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Interaction effects between economic development and forest cover determine deforestation rates

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Abstract

Recent work on global patterns of deforestation has shown that countries with high per capita GDP or low remaining forest cover are more likely to be experiencing afforestation than deforestation. Here, I show that the relationship is more complex than previously described, because the effect of one variable is dependent upon the value of the other. As a result, high-income nations exhibit the opposite response to disappearing forest cover than low-income nations. In an analysis of 103 countries, I found that high-income countries with low forest cover have the highest rates of afforestation, typically through the establishment of new plantations. In contrast, low-income countries with little forest are more likely to consume that remaining portion at a faster proportional rate than do low-income countries with more forest. Nations with large amounts of forest have approximately equal deforestation rates, regardless of national wealth. These results highlight for the first time that there is a strong interaction between forest cover and economic development that determines rates of forest change among nations.

Keywords: Afforestation; Deforestation; Economic development; Forest cover; GDP; Plantation

1. Introduction

Global deforestation is widely recognised as one of the world's leading environmental problems (Dobson et al., 1997; Brook et al., 2003; Sodhi et al., 2004). Landuse change, of which deforestation is a major component, is listed as the biggest threat to global biodiversity (Sala et al., 2000) and deforestation alone accounts for up to one quarter of all anthropogenic carbon emissions, contributing directly to ongoing concern over global warming (Houghton 1991). Furthermore, the impacts of widespread deforestation are reflected at a regional level in vastly elevated rates of soil erosion, the sedimentation of major waterways and an increased frequency and severity of floods (Sánchez-Azofeifa et al., 2002; Bruijnzeel, 2004; Sweeney et al., 2004). Because of the hefty economic consequences of these deforestation-related processes (Costanza et al., 1997; Balmford et al., 2002), there is now a considerable need to enhance our understanding of global patterns of deforestation and how they might be reversed.

Multi-national studies of the links between national wealth and national deforestation rates have become more common in recent years (e.g. Barbier and Burgess, 2001; Koop and Tole, 2001; Ehrhardt-Martinez et al., 2002; Rudel, 2002; Meyer et al., 2003; Rudel et al., 2005). The underlying assumption in the majority of these analyses is that deforestation rates are related to per-capita income in an inverted U shape—the Environmental Kuznets Curve (EKC; after Kuznets, 1955; see review by Dinda, 2004). The EKC theory states that in the initial stages of economic development, a nation draws heavily on environmental capital like forests to spur economic growth (Walker and Nautiyal, 1982; Barbier, 2004, 2005; Naidoo, 2004) and consequently rates of environmental degradation accelerate with growth in income. Eventually, natural

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capital becomes less central to the national economy (Koop and Tole, 2001; Barbier and Cox, 2003), and as people become more wealthy, pressure builds to improve and conserve environmental quality (Koop and Tole, 2001; Meyer et al., 2003). This eventually leads to reductions in the rate of environmental degradation as income increases further (Bhattarai and Hammig, 2001; Ehrhardt-Martinez et al., 2002; Dinda, 2004). Support for this theory as it pertains to deforestation has been equivocal at best (Dinda, 2004), with some authors presenting empirical data in support of the theory (Cropper and Griffiths, 1994; Rudel, 1998; Bhattarai and Hammig, 2001), others presenting data against it (Koop and Tole, 1999; Meyer et al., 2003), and yet others showing that it can be present or absent depending on the nature of the covariables used in the analysis (Ehrhardt-Martinez et al., 2002; Barbier, 2004). Refreshingly, this debate has recently been recast by Rudel et al. (2005). Instead of focusing on the shape of the relationship between deforestation rate and economic wealth, Rudel et al. (2005) focus solely on the 'forest transition', or the point at which declines in forest cover cease and recoveries in forest cover begin. They identify two causes for forest transitions (Rudel et al., 2005): (1) the 'economic development path' which is similar in theory to the EKC approach, and (2) the 'forest scarcity path', in which the loss of forest cover spurs increases in the price of forest products, encouraging landowners to invest in forestry schemes.

