Economic Growth and Liquidation of Natural Capital: The Case of Forest Clearance

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ABSTRACT. *The importance of natural capital to economic systems is increasingly recognized. Previous empirical models of economic growth rates, however, have emphasized accumulation of physical and human capital. This paper shows that the economic growth of over 70 countries has been positively affected by liquidation of one aspect of natural capital, forests, while controlling for factors typically associated with national growth rates. The positive association was robust to additions of various covariates, such as forest exports, level of economic development, agricultural area, and geographical position. These results suggest that conversion of forests has partially fuelled the economic expansion of countries.* (JEL Q23)

I. INTRODUCTION

The world's natural capital is a valuable resource endowment that has been provided to the human population free of charge by natural processes. Natural capital can be defined as the sum of all natural resource stocks that provide beneficial flows of goods and services, and includes resource stocks that are potentially renewable, such as forests and fish populations, as well as non-renewable stocks such as oil and precious metals (Daily 1997; Repetto et al. 1989). Curiously, for an item of such apparent worth, there is a remarkable divergence on viewpoints regarding sustainable use of natural capital, as noted by Dasgupta (2002). On the one hand, natural capital is often described as under increasing threat from expanding human economies (e.g., World Resources Institute 2000), and Repetto et al. (1989) have shown that liquidation of natural capital can lead to unsustainable economic growth in resource-rich countries. More recent work on natural resource accounting has also supported the notion that depletion of both renewable and non-renewable natural capital is leading to progressive impoverishment of many countries, particularly those in the developing world (Hamilton and Clemens 1999; Pearce, Hamilton, and Atkinson 1996). Conversely, others claim that economic growth will result in environmental benefits (Beckerman 1992; World Bank 1992), or that the drawing-down of natural capital is not as severe as is generally portrayed (Lomborg 2001). Because increasing national per-capita incomes is a universal objective of national-level policies and development strategies (World Bank 2001b), expansion of the human enterprise will continue through the near future. It is therefore crucial to understand the relationship between economic growth and natural capital, so that informed decisions regarding sustainable development policy can be made.

The factors associated with economic growth have been the subject of much research, and theoretical models of economic growth have a long and venerable history (Domar 1946; Solow 1956). The compilation of large data sets consisting of a multitude of socioeconomic variables for many years and countries has led to the development of the empirical growth literature, in which researchers have tested long-held theories regarding the role of capital and labor in economic growth using country-level data (Barro 1991; Mankiw, Romer,

Land Economics • May 2004 • 80 (2): 194–208
ISSN 0023-7639; E-ISSN 1543-8325
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The author is a WWF Science Post-doctoral Fellow, Fundacion Moises Bertoni, Asuncion, Paraguay. This research was conducted while the author was a PhD candidate in an interdisciplinary ecology/economics program in the Department of Biological Sciences, University of Alberta, Edmonton, Canada. Vic Adamowicz, Andrew McAdam, Doug Manzer, Terry Veeman, and two anonymous reviewers made helpful comments on an earlier version of the manuscript. All remaining errors are the responsibility of the author.

and Weil 1992; Sachs and Warner 1995a). Syntheses of this literature have confirmed the positive effect of physical and human capital accumulation on growth, while also highlighting the importance of initial per-capita income, political freedoms, and economic openness to fast-growing economies (Levine and Renelt 1992; Sala-i-Martin 1997).

Despite much careful research in this field, there is remarkably little evidence regarding the relationship between natural capital and economic growth at the cross-country level (but see Sachs and Warner 1995b). Indeed, a recent literature review provided no discussion of natural capital; the words "environment" and "natural capital" were not mentioned in the text, and "natural resources" appeared in only one sentence (Temple 1999). Ignoring the role of natural capital in economic growth may be an outcome of its omission in earlier theoretical growth models (Solow 1956). Yet, the divergence of views on a topic of such significance suggests that this is a serious oversight.

In this paper, I assess the importance of natural capital to the economic growth of countries in the style of the empirical economic growth literature. I make an effort to use methods and data similar to those of the classic papers in this field, in order to maintain continuity, ensure comparability of results, and retain the legitimacy of accepted procedures. At the same time, the analyses presented here go beyond those that exist by including measures of natural capital liquidation in traditional growth regressions. As is common to most fields, the empirical economic growth literature is not without its flaws and detractors. Criticisms include the lack of a theoretical basis to regression models, the unwarranted assumption of a common growth process among countries, and endogeneity of explanatory variables. It is beyond the scope of this paper to provide a justification of the assumptions and methods of this field; readers are referred to Temple (1999) for a thorough review of both the positive and negative aspects of this research.

In Section 2, I provide a very brief overview of the theory behind empirical growth regressions. Section 3 of the paper describes the general methods used, the empirical data set, and some details of specification. In Section 4 results from economic growth models that include natural capital are presented, and a "core" model of explanatory variables is established. Subsequently, variables are added to this core model, including those representing scale and structure of the economy (Section 5), and geographical variables (Section 6). Section 7 concludes the paper with a review and discussion of the results.

