unlikely that longer life-spans cause people to think more carefully about forest depletion; it is more likely that life-span and other health indicators also indicate the efficacy of government services (if nothing else works, we cannot expect wise management of forests), the ability of people to gain alternative employment, and the demand for fuelwood to sterilize water. The World Bank's (2000) estimate of access to improved water is positively correlated with afforestation, but is significant only at the global scale (Table 1).

[Figure 10 near here]

Wealth

Wealth, both personal and national, also influences deforestation, because wealthy people and nations have more options for using and managing resources. This is evident in the afforestation trend with domestic savings and international reserves, both of which are positively correlated with afforestation (Figure 11).

[Figure 11 near here]

The wealth of individuals and families also affects the propensity to deforest, and this is evident in the trend exhibited by poverty (% of national population below the poverty line), rural poverty (% of rural population below the poverty line), and in the Gini coefficient (an index of equality, in which 0 implies wealth is equally shared and 1 implies that all the wealth is in the hands of one person; e.g., Sweden has a Gini index of 25, and Brazil has 60). Globally, the Gini index has a good correlation with afforestation ($r = -53\%$, $P<0.0001$, Table 1 and Figure 12), but the correlation is weak within the tropics and it is not clear if this indicator is useful in explaining deforestation patterns. In contrast, and despite a small sample size, the correlation between rural poverty and afforestation is significant both in the tropics and globally ($P<0.05$, Table 1 and Figure 12), and may reflect that those with no better alternatives, resort to using (and perhaps clearing) forest to earn an income.

[Figure 12 near here]

Information

The ability to realize alternatives requires information, both to enable people to find jobs, and to envisage new business opportunities. Thus there should be a correlation between afforestation and information services. In Table 1 and Figure 13, we see significant correlations with adult literacy, internet use and daily newspapers ($P\leq0.02$). Other indicators offer a correlation similar to that of literacy (e.g., expected years of schooling) and daily newspapers (e.g., radio and telephone ownership). Clearly, these indicators reveal not only access to information, but also disposable income and the efficacy of basic services.

[Figure 13 near here]

Government services

In some developing countries, few services work properly, so it is no surprise that forestry does not work as it should. Forest management does not stand in isolation, so halting deforestation also means getting government services to work. This is evident in several entries in Table 1, including the correlations with electricity consumption and paved roads (Figure 14). The correlation with paved roads is an indication of the ability of a society to provide and maintain infrastructure, not an indication that paved roads are the path to forest conservation. One should not assume that paving the trans-Amazon highway will help to reduce deforestation (it is likely to have quite the opposite effect!). The inference that should be drawn is that a society with the financial and intellectual resources to pave and maintain roads should also have the ability to provide incentives to manage forests wisely. Similarly, consumption of electricity reflects the ability of society to maintain an electrical distribution network, the presence of industry, and of households wealthy enough to have electrical appliances.

[Figure 14 near here]

Confidence

Forestry is a long-term enterprise, and conserving forests requires confidence in the future. Hence concern for, and conservation of forests requires people who are not pre-occupied with finding their next meal, and governments and investors who have confidence in the future. There is ample empirical data to support this contention. Both foreign investment and credit rating are correlated with the propensity to afforest (Figure 15). The trend with foreign investment holds for both total and relative investment (i.e., per capita or per unit GDP).

[Figure 15 near here]

Population

One-quarter of recent studies attribute deforestation to population (Rudel *et al* 2000), so it is appropriate to examine the correlation between afforestation and population. FRA 2000 data suggest that population density has a negligible effect on deforestation, both in the tropics and world-wide ($P>0.5$), although there is some evidence that rapid population growth may contribute to deforestation (Table 1 and Figure 16).

[Figure 16 near here]

Subsidies

Subsidies have received much attention, and are generally viewed as detrimental to forests (e.g., Browder 1985). However, the FRA 2000 data offer a different view. Figure 17, based on World Bank (2000) data, reveals that most countries that afforest have subsidies exceeding 20 percent of total government expenditure, and that many countries that deforest have lower subsidies. The correlation between subsidies and afforestation is significant at the global scale ($r = 53\%$, $P<0.0001$), and comparable within the tropics ($r = 21\%$, $P=0.1$, Figure 17). The trend holds for subsidy data from 1990, 1997, and for the average of both these years. This does not imply that an increase in subsidies will reduce deforestation; it may simply reflect the fact that nations that can afford such subsidies are wealthy nations that have already solved their deforestation problems in other ways. However, it does suggest that the role of subsidies in managing deforestation should be reconsidered.

[Figure 17 near here]

Synthesis

Clearly, there are many factors that may help to explain observed patterns of deforestation, alone or in conjunction. This study commenced by exploring single factors, but it can be informative to consider several factors in conjunction (cf. Figure 6). Such analyses are not straight-forward, because the available data contain many correlated variables (cf. life expectance and infant mortality, Figure 10), and there may be no single 'best' explanation of the observed trends. Nonetheless, conventional stepwise linear regression with the variables explored in this study leads to a plausible model for afforestation:

$$Affor = 0.02\ Roads + 0.01\ Subsidies + 0.02\ Industry - 0.7\ Forest - 0.3\ Population - 1.2 \qquad (2)$$

(see Table 2 for details). A similar equation which also performed well included the terms roads, subsidies, population and poverty (% population below poverty line; $r^2 = 61\%$, $n = 57$). The number of treaties signed was considered, but when included in a model was generally not significant (i.e., $P>0.05$) and was never positive, adding weight to the argument that treaties are ineffective. Partial correlations indicate the performance of a model by revealing any residual trends not accommodated and highlighting variables which may have been omitted. Table 1 reveals that none of the partial residuals resulting from Equation 2 are significant, confirming that Equation 2 is a sufficient model. The adequacy of Equation 2 is demonstrated by the probabilities reported in Table 2, and by an F-test assessing overall model performance ($F_{5,68} = 18.9$, $P < 0.0001$).

[Table 2 near here]

Equation 2 should be interpreted cautiously. It is descriptive, not predictive, and thus one should not conclude that paving more roads will help to save forest. Equation 2 does not predict future afforestation patterns, but helps to explain the patterns that were observed during 1990-2000. It could be used to infer likely afforestation rates for a nation not surveyed in FRA 2000, provided that the nation was representative of those in FRA 2000 (e.g., that it did not have extraordinary soil fertility, a benevolent dictator, etc).

Equation 2 includes *roads, subsidies, industry, forest* and *population*. Some of these variables are consistent with those in other studies (e.g., *forest* and *population* in

Mahapatra and Kant 2005; subsidies in Fredj *et al* 2004), but the *roads* variable has a different sign, suggesting that it should be interpreted broadly. For instance, it is likely that in equation 2, the variable *roads* reflects the general ability of a nation to provide and maintain government services, rather than the relative amount of paved and unpaved road *per se*. Similarly, *industry* is likely to reflect employment opportunities other than primary agriculture and timber-getting. Even population, which appears straight forward, is unlikely to represent a causal relationship, and probably reflects the fact that it is profitable to convert fertile lands (which support high populations) to agriculture, whereas infertile and remote lands remain forested and sparsely populated. Hence one should not assume that condoms and concrete can save the forests.

A better understanding of Equation 2 is gained by recognizing that each of the five variables can be interpreted more broadly. The proportion of paved roads is just one easy-to-measure indicator of good governance, and it is good governance that fosters wise land use decisions (which of course, need not preclude the judicious conversion of forest to agriculture where it is in the national interest). Subsidies may act directly to foster afforestation, but may also reflect governments that have made considered strategic decisions to foster particular activities, and which have also created deliberate land-use policies. Value-adding by industry is likely to reflect employment (and small-business) opportunities that are attractive alternatives to timber-getting and primary agriculture (and hence forest clearance).

On its own, relative forest area has a weak correlation with afforestation ($r = -10\%$, $P=0.09$), but its partial correlation increases substantially when used in conjunction with other variables (Table 2). When considered on its own, the correlation with relative forest area suggests that nations will tend towards 29% forest. This probably reflects the attitude common in many frontier areas that there is plenty of forest and too little agricultural land. The 29% equilibrium-point will depend on the other variables in Table 2, but may also be influenced by changing this attitude, through education of both politicians and the populace about the environmental services provided by forests. Such education has been found to enhance the effectiveness of conservation parks (Vanclay 2001). Curiously, this 29% equilibrium point is close to that observed in empirical studies in Costa Rica (Kleinn *et al* 2002). However, the inference from Table 2 (with the mean values of other variables) is that nations will tend towards no forest, unless the other variables vary (i.e., roads/governance, subsidies/strategies, industry/alternatives) from their overall mean. An analysis of Table 2 indicates that a 13% improvement in these three variables could be sufficient to stabilize forest areas. While this estimate of 13% should not be taken literally, it does suggest that the task is not insurmountable.

In Table 2, the probabilities (P) indicate the certainty that the effect exists, and the elasticity indicates the nature of the change in response to a unit change in the variable. An ever-diminishing area of forest has little effect on deforestation trends (elasticity = -0.14), but relatively small change in governance (viz. *roads*) has a relatively large influence (elasticity = 0.53). Thus the elasticities reported in Table 2 suggest possible priorities for development assistance, with good governance deserving top priority.

Correlation or co-incidence?