In this paper, I present the first test for an interaction between the economic development and forest scarcity paths of Rudel et al., (2005). I hypothesised that a nation's response to declining forest cover would be dependent on it's economic wealth, because wealthy governments should be more able than poor governments to implement afforestation schemes to actively reverse deforestation rates (Table 1). Although halting deforestation is clearly of paramount importance in nations with rapidly declining forest cover, a secondary response is to invest in plantation forestry which can substitute for the exploitation of natural forests (Matthews et al., 2000). Plantations of fast-growing trees present the quickest route to afforestation, they have proven economic benefits (Wright et al., 2000) and can ameliorate some of the environmental damage that occurs unimpeded in deforested landscapes (Matthews et al., 2000). To assess the extent to which plantation forestry underlies differences in deforestation rates between wealthy and poor nations, I examined the proportion of forest cover that was comprised of plantations, and tested to see if this could also be explained by among-nation differences in economic wealth, forest cover and their interaction.

Table 1
Summary of predicted variation in deforestation activities according to national wealth and extant forest cover

Forest cover	National wealth	
	Wealthy	Poor
High	No change	Deforestation
Low	Afforestation	Deforestation

Poor nations are expected to be drawing heavily upon natural resources to secure economic development and therefore are predicted to be experiencing deforestation, irrespective of the amount of forest cover remaining. Wealthy nations are less likely to be reliant of natural resources for maintaining economic growth, so should not be experiencing deforestation. Wealthy nations with little remaining forest cover are more likely to be increasing their forest cover than poor nations, because they are more able to fund expensive afforestation schemes.

2. Methods

I obtained rates of forest cover change for all available nations from the Food and Agricultural Organization of the United Nations (FAO, 2001). These data have been criticised for their uneven quality across nations and inconsistencies in definitions (Rudel and Roper, 1997; Barbier and Burgess, 2001; Rudel et al., 2005), but despite this they remain the sole source of cross-national information on deforestation rates through time (Matthews, 2001; Meyer et al., 2003). As such, they present the best opportunity for investigating variation in forest cover changes among nations (Matthews, 2001; Rudel et al., 2005). Rates of forest cover change were measured over the period 1990–2000 and are presented as a per-year percentage change in forest cover. Negative forest change rates reflect deforestation and positive values afforestation. The raw data exhibited a leptokurtic distribution, so positive values were transformed to $\log_{10}(x+1)$ and negative values to $-\log_{10}(|x|+1)$. The transformed data were normally distributed (Shapiro–Wilk normality test, $W = 0.985$, $P > 0.3$).

I tested for an effect of two variables and their interaction on rates of change in forest cover: per-capita gross domestic product (GDP) which is a widely used index of economic development (Koop and Tole, 2001; Meyer et al., 2003; Godoy et al., 2004), and the total amount of forest cover remaining (after Rudel et al., 2005). The analysis was repeated using the percent of land area covered in forest in lieu of total forest cover, but the results were quantitatively similar. Per-capita GDP in 1990, the first year of the period over which forest change was assessed, was obtained from the World Bank World Development Indicators Dataset (World Bank, 2004) and transformed to constant 2000 US$ for analysis. Total forest cover was obtained from the same source as the rates of forest change (FAO, 2001). Both GDP and forest cover were $\log_{10}$ transformed prior to analysis. Only nations for which data on all three variables (forest cover change, GDP and forest cover) were available were included in the analysis ($N = 103$). Data were analysed with multiple linear regression using R-software (R Development Core Team 2004).

To determine if the observed patterns in forest cover change could be partially explained by patterns of plantation forestry, I used two-way ANOVA to assess the effects of GDP and percent forest cover on the percent of a nation's forest that is comprised of plantations. Countries were classified into one of three income categories (Low, Middle or High; $N = 42$, 45 and 16, respectively) according to World Bank criteria (http://www.worldbank.org). The majority of low-income nations were African (69%), middle-income nations were predominantly Latin American (44%) and eastern European (29%), whereas high-income nations were mostly western European (75%). Nations were also categorized as having Low, Medium or High forest cover ($N = 33$, 30 and 40, respectively). The forest cover classes were determined arbitrarily to ensure there was an approximately equal sample size in each category (Low < 2 million ha, $N = 33$; Medium 2–10 million ha, $N = 30$; High > 10 million ha, $N = 40$). There were three countries included in the previous analysis for which data on the extent of plantations were not available, so these were excluded from this analysis.