II. GROWTH THEORY

Most papers in the empirical economic growth literature are loosely based on the Solow aggregate production function (Solow 1956), which specifies that capital and labor interact to determine changes in total output by means of a Cobb-Douglas production function,

$$Y = K^{\alpha} (AL)^{1-\alpha}, \qquad [1]$$

where K is physical capital, L is labor, A is the level of technology, and α is the output elasticity of capital. Almost all papers in the field augment this original specification by adding human capital, H, to the aggregate production function,

$$Y = K^{\alpha}H^{\beta} (AL)^{1-\alpha-\beta}. \qquad [2]$$

The addition of natural capital, N, as another aspect of capital's importance to output in the aggregate production function, is easily accomplished within the Solow framework,

$$Y = K^{\alpha} H^{\beta}N^{\gamma}(AL)^{1-\alpha-\beta-\gamma}, \qquad [3]$$

although as has been mentioned, this aspect of capital has not been investigated in the present context. This twice-augmented growth function [3] thus includes two additional measures of capital, human and natural, along with the original physical capital measure of Solow, and forms the basic theoretical background for the work presented here.

In practice, most empirical growth studies have extended far beyond Solow's theory of economic growth, and have specified regression models that include numerous other variables in addition to those predicted by theory. Theoretically relevant variables such as the savings rate, population growth, and initial income are joined by a host of other variables, encompassing economics, politics, and trade. Many of these have been established as robust, significant explanators of growth. I follow this same, somewhat ad hoc procedure here; the next section reports on the specifications used in this paper.

One final theoretical issue is the relationship between stocks of natural capital and other forms of capital, particularly physical capital. The Cobb-Douglas production function described above imposes constant elasticity of substitution among inputs. This corresponds to the notion of weak sustainability, in which substitutability between capital inputs implies that sustainability can be achieved through maintenance of capital in the aggregate, without particular regard for individual stocks of capital, natural or otherwise (Pearce and Atkinson 1995). The alternative viewpoint is that of strong sustainability, which holds that possibilities for substitution between capital stocks are minimal, and hence that each stock of capital must be individually maintained to achieve sustainability. Mounting evidence suggests that at least some forms of natural capital have unique ecological and economic value (Daily 1997), and this then argues for a strong sustainability concept. While I have followed the empirical growth literature in assuming substitutability between inputs, I assume nevertheless that the development of economic policies that result in the independent maintenance of all capital stocks is desirable.

II. METHODS

I assessed the importance of natural capital to the economic growth, from 1960–1999, of over 70 countries using linear regression models. These models included variables typical of past growth regression efforts, as well as an estimate of the level of liquidation of an important aspect of natural capital, forests. Forests provide a diverse array of ecological goods and services of benefit to humans (Daily 1997). They are also critically important to the conservation of biodiversity; one-half to two-thirds of all species on earth are thought to live in forests (World Resources Institute 2000). Finally, forests are among the most widely distributed of ecosystems, covering about one-third of the Earth's land surface (Noble and Dirzo 1997), thus permitting a detailed cross-country comparison. I use the term "liquidation" here because the conversion of land from forest to another land-use type results in at least a semi-permanent depletion of this stock of natural capital.

To properly assess the effect on economic growth of the amount of forest area that has been cleared in a country, it is necessary to control for several confounding areal measurements. The fact that countries have different geographical areas must be accounted for, as must the area of forest that was initially present in a country. Without including these measurements of area, large countries with a small area of original forest cover would be analytically indistinguishable from small countries with a high percentage of their area originally covered by forests. I therefore specified country area, area originally covered by forests, and area of forest cleared, as separate explanatory variables in growth regressions. This specification also allows for the effects of all three of these variables on economic growth to be individually assessed. In particular, if ecosystem goods and services provided by forests are more important to economic growth than goods and services provided by alternative land uses, then countries with a proportionally greater original forest endowment and greater area of remaining forest would have higher economic growth rates than those with fewer original forests that have been mostly cleared.

Data

All variables used in the analysis are summarized in Table 1. Data on economic growth of countries were obtained from

TABLE 1
Continuous Variables Used in Regression Models of National Economic Growth Models (N = 77)