In an analysis of this kind where many relationships are explored, there is always the danger that the selected relationships may arise simply due to chance variation. For instance, if we compare the afforestation data with twenty sets of random numbers, we expect that one of the sets of random numbers will show a correlation with a statistical significance of $P \leq 0.05$. I have tried to minimize that danger by avoiding an exhaustive analysis of all possible combinations; instead targeting indicators selected to shed light on the hypotheses stated earlier (halting deforestation requires profitable alternatives and services such as health, education and transport). Nonetheless, it is useful to construct a test to examine the likelihood that these findings are due to chance. Chance findings should exhibit probabilities that are randomly distributed between zero and one, so the ranked probabilities will tend to fall in a straight line. Selective reporting of chance probabilities would lead to ranked probabilities that form a straight line between zero and the threshold probability level (e.g., 0.5), whereas substantive findings are likely to depart from such a trend. Figure 18 illustrates the ranked probabilities reported in this study. The cumulative distribution departs significantly from a straight line, offering reassurance that the reported results are not merely due to chance. Another test is to observe that 36 instances of $P \leq 0.001$ have been reported. If these were due to solely to chance, they would represent a censored sample from 36,000 statistical tests (in fact, a total of some 300 statistical tests were made). While it is impossible to rule out the possibility that some individual correlations are entirely due to chance, it is likely that the overall findings are reasonable, given the nature of the underlying data.

[Figure 18 near here]

CONCLUSION

Deforestation patterns are complex and diverse, and it is unreasonable to expect that a single variable should offer a unique insight into the various mechanisms at work. Nonetheless, the figures presented here offer some thought-provoking trends that may help to stimulate discussion and provoke further research. This paper was precipitated by a discussion about the utility of a global convention on forests. Given the nature of deforestation, it is not surprising that there is no evidence that existing environmental treaties have been effective in halting deforestation. It is unclear what this means for a global convention on forests, but it is tempting to conclude that such a convention will only be effective if it is supported by other measures (such as payments for environmental services, e.g., Wunder 2005). The evidence regarding the efficacy of development assistance in reducing deforestation is equivocal, so it is clear that international and bilateral efforts to halt deforestation will need to be carefully targeted. The FRA 2000 data offer some indications that deforestation may be halted through efforts to foster good governance, encourage education and provide opportunities for employment. The FRA 2000 data also suggest that subsidies may be effective and these and other payments for environmental services warrant further examination.

ACKNOWLEDGEMENTS

Tim Boyle and two anonymous reviewers provided helpful comment that substantially improved the manuscript.

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Table 1. Correlation between selected indicators and afforestation (square-root of % change in forest area), ranked by significance (P) of the correlation for tropical nations. Indicators that are consistently contrary to the expected trend are shown in **bold**.

Indicator	Units	Years	Tropical (<25º)			Global			Partials[7]		
			R	n	P	R	n	P	r	n	P
Rural population[1]	% of population	1999	-40%	109	<.0001	-45%	181	<.0001	-3%	74	0.4
Life expectancy[2]	years (at birth)	2004	40%	108	<.0001	46%	180	<.0001	7%	74	0.3
Gross domestic savings[4]	%GDP	1990-99	46%	58	0.0001	37%	128	<.0001	-5%	71	0.3
Gross domestic product[2]	Log_{10}(US$/capita)	1999	34%	108	0.0002	41%	180	<.0001	1%	74	0.5
Infant mortality[2]	Log_{10}(deaths/1000 live births)	2004	-33%	108	0.0002	-41%	180	<.0001	-3%	74	0.4
Adult illiteracy[2]	Log_{10}(% unable to read/write)	1997	30%	106	0.0009	42%	176	<.0001	0%	74	0.5
Internet access[2]	Log_{10}(% using internet)	2000	29%	104	0.001	40%	175	<.0001	2%	74	0.4
Credit rating[4]	% institutional investor	2000	38%	53	0.002	46%	120	<.0001	-6%	70	0.3
CO^2 emissions[4]	Log_{10}(tons/capita)	1990	36%	57	0.003	52%	126	<.0001	-6%	69	0.3
International reserves[4]	Log_{10}(US$ million)	1990	33%	59	0.005	22	127	0.006	-12%	74	0.2
Commercial services[4]	Log_{10}(US$ million)	1990-98	33%	59	0.005	31%	111	0.0005	-3%	73	0.4
Agricultural value-adding[4]	% of GDP	1990-99	-33%	60	0.005	-42%	114	<.0001	2%	74	0.4
Electricity consumption[4]	Log_{10}(Kwh/capita)	1990-97	38%	41	0.007	34%	109	0.0001	5%	62	0.3
Poverty[2]	% below poverty line	2000	-27%	69	0.01	-42%	111	<.0001	-9%	55	0.3
Agricultural productivity[4]	Log_{10}($ value added/worker)	1996-98	31%	56	0.01	31%	112	0.0004	-1%	64	0.5
Environmental treaties[5]	count (0-10)[6]	2000	-22%	94	0.02	-1%	166	0.4	-18%	74	0.06
Daily newspapers[4]	Log_{10}(Papers/1000 people)	1996	29%	52	0.02	46%	125	<.0001	3%	68	0.4
Rural poverty[4]	% below poverty line	1993	-36%	30	0.03	-46%	48	0.0005	-6%	30	0.4
Industrial value-adding[4]	% of GDP	1990-99	24%	60	0.03	42%	113	0.0004	*		
Paved roads[4]	% by distance	1990	24%	55	0.05	68%	123	<.0001	*		
Foreign direct investment[4]	Log_{10}(US$ million)	1990-98	22%	54	0.05	15%	124	0.05	-2%	71	0.4
Corruption index[3]	0=corrupt - 10=honest	2003	22%	56	0.05	38%	120	<.0001	-1%	68	0.5
State industries[4]	Log(%GDP value-added)	1990-97	16%	29	0.06	9%	42	0.3	23%	25	0.3
Population growth[4]	%/year	1990-99	-15%	108	0.06	-37%	180	<.0001	-10%	73	0.1
Inflation rate[2]	%/year	2002	-15%	102	0.07	-3%	172	0.4	-1%	74	0.5
Subsidies[4]	% of total expenditure	1990-97	21%	38	0.1	53%	92	<.0001	*		
Wealth distribution[2]	Gini coefficient	1995	-14%	110	0.2	-53%	104	<.0001	-3%	63	0.4
Access to clean water[4]	% of population	1990-96	11%	58	0.2	46%	100	<.0001	-11%	52	0.2
Unemployment[2]	% of population	2001	-10%	72	0.2	-27%	139	0.0006	-9%	65	0.3
Education[4]	years of schooling	1997	14%	23	0.3	56%	69	<.0001	-16%	43	0.2
Forest area	%	2000	8%	110	0.2	-10%	182	0.09	*		
Population density[1]	Log_{10}(people/km2)	1999	1%	110	0.5	3%	182	0.7	*		

1. FRA 2000;

2. CIA 2004;

3.Transparency International 2003.

4. World Bank 2000.

5. ENTRI 2004.

6. Score 1 for party to (½ for signing but not ratifying) each of the following treaties: Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, 1971); Convention concerning the Protection of the World Cultural and Natural Heritage (1972); Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES, 1973); International Tropical Timber Agreement (1983); Montreal Protocol on Substances that Deplete the Ozone Layer (1987); *Convention on Biological Diversity* (1992); United Nations Framework Convention on Climate Change (1992); International Tropical Timber Agreement (1994); *United Nations Convention to Combat Desertification in those Countries experiencing Serious Drought and/or Desertification, particularly in Africa* (1994); *Kyoto Protocol to the United Nations Framework Convention on Climate Change* (1998).

7. Partial correlations indicate any residual trends not explained by Equation 2; asterisks indicate variables included in Equation 2.

Table 2. Parameter estimates for equation 2, based on 74 observations (r^2 = 58%).

Source	Units	Estimate	s.e.	P	Elasticity
Intercept		-1.241	0.379	0.002	
Roads	% of roads paved	0.016	0.003	<.0001	0.53
Subsidies	% total government spending	0.011	0.004	0.01	0.23
Industry	% value added	0.018	0.009	0.03	0.16
Forest	% of land area in 2000	-0.699	0.382	0.04	-0.14
Population	Log_{10}(people/km^2)	-0.258	0.145	0.04	-0.16

Figure 1. Cumulative distribution of forest change data (FRA 2000) before (left) and after (right) square-root transformation. Notice that after transforming, the data points correspond more closely to the normal distribution (dashed line) assumed in statistical analyses.