3. Results

There was a strong positive effect of GDP on rate of forest cover change, and also a strong interaction between GDP and forest cover, indicating that the effect of forest cover on rates of forest cover change is dependent on economic development (Table 2; Fig. 1(a)). This result was the same whether forest cover was analysed as an absolute or ratio variable (Table 2). There was no overall trend in rates of forest cover change with respect to total forest cover, but interestingly, this was heavily dependent on GDP, with rich countries exhibiting a strong negative slope and poor countries a positive slope (Fig. 1(b)). Countries with medium incomes were intermediate between the rich and poor nations. All countries with large amounts of forest cover had similar rates of change in forest cover, regardless of income.

The proportion of a nation's forest that was plantation was significantly affected by both GDP and forest cover, but no significant interaction was detected (Table 2). Plantations accounted for a greater proportion of the total forest in countries with high incomes than in countries with medium and low incomes, and, surprisingly, also in countries with medium total amounts of forest cover (Fig. 2). This was not because high-income nations were more likely to have medium amounts of forest cover, as a χ^2 test of independence showed no relationship between the

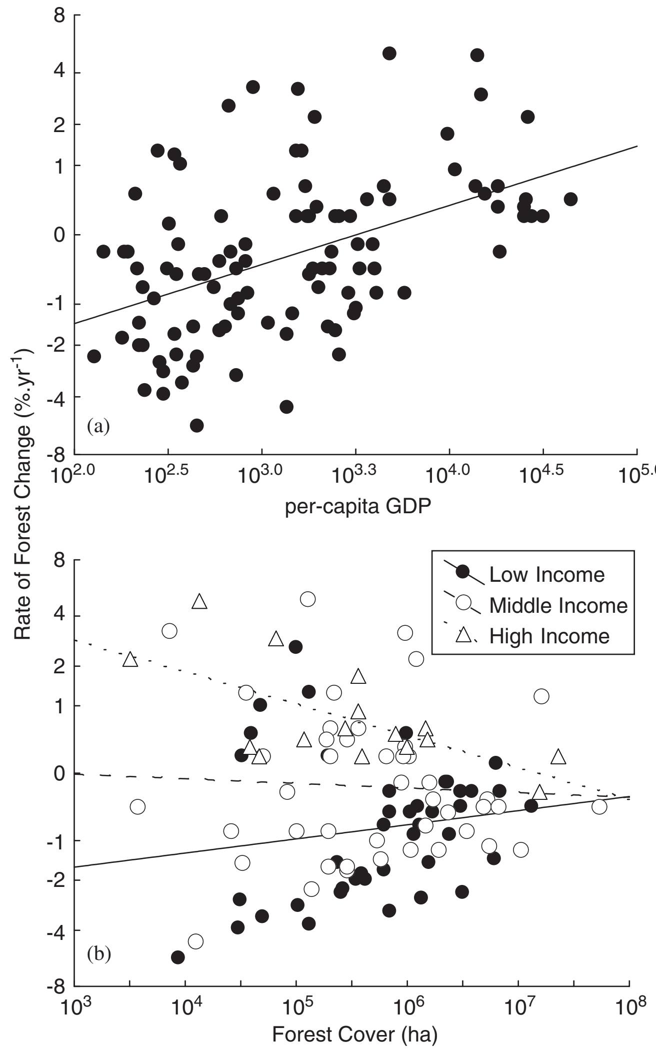

Fig. 1. Relationship between rates of change in forest cover and (a) per-capita GDP, and (b) total forest cover. Negative rates of change indicate deforestation, positive rates are afforestation. The countries in (b) are divided into three income categories based on World Bank criteria. Note the logarithmic scale on the *X*-axis and the non-linear *Y*-axis, which was transformed to normalise a leptokurtic data distribution.

Table 2
(a,b) Results of multiple regression analysis testing for an effect of 1990 per-capita GDP and forest cover on rates of forest change for 103 nations over the period 1990–2000. The analysis was repeated treating forest cover as (a) an absolute variable (ha), and (b) a ratio variable (%). (c) Results from a two-way ANOVA testing for an effect of 1990 per-capita GDP and forest cover on the proportion of a nation's forest that is comprised of plantations. The analysis was conducted over 100 countries