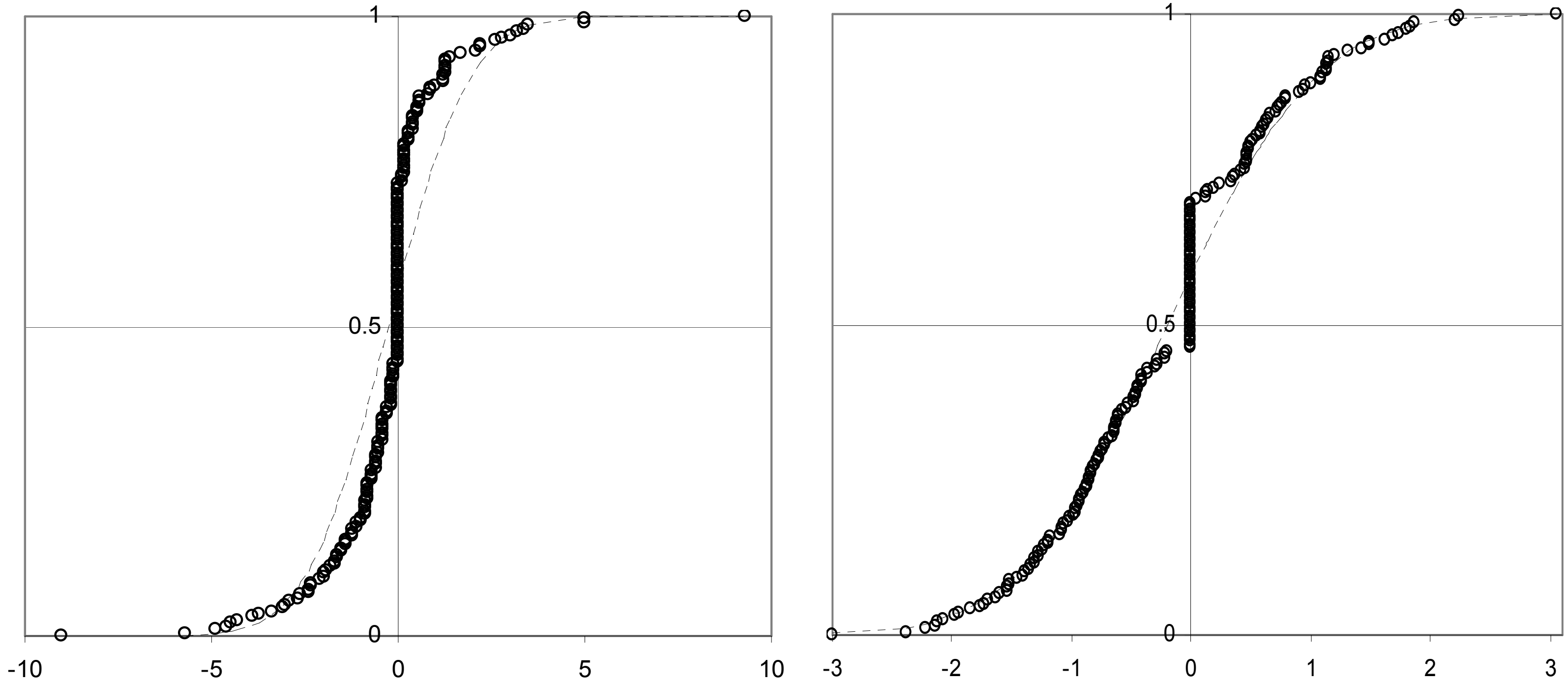


Figure 2. The effect of a logarithm transformation on population density data and its relationship with afforestation (square root of change in forest area). Solid circles and solid line are tropical nations; empty circles are temperate nations, and the dotted line is the global trend.

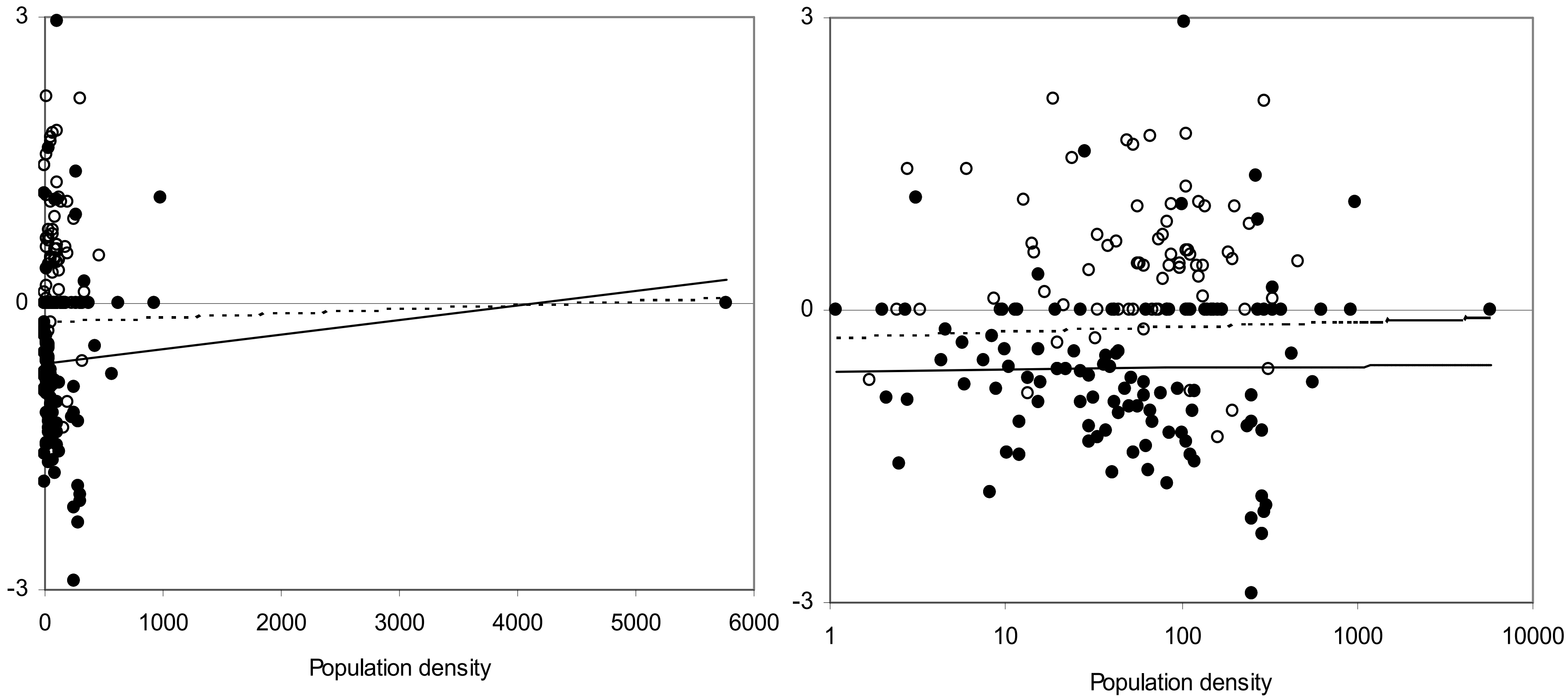


Figure 3. Afforestation (square root of change in forest area) is correlated with latitude, with most deforestation occurring in the tropics (≤25º latitude).

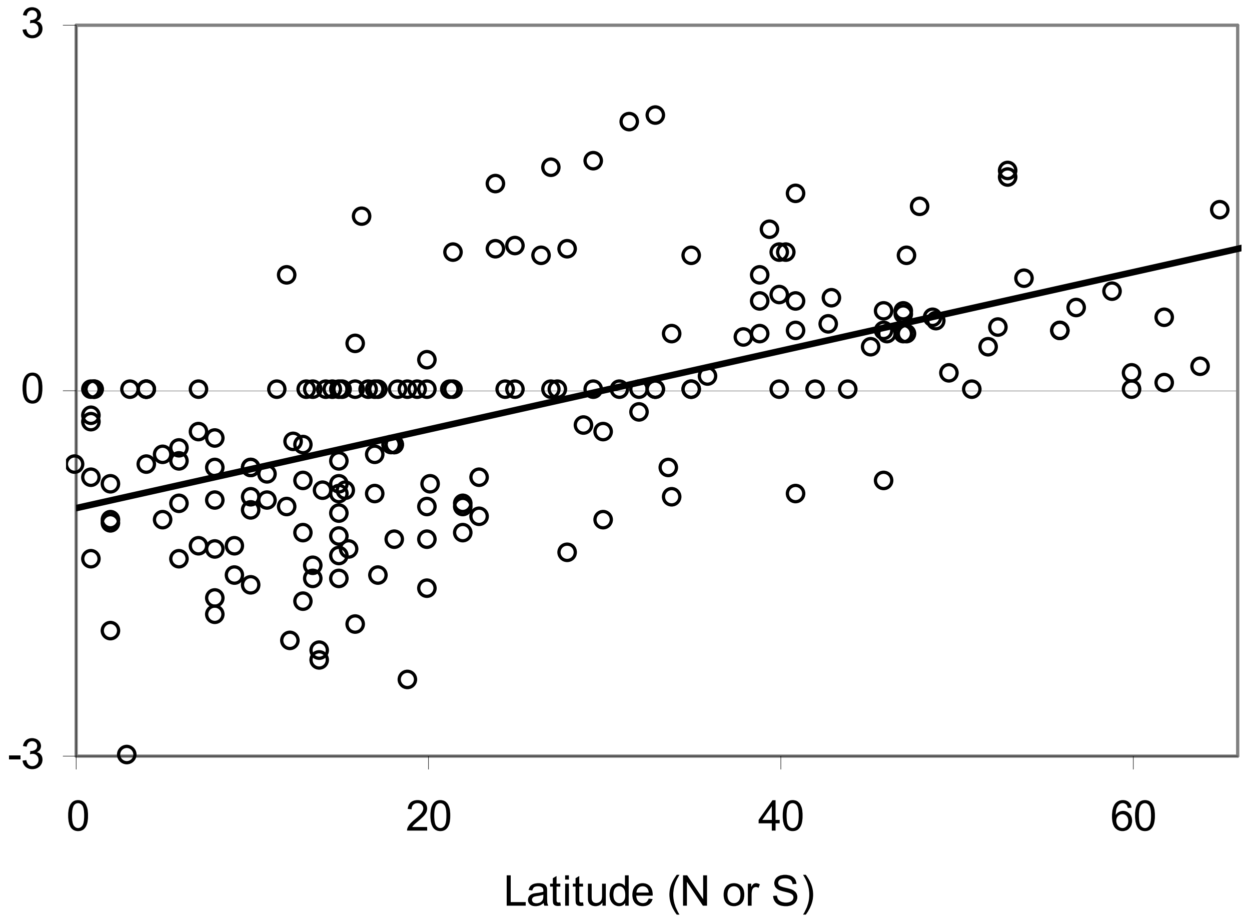


Figure 4. Participation in international treaties provides no guarantee that deforestation will cease. Solid circles and solid line are tropical nations; empty circles are temperate nations, and the dotted line is the global trend. There is no evidence that treaties are effective in conserving forest.