Variable	df	SS	MS	*F*	*P*
(a) Forest change					
GDP	1	2.7548	2.7548	30.77	<0.001
Forest cover (ha)	1	0.0122	0.0122	0.14	0.71
Interaction	1	0.6992	0.6992	7.81	0.006
Residuals	99	8.8633	0.0895		
(b) Forest change					
GDP	1	2.7548	2.7548	31.22	<0.001
Forest cover (%)	1	0.1910	0.1910	2.17	0.14
Interaction	1	0.6475	0.6475	7.34	0.008
Residuals	99	8.7360	0.0882		
(c) Proportion of forest as plantation					
GDP	2	17.015	8.507	6.26	0.003
Forest cover	2	33.554	16.777	12.35	<0.001
Interaction	4	1.150	0.287	0.21	0.931
Residuals	91	13.614	1.358		

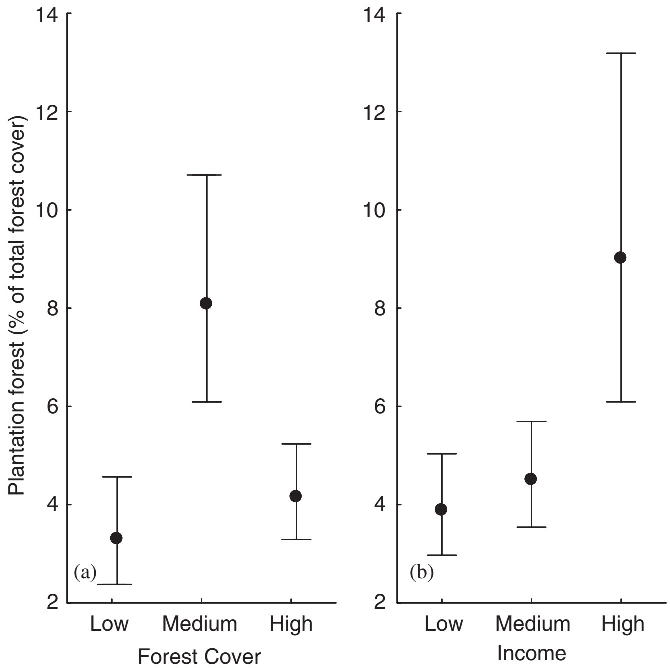

Fig. 2. Proportion of total forest cover that is comprised of plantations in relation to (a) total forest cover and (b) income levels for 100 nations. Presented values are back-transformed mean ± 1 SE from data that was $\log_{10}$-transformed for analysis.

income and forest cover categories ($\chi^2 = 0.785$, df = 4, $P > 0.90$).

4. Discussion

4.1. Direct effect of national wealth on rates of forest change

It is clear from this analysis that economic wealth has a direct effect on deforestation rate, with wealthy nations typically experiencing lower levels of deforestation, or even net afforestation, and poor nations exhibiting the highest deforestation rates. This conclusion is in agreement with a substantial literature that has reported similar trends (Barbier and Burgess, 2001; Koop and Tole, 2001; Ehrhardt-Martinez et al., 2002; Rudel, 2002; Meyer et al., 2003; Rudel et al., 2005). Likely, the pattern results from a combination of two factors. First, poor countries may experience high rates of deforestation simply because they are poor (Meyer et al., 2003). This is aptly illustrated by the cases of Ethiopia, Haiti and Togo (Rudel et al., 2005), where poverty-traps ensure farmers are forced to convert the last forests in a region into fields (McPeak and Barrett, 2001). This occurs because of a lack of off-farm employment opportunities, lack of access to markets, and a lack of technology and capital that prevents farmers from maintaining or improving the productivity of existing farmland (McPeak and Barrett, 2001). Furthermore, natural resources such as forests have been shown to be fundamental to the economic development of many nations (Walker and Nautiyal, 1982; Barbier, 2004, 2005; Naidoo, 2004) and are the principal source of export earnings for many low-income nations (World Bank, 1992; Barbier, 2005), indicating that their continued exploitation is vital to maintaining these economies.

Second, high-income nations are more likely to have economies based on services and high-tech industries (Koop and Tole, 2001; Barbier and Cox, 2003), which have a low reliance on environmental capital like forest resources and so are less likely to result in deforestation (Barbier and Cox, 2003; Grau et al., 2003). At the same time, growing public awareness of environmental issues leads to the deliberate inclusion of environmental protection laws in public policies (Koop and Tole, 2001). However, it is necessary to point out here that wealth alone is not enough to guarantee a switch from deforestation to afforestation. For instance, Koop and Tole (2001) showed that economic development, if not unaccompanied by a reduction in economic inequality, will excacerbate deforestation rates, rather than reduce them (but see Heerink et al. (2001) for a counter-example). Moreover, human population pressure (Cropper and Griffiths, 1994; Pfaff, 1999; Geist and Lambin, 2001), governmental and financial institutions (Bhattarai and Hammig, 2001, Klooster, 2003; Meyer et al., 2003), economic freedom and stability (Barbier, 2001; Meyer et al., 2003), the spatial distribution of employment opportunities (Helmuth, 1999), the processes of globalisation (Rudel, 2002; Grau et al., 2003; Ehrenfeld, 2005), and national or civil wars (Álvarez, 2001; Kaimowitz and Faune, 2003; Rudel et al., 2005) all have important, confounding effects on rates of change in forest cover.

4.2. Conditional effect of forest cover on rates of forest change

Rudel et al. (2005) recently showed that the amount of forest cover remaining in a nation is a strong determinant of whether or not that nation has undergone a transition from deforestation to afforestation (a result similar to those shown by Ehrhardt-Martinez et al. (2002) and Bhattarai and Hammig (2004), who both showed that deforestation rate was related to the amount of remaining forest cover). Here, I have shown that the relationship is more complex than previously shown, because the effect of forest cover on deforestation rate is dependent on national wealth. As hypothesised by Rudel et al. (2005), nations with little forest cover do tend to experience net afforestation, but this result holds only for wealthy nations. Poor nations exhibit the exact opposite trend, in which low forest cover leads to an increase in the rate of deforestation.

The result that deforestation rates are dependent on an interaction between economic development and forest cover is different from those of studies that have reported direct, independent effects of the two variables (e.g. Ehrhardt-Martinez et al., 2002; Bhattari and Hammig, 2004; Rudel et al., 2005). The amount of forest cover has no bearing on rates of forest cover change in medium income nations, but a strong effect in high- and low-income nations. Furthermore, the effect of forest cover in high-income nations is completely the opposite to the effect in low-income nations. This conditional effect of forest cover has not been noted before, and may explain why some models find a significant effect of forest cover on deforestation but others do not (e.g. Ehrhardt-Martinez et al., 2002; Foster and Rosenzweig, 2003; Bhattari and Hammig 2004).

4.3. Potential confounding factors in the analysis

There is a small group of five low-income nations that appear to contradict the general pattern of an interaction between economic development and forest cover (Fig. 1(b); the nations are Kyrgyzstan, Uzbekistan, Republic of Moldova, Tajikistan and Gambia). These nations all have low forest cover and are expected to be experiencing rapid rates of deforestation, but instead have net afforestation. In the case of the first four, which are all former states of the former USSR, this likely reflects data deficiencies. These four nations did not exist in 1990, which was the beginning of the period over which deforestation was assessed, so the estimates of forest cover for this time period are derived from data from the former USSR. The fact that national data was used as a source of regional data, i.e. large-spatial scale data was extrapolated down to a finer spatial scale, raises considerable doubt as to the validity of the forest cover estimates for this time period. There is also a lack of accurate data for the fifth nation, Gambia (Bojang, 2000). However, the data that are available indicate that closed forests are currently being reduced in area (Silla, 1999), but that this effect is masked by increases in the amount of land that is reverting from former agricultural land to open savanna forests (Silla, 1999), resulting in net afforestation. These five nations were retained in the analysis because their exclusion does not greatly alter the results. In fact, removing these nations results in a *strengthening* of the already significant interaction effect in Table 1, and so does not alter the nature of the conclusions that are drawn from the analysis.

One possible confounding effect in this analysis is that when a nation has low forest cover, a small change in the absolute amount of forest cover is recorded as a large percentage change. This would result in nations with low forest cover being more likely to exhibit high rates of change, either positive or negative, than nations with high forest cover. However, it could not have created the result observed in Fig. 1(b), which illustrates how wealthy nations with low forest cover all have high rates of net afforestation, and that almost all of the poor nations with low forest cover are experiencing high deforestation rates. This is because a simple bias towards high percentage changes in forest cover for nations with low forest cover would have been distributed randomly across *all* nations with low forest cover, with the effect that both wealthy and poor nations would have had approximately equal numbers of nations experiencing afforestation and deforestation.