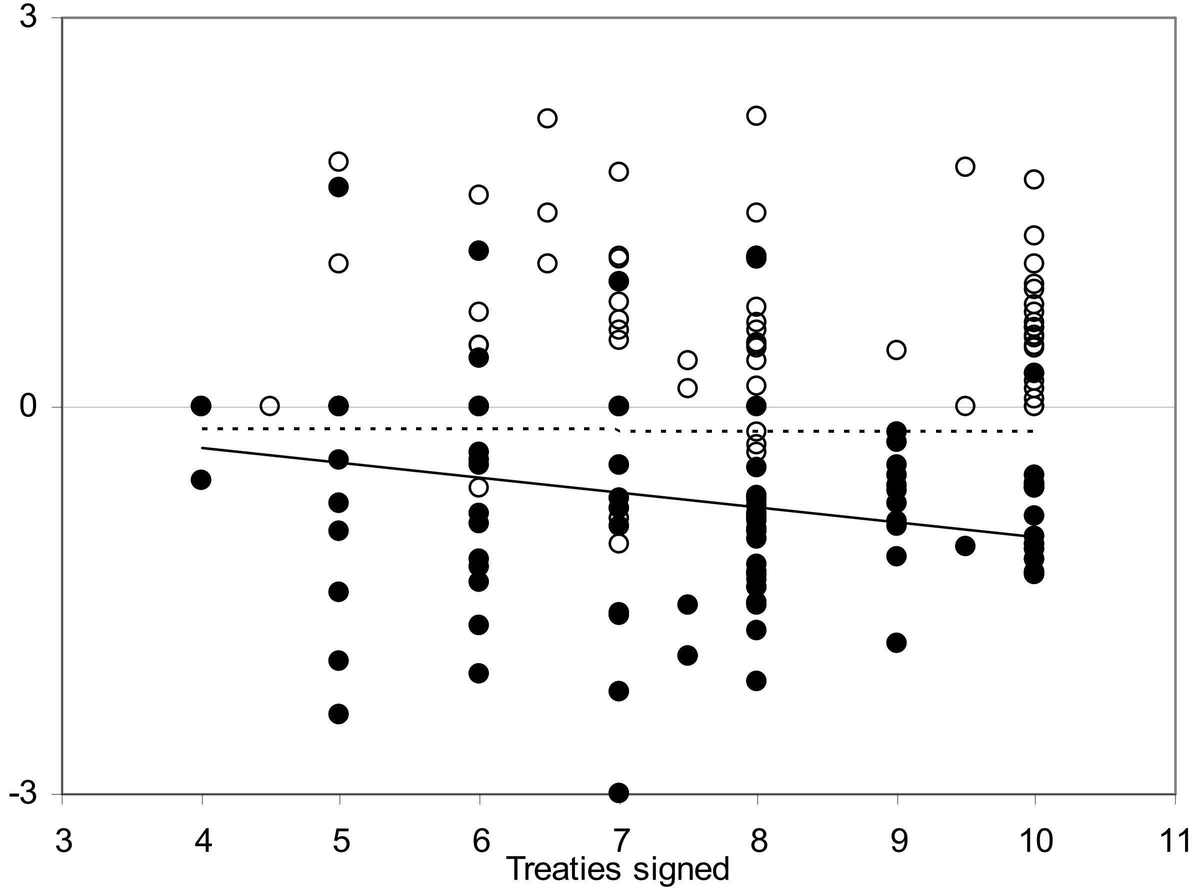


Figure 5. Development assistance and afforestation, based estimates from CIA (2004) and World Bank (2000). Filled circles and solid line are tropical, empty circles are temperate nations, and the dashed line represents the global trend.

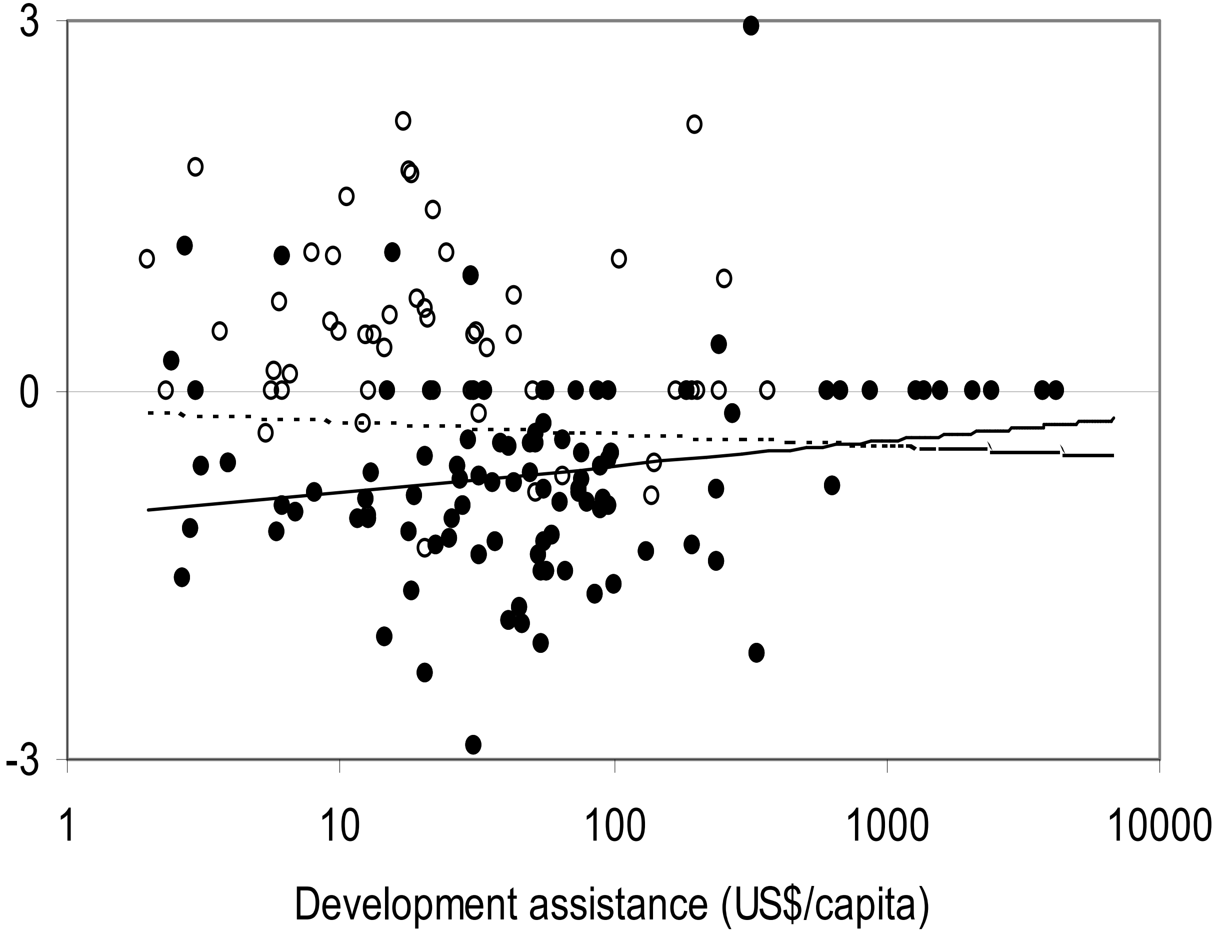
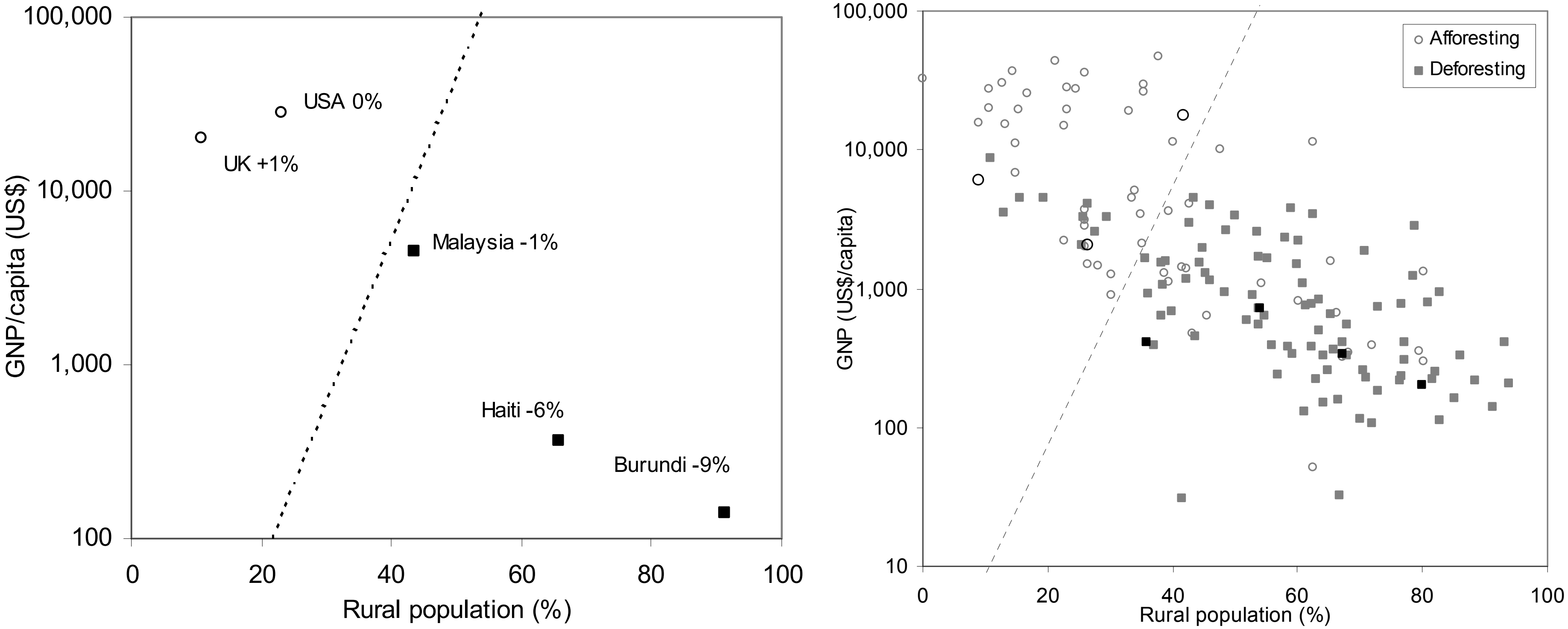


Figure 6. Propensity to afforest plotted against GNP (US$/capita in 1997) and rural population (% in 1999) for selected countries (left) and for all FRA 2000 countries (right). Filled squares are deforesting nations, and open circles are afforesting countries. The 3 large circles and 4 black squares denote countries with rates exceeding ±3% and 500,000 ha/year.



599 **Figure 7**. Indicators reflecting alternative employment and their correlation with afforestation.

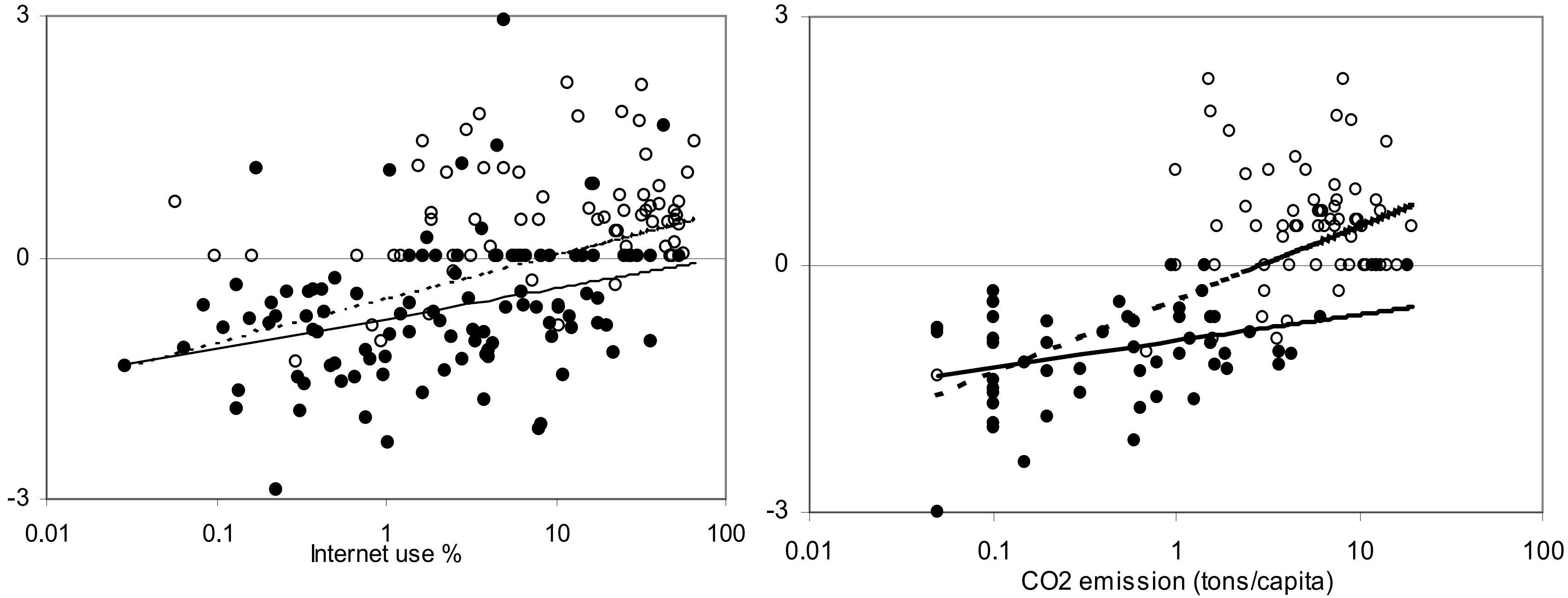


Figure 8. Increased commercial and industrial activity may lead to a reduction in deforestation.

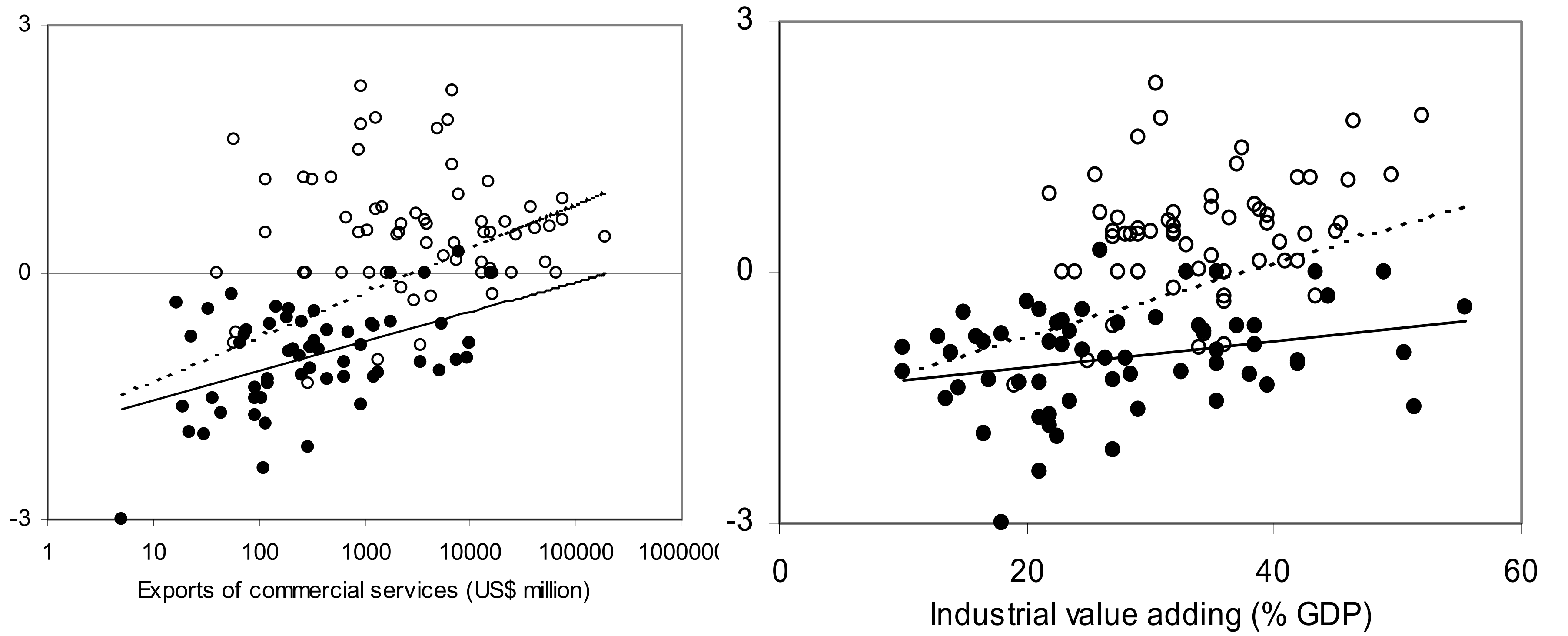


Figure 9. Afforestation is favoured by increasing the value-added per worker, but not by increasing the agricultural contribution to GDP.