To further eliminate the possibility that the relationship between absolute forest cover and percentage rates of change in cover was driving the results shown in Fig. 1(b), I repeated the analysis using the percent of land area with forest cover as the predictor variable in lieu of the absolute amount of forest cover. This analysis standardized the data for variability in land area among nations, and for variability in the total amount of forest cover remaining among nations. The results of this second analysis were quantitatively similar to the first, in that there was a significant main effect of per-capita GDP and a significant interaction effect, but no direct effect of forest cover (Table 2). This indicates that the results and conclusions of this study are not an artefact of the 'starting conditions' for the analysis, where the starting conditions are the nations' land area and the amount of the land area that was forested at the beginning of the period over which deforestation was calculated (1990–2000).

4.4. Factors determining a nation's ability to make a forest transition

There are two factors that likely affect a nation's ability to make a transition from deforestation to afforestation: (1) the quality of the government and supporting institutions; and (2) the money available to that nation for investment. Some of the responsibility for rapid deforestation rates in poor nations with low forest cover must be laid squarely at the feet of the governments of these nations, because central governments are the only institutions with the power to control deforestation (Lang, 2002). Thus, it has been argued that the ultimate cause of deforestation is that governments allow it to happen (Bromley, 1999; Meyer et al., 2003), although it is unlikely that all governments are strong enough to enforce anti-deforestation measures whether they want to or not. As a consequence, weak governments are more likely to permit ongoing forest conversion as an alternative to dealing with difficult problems of land reform (Meyer et al., 2003; Cullen et al., 2005; Fearnside, 2005). More sinisterly, the individuals in power may be exploiting the forests for personal gain (Meyer et al., 2003; Smith J. et al., 2003; Laurance, 2004), with no regard for the long-term future of the nation's natural resources. It could also be that some forested lands are more economically valuable to poor nations if they are converted to other landuses (Byrne et al., 1996; Wilkie et al., 2001; Meyer et al., 2003; Chomitz et al., 2005). Many of these issues are not present (or at least are less prevalent) in wealthy nations that typically have stronger central governments with lower levels of corruption (López and Mitra, 2000; Smith R.J. et al., 2003; Laurance, 2004) and a public that does not depend on the constant opening up of new agricultural lands to generate wealth. Moreover, the public in wealthy nations are simultaneously more aware of government activities and less tolerant of government-sanctioned environmental damage (Koop and Tole, 2001; Foster and Rosenzweig, 2003; Meyer et al., 2003).

Governments in poor nations are also at a considerable disadvantage to those in wealthy nations when it comes to reversing trends in deforestation, because effective and deliberate afforestation programs are typically reliant on plantation forestry rather than natural processes of forest regeneration (e.g. Stanturf and Madsen, 2002; Alig and Butler, 2004; Gardiner et al., 2004). It should be noted that some nations do exhibit substantial afforestation as a result of abandoned land naturally reverting to forest (e.g. Puerto Rico: Grau et al., 2003; Lugo and Helmer, 2004), but this is not the result of a deliberate, conservation-oriented government policy. Rather, it is the result of human migration from rural to urban areas in response to shifts from agriculture to industry-based economies (Rudel et al., 2000; Grau et al., 2003).

Nations with net afforestation have invested heavily in plantation forestry because either they are able to profit financially by exporting large quantities of wood products to the global market (e.g. New Zealand; Matthews et al., 2000), or because the high cost of wood products in denuded landscapes makes it economically profitable to re-convert existing landuses back to forest (Foster and Rosenzweig, 2003; Rudel, 1998; Rudel et al., 2005). Large-scale plantation schemes have also been implemented in middle-income countries such as China in response to a shortage of wood products and to combat widespread problems with flooding and soil erosion (Lang, 2002; Li et al., 2004). However, these programs require a strong presence from the government (Varmola and Carle, 2002) and substantial capital that must be financed either by the government itself, by international donors, or by private corporations. Obviously, low-income governments have little cash to invest in any environmental project (Wilkie et al., 2001; Balooni, 2003), and the costs of afforestation schemes must be balanced against the opportunity costs of putting that limited pool of money into other economic development schemes (Norton-Griffiths and Southey, 1995; Wilkie et al., 2001; Chomitz et al., 2005). Therefore, it is difficult for them to lead a country through a forest transition from their own resources. Simultaneously, large, overseas-based corporations may view many low-income nations as high-risk investments because of ill-defined property laws (Varmola and Carle, 2002; Cropper and Griffiths, 1994; Meyer et al., 2003; Karp, 2005) and unstable currencies and monetary policies (Meyer et al., 2003; Laaksonen-Craig, 2004). These problems are reflected in poor country investment ratings, as indicated by the preponderence of low-income nations categorised as 'Speculative' and 'Very Risky' by the international rating agency Moody's Investors Services (http://moodys.com). As a result, plantation forests typically represent a more viable investment in wealthier nations, so external investments in forestry schemes are likely to be much reduced in low-relative to high-income nations. In combination with the greater investment capital available to wealthy governments, increased overseas investment in already wealthy nations likely results in plantations accounting for a much greater proportion of total forest cover for high-income nations than for nations with low- or middle-incomes.