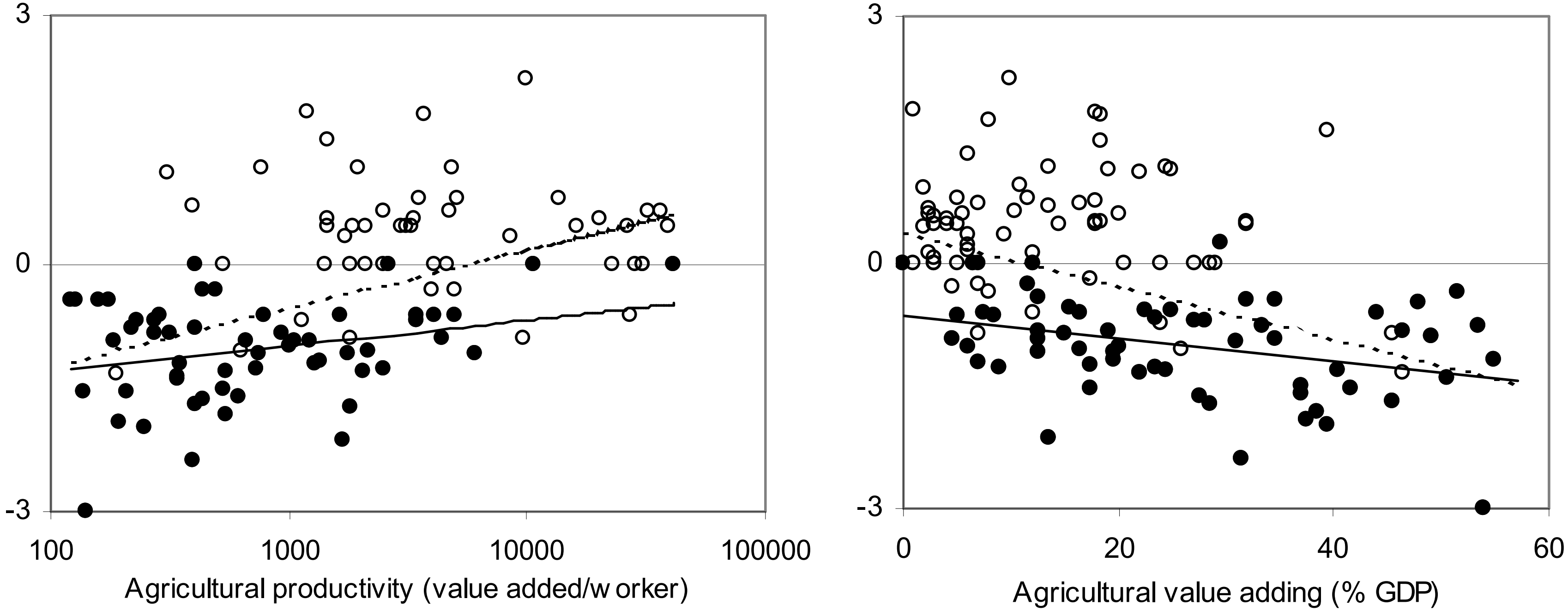


Figure 10. Health indicators and propensity to afforest. Nations with better health (longer life expectancy and fewer infant deaths) tend to have less deforestation.

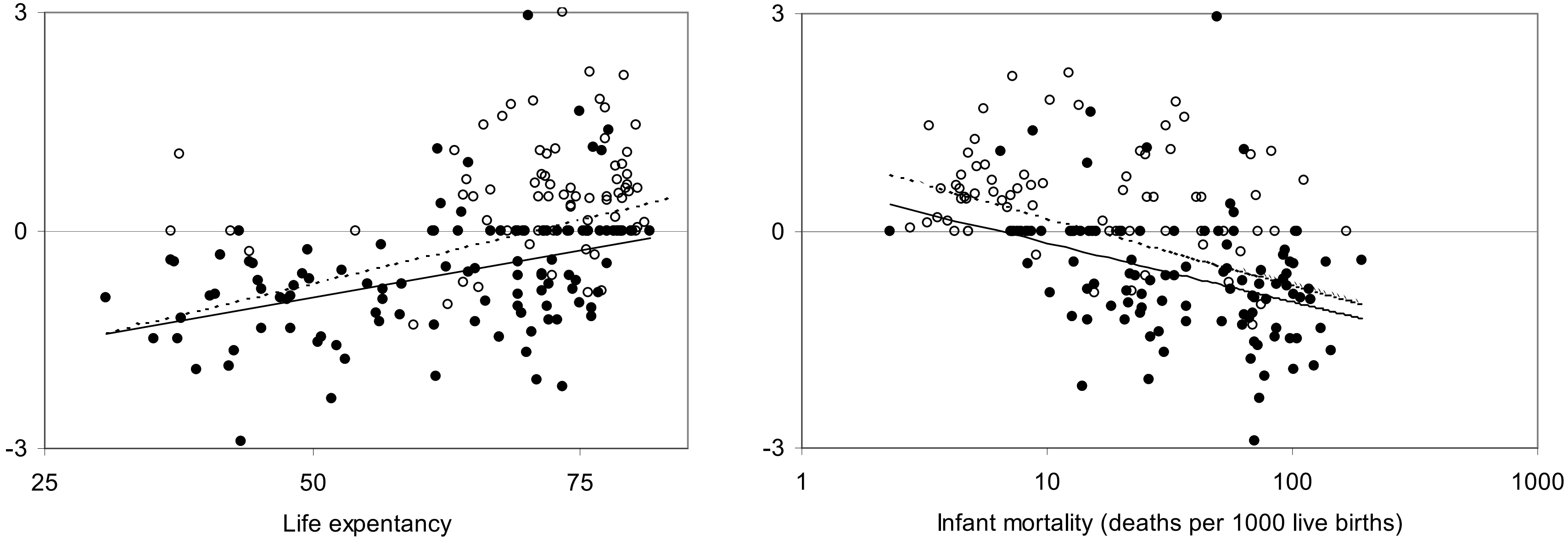


Figure 11. Afforestation tends to increase as national savings (as a % of GDP) increase, and as international reserves increase.

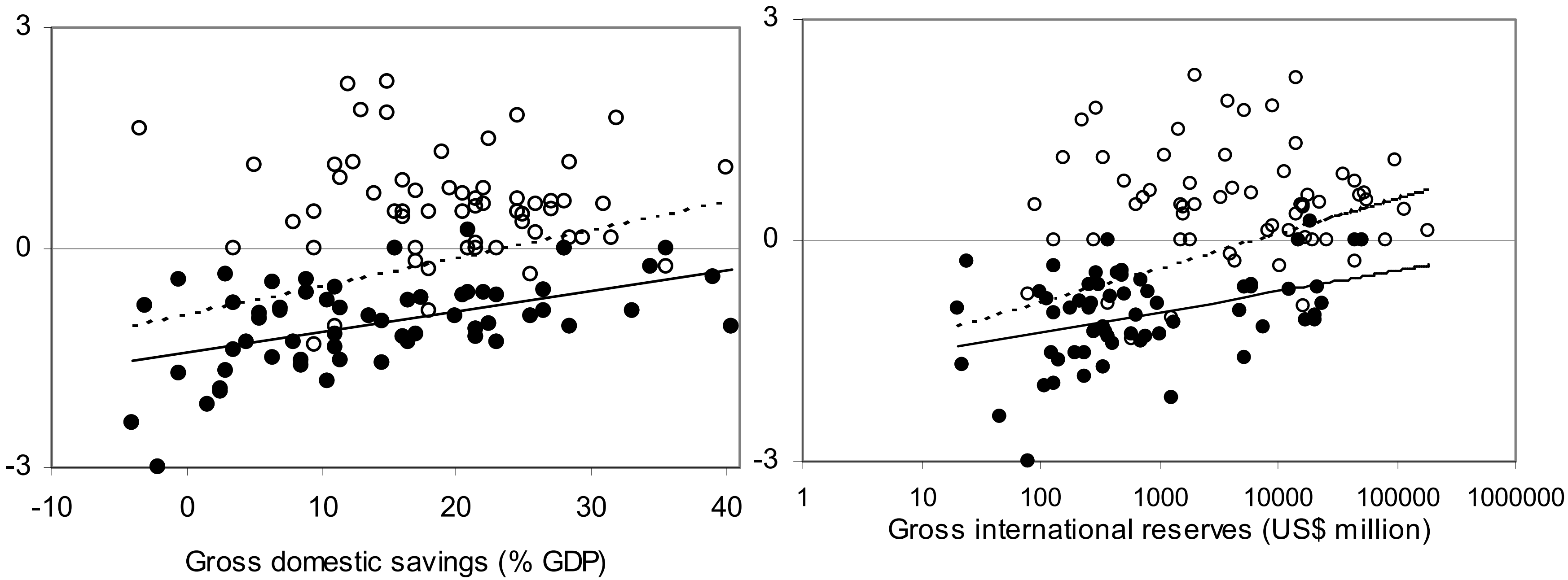


Figure 12. Afforestation may be influenced by wealth distribution (left) and rural poverty (right). Less rural poverty, and a more equal distribution of wealth, favour afforestation.

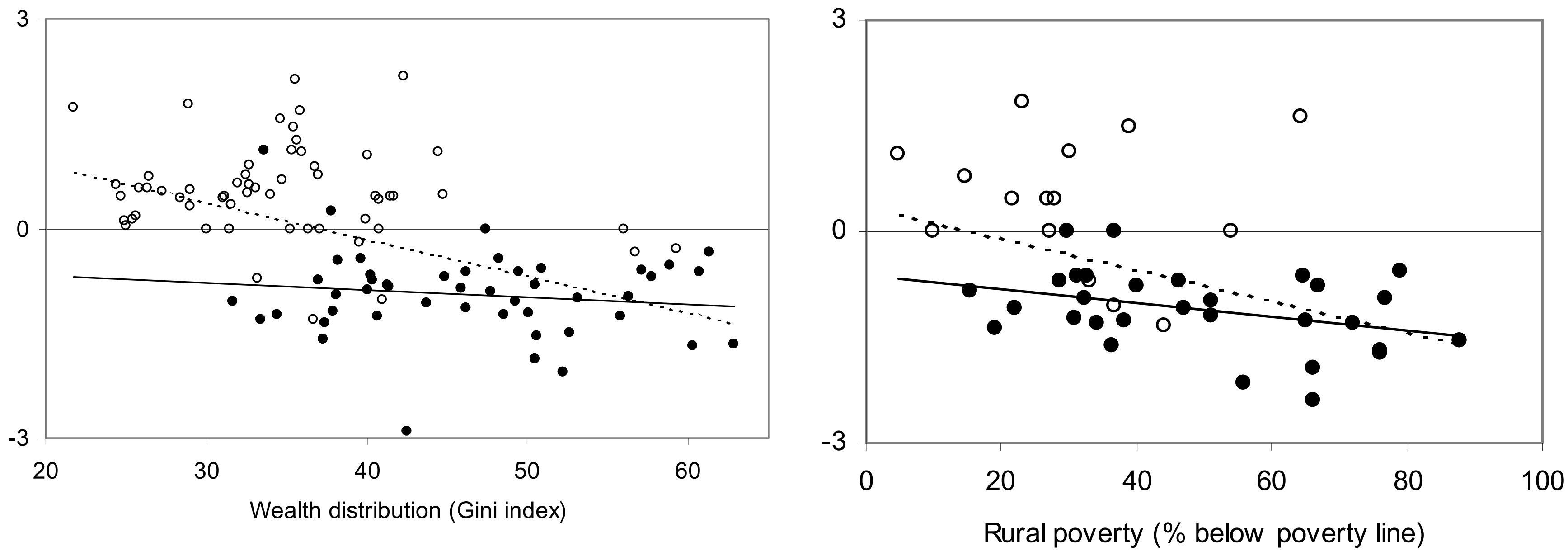


Figure 13. Making information accessible helps to halt deforestation. Left shows illiteracy, the percentage of adults over 15 unable to read, on a logarithmic scale.

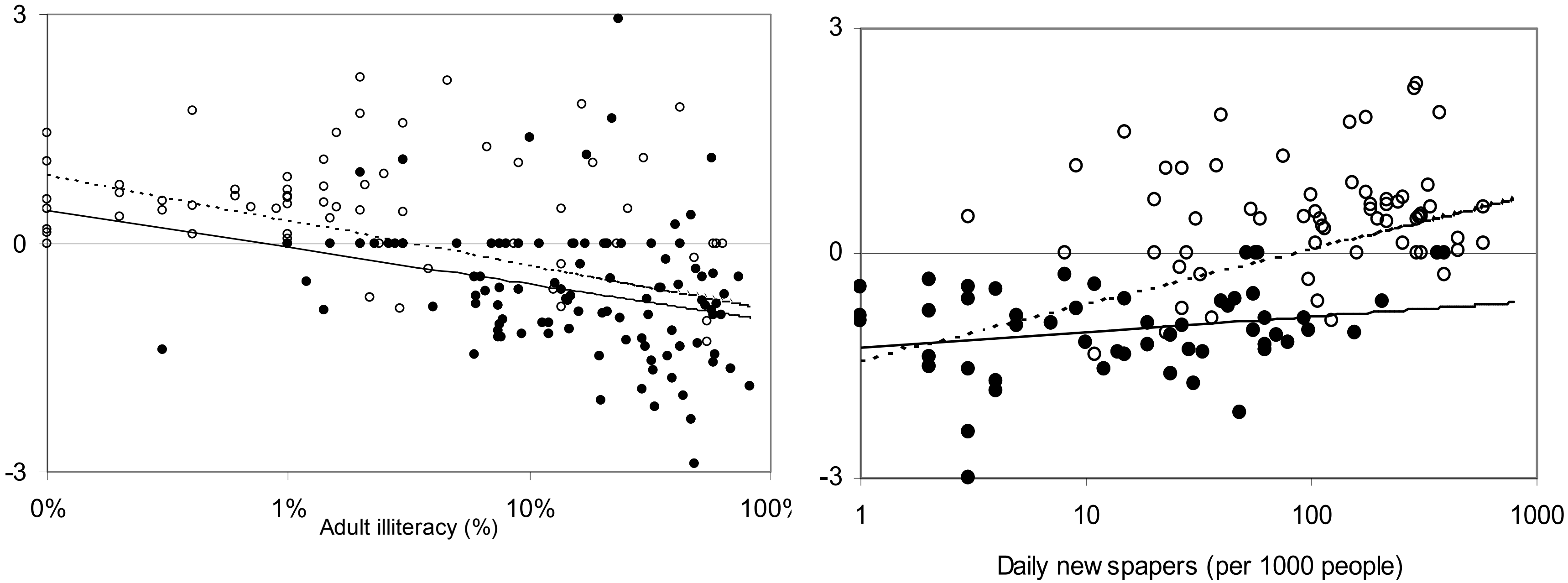


Figure 14. The provision of paved roads and of electricity are indicators of society's ability to provide and maintain services.

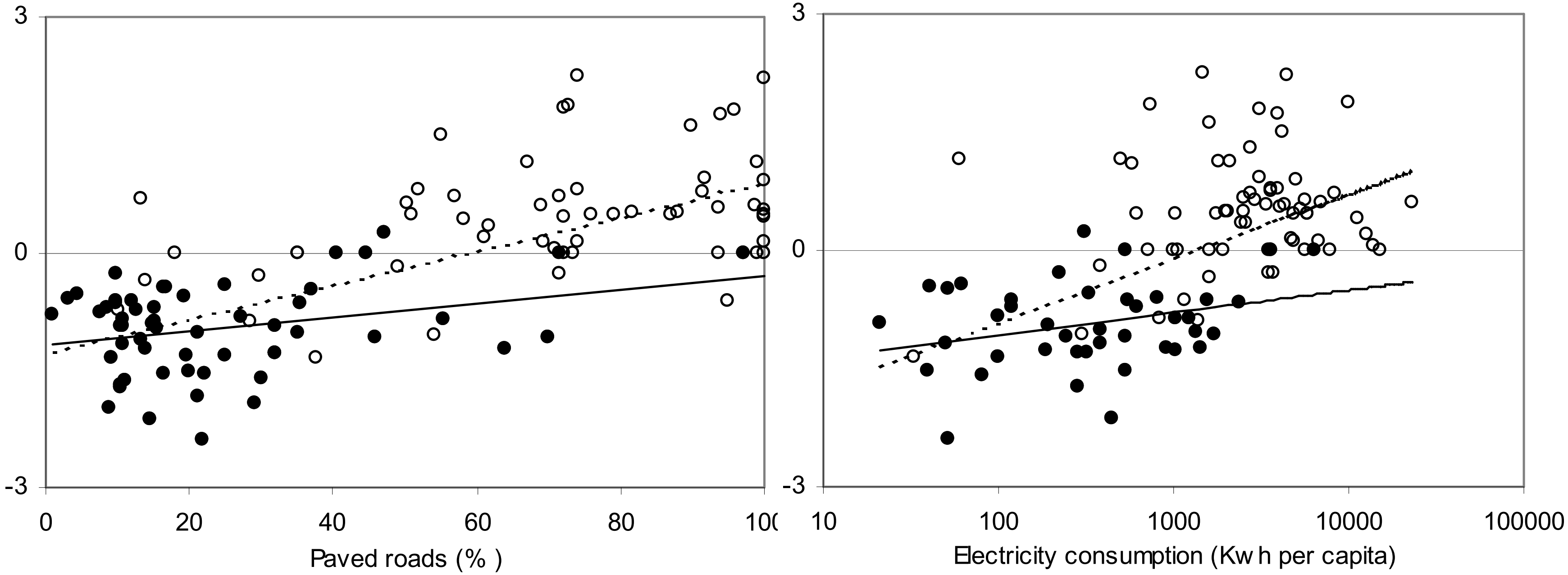


Figure 15. Confidence, reflected here as foreign investment (left) and credit rating for institutional investors (right), increases the propensity to afforest.