4.5. *Why levels of plantation forestry vary among nations*

Nations with a medium level of forest cover (2–10 million ha) tended to have a higher proportion of their forests comprised of plantations than nations with either high or low forest cover. Low average values of proportional plantation cover in nations with low total forest cover may result because many of the low-forest countries were either small (e.g. Haiti and Ireland), comprised largely of deserts (e.g. Mauritania and Egypt), or both (e.g. Lebanon). As such, these nations may not be able to spare productive land for conversion to forestry. However, this pattern obscures the fact that some of these nations actually have very high proportions of their forest cover in plantations as a response to deliberate government policies (e.g. Iceland and Israel have 48% and 40% proportional plantation, respectively). At the other extreme, nations with high forest cover would need to plant huge expanses of forest to record just a small increase in proportional plantations. Furthermore, nations with large standing stocks of native timbers already have a large resource providing essential ecosystem services, thereby obviating some of the need for afforestation that is so pressing in countries that have experienced widespread deforestation. It is unlikely then, that nations with high forest cover would have large amounts of that forest as plantations. Lastly, nations with medium forest cover tended to have much higher proportions of forest in plantations because of a combination of the above reasons; they have more land that is both suitable and available for conversion to forestry than nations with low forest cover, and a similar sized expansion in plantations results in a much higher proportional increase than in nations with high forest cover.

5. Conclusion

It is already well recognised that economic development may provide the necessary conditions for afforestation (Meyer et al., 2003). Furthermore, the quality of a nation's natural resource base, including forests, is an important factor determining economic growth (Walker and Nautiyal, 1982; Koop and Tole, 2001; Barbier, 2004, 2005; Naidoo, 2004). Some authors have rejected this second notion in favour of the 'resource curse' hypothesis, which states that large endowments of natural resources serve to reduce, rather than enhance, economic growth (e.g. Sachs and Warner, 1995, 2001; Neumayer, 2004). However, analysis of the underlying mechanisms indicate that this effect is due almost entirely to the presence of weak governments, bad macroeconomic policies, and poor institutions, suggesting that the resources themselves are not responsible (Mikesell, 1997; Auty, 2001; Papyrakis and Gerlagh, 2004; Larsen, 2005). Furthermore, the resource curse is most directly applicable to 'point' resources, such as oil and mineral deposits, which are concentrated in space and so relatively easy to protect and control (Bulte et al., 2005). In contrast, 'diffuse' resources, such as forests, which are accessible across large spatial areas and by large groups of people, are more likely to be associated with positive development outcomes (Bulte et al., 2005).

The data presented here indicate that there is an important feedback mechanism between economic development and forest cover. High levels of economic development probably do allow afforestation to proceed, because those nations are able to compensate for a lack of natural resources, in this case forests, by investing in plantations. This then lays a foundation for further growth, because plantations are an increasingly important component of economic growth for many nations (Wright et al., 2000). But the reverse process also appears to happen; poor nations may be relying heavily on conversion of native forests to spur economic growth (e.g. Barbier, 2004; Naidoo, 2004), but they are still too poor to be in a position to replace them, leading to a downward spiral in environmental quality and an ongoing reduction in the likelihood of sustainable economic development (Repetto et al., 1989; Naidoo, 2004).

Although the strength of this feedback loop is unknown, it still raises a new question of pressing importance: can the feedback cycle in low-income nations be reversed so that instead of working against them, it works in their favour? One potential avenue is the Clean Development Mechanism of the Kyoto Protocol, whereby nations could be economically compensated (through carbon credits) for avoided deforestation: they would be paid to *not* cut down forest (Fearnside, in press). This would provide economic incentives to governments in poor nations to actively protect their few remaining forested areas from future destruction. Although still in negotiation, such a process has the potential to provide the economic impetus required to reduce deforestation rates in low-income nations.

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