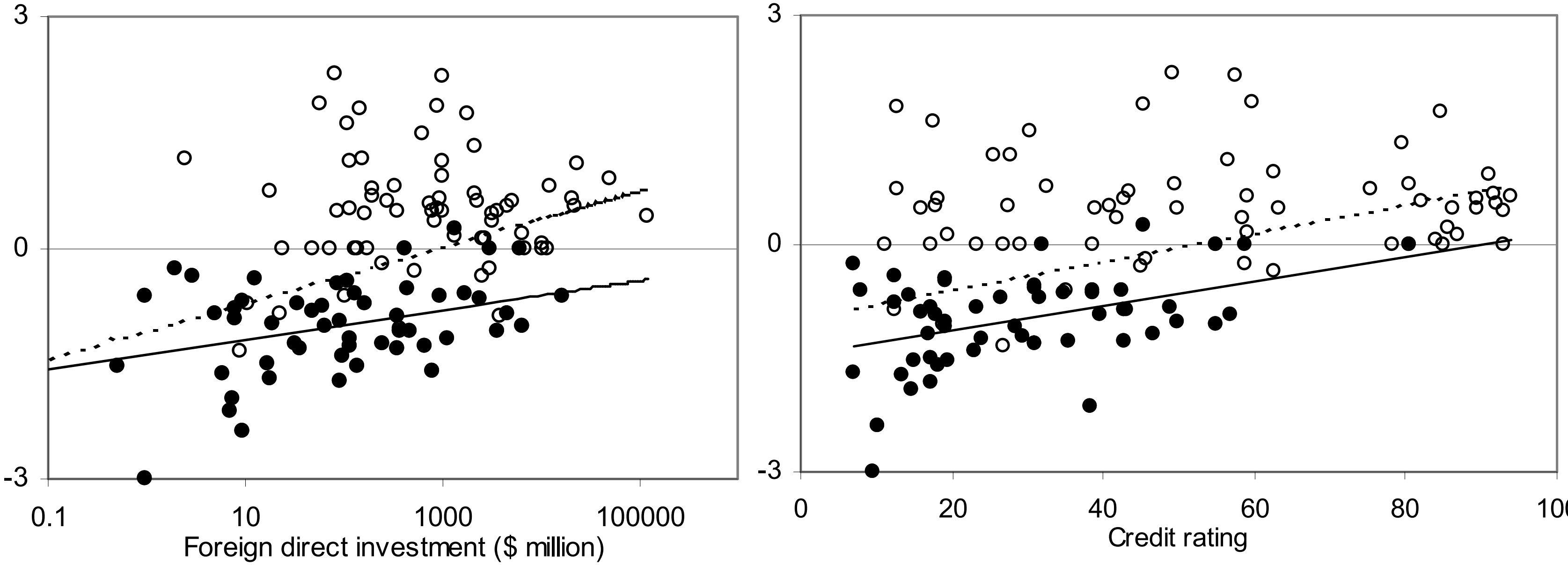


Figure 16. The correlation between population density and afforestation is weak, whereas rapid population growth rates tend to be associated with deforestation.

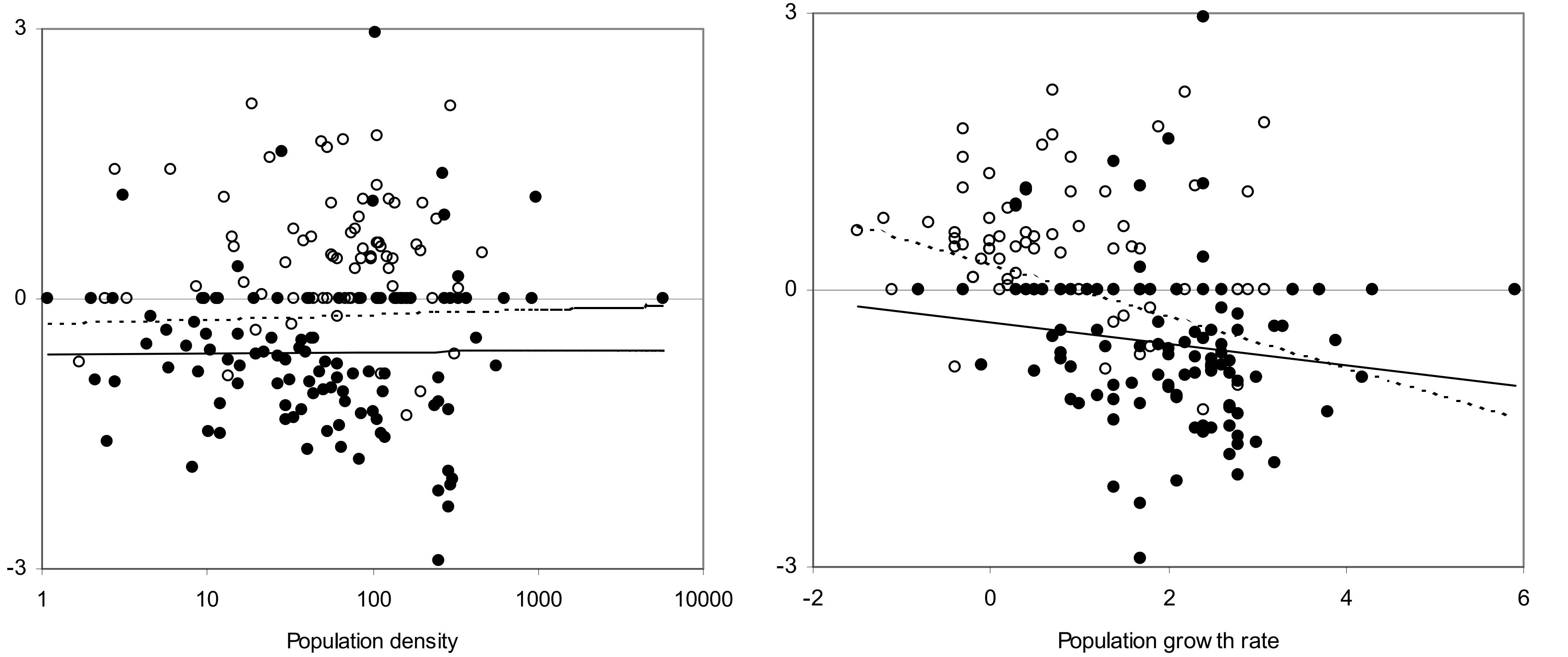
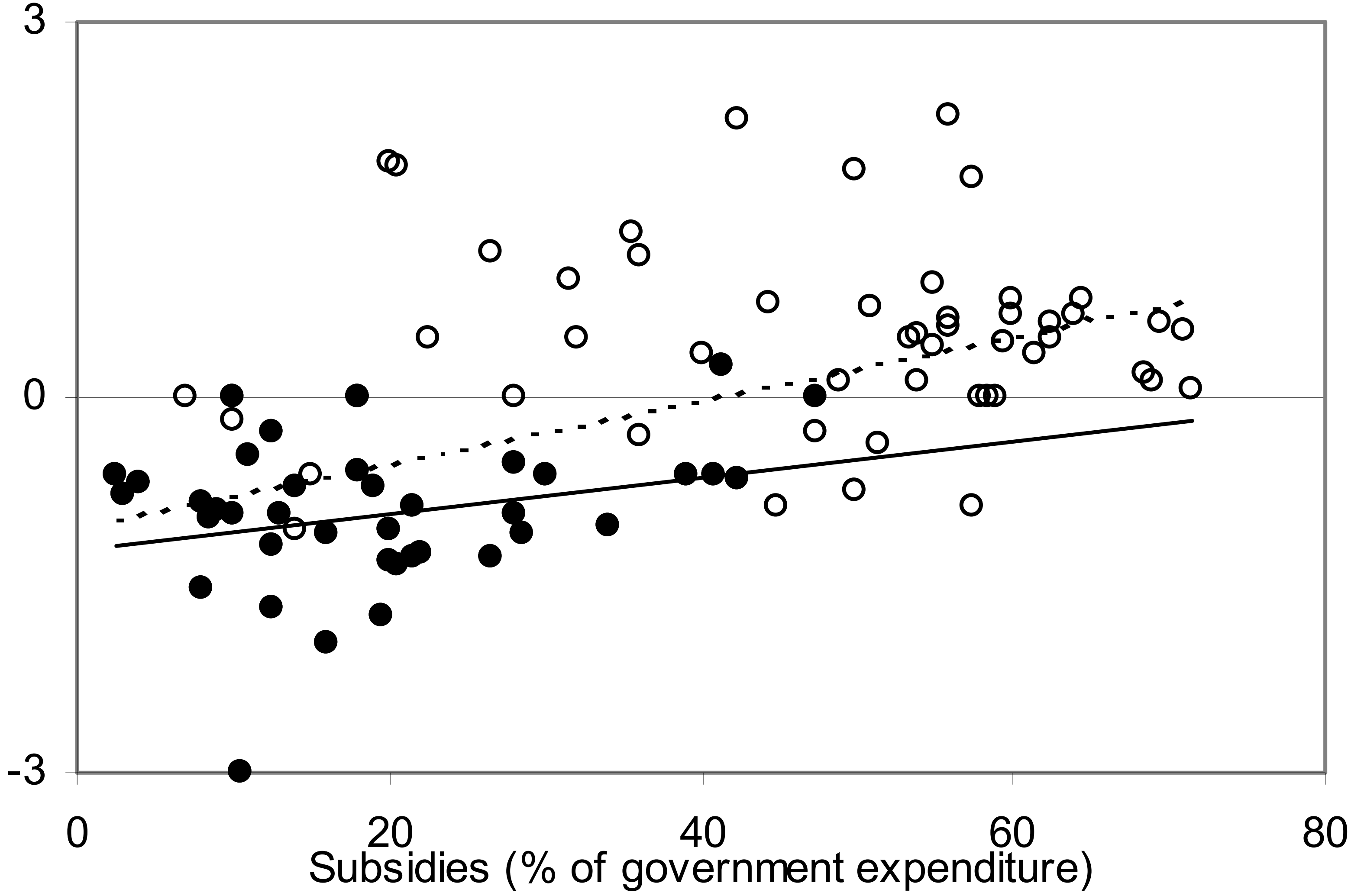


Figure 17. Subsidies and afforestation.



616 **Figure 18**. Ranked probabilities reported in this study are not random.