Variable (units)	Abbreviation	Mean	Std. Dev.	Min.	Max.
Dependent variable					
Slope of ln (Per-capita GDP (1995 US$) time series, 1960−1999)	LOGSLOPE	0.0140	0.0163	−0.03	0.06
Independent variables					
Average no. of assassinations per year	ASS	0.2657	0.4743	0	2.74
Average no.of revolutions and coups per year	REV	0.1962	0.2357	0	1
Annual population growth rate (%)	POPGRWTH	1.9838	0.9269	0	3.5
Ln (Country area (km^2))	LNAREA	10.264	1.5601	6.24	13.74
Ln (Original area (km^2) of forest)	LNORGAREA	9.1436	2.4299	5.63	13.2
Ln (Area (km^2) of original forest cut)	LNAREACUT	8.5861	2.2725	5.63	12.84
Life expectancy in 1960 (years)	LIFEEX60	53.183	12.798	31.6	73.4
Average savings rate 1960−1999 (%)	SAV6099	17.924	9.0608	1.24	46.75
Ln (per-capita GDP (1995 US$) in 1960)	LNGDPCAP60	7.0586	1.4485	4.58	10.18
No. of years an economy has been open	YRSOPEN	12.712	14.530	0	43
Ln (Exports of forest products as a proportion of GDP)[a]	LNFDPGDP	−5.9702	2.007	−10.66	−2.44
Ln (Area (km^2) of country domesticated)[b]	LNDOMES	9.1341	1.6908	4.73	13.11

[a] $N = 71$
[b] $N = 80$

World Development Indicators 2001 (World Bank 2001a).[1] For each country, I fitted linear regressions to the 1960–1999 time series of the natural log of per-capita GDP (1995 US$), and used the slope of these regressions as the measure of economic growth in each country over this time period. Many previous studies have used per-capita GDP in international dollars, and have not estimated growth trend, but rather used the start and end years of the time period in question to estimate economic growth. Both of these procedures have been criticized, and the method I used has been recommended by several authors (Temple 1999; Nuxoll 1994). Growth estimators using 1995 US$ and international dollars are so highly correlated ($r = 0.88$, $n = 91$, $P < 0.0001$) that results are likely to be similar regardless of which is used, however GDP in international dollars is available for fewer countries and years.

Data on life expectancy in 1960 (a measure of initial human capital formation), average annual savings rate 1960–1999 (a measure of physical capital accumulation), per-capita GDP in 1960 (a proxy for initial per-capita income), and average annual population growth rate from 1960–1999 (crude proxy for growth of the labor force) were obtained from *World Development Indicators 2001* (World Bank 2001a). Data on the average number of assassinations per year and average number of revolutions per year (measures of political stability) were obtained from the Global Development Network Growth Database.[2] These were averaged over the years 1960–1999, or in the case of countries missing data for certain years, over whatever subset of

[1] *World Development Indicators* is a comprehensive publication that provides annual statistical indicators of economic development for over 150 countries.

[2] These variables are considered to be correlates of the level of economic freedom a country enjoys. The World Bank's Global Development Network Growth Database contains time series data on macro- and micro-economic variables, as well as social indicators and fixed factors. Web address: http://www.worldbank.org/research/growth/GDNdata.htm.

years was available. Data on number of years an economy has been open were obtained from the Harvard Center for International Development.[3] Data on geographical area, countries' original forest cover, and remaining forest cover (at about the mid-1990s; estimate years vary slightly for countries) were obtained from the World Resources Institute.[4]

Transformations/Outliers

Per-capita GDP in 1960, country area, area extent of original forest, area of forest cleared, and ratio of forest exports value to GDP (see below for description of this variable) were log-transformed to satisfy distributive assumptions of OLS regression analysis. Botswana and South Korea, two countries with extremely high economic growth rates, were removed from all analyses following statistical screening for outliers. These were the only two countries with growth values outside of 2.7 standard deviations from the mean (1.5 interquartile ranges), indicating significant deviance from the rest of the sample (Fox 1997). They were also the countries exerting the greatest degree of influence in preliminary regression analyses. Studentized residuals (Fox 1997) were 3.66 and 3.02 for Botswana and South Korea, respectively; no other country had an absolute value greater than 2.2. Cook's D-statistic (Fox 1997) for these two countries was also higher than any country remaining in the analysis, and was an order of magnitude greater than the nearest remaining country in the case of Botswana.

Three Sahelian countries with below-average growth rates (Burkina Faso, Chad, and Niger) were also removed from the analysis because their complete lack of original forest cover was overly influencing the partial relationship between area of forest cut and economic growth. Note that their effect was to *strengthen* the negative relationship between these two variables (a partial correlation of –0.785 with these variables included, as opposed to –0.652 without them), hence removing these three countries resulted in a more conservative estimate of the effect of natural capital on economic growth.

Economic Scale/Structure

The structure and level of development of a country's economy may affect the way in which forest conversion has influenced economic growth. The effect of forest clearance on economic growth in countries with large forestry sectors or very low per-capita incomes may be quite different from its effect in countries with small forestry sectors or high per-capita incomes. While economies of less-developed countries generally have larger natural resource and agriculture sectors than developed countries (Perkins et al. 2001), some richer countries with abundant forest resources have developed economies with a relatively high dependence on timber as an exportable commodity (e.g., Canada, Finland). To investigate these issues, I included two variables in additional models: the importance of the forest sector (the log-transformed ratio of forest product exports to total GDP), and the level of a country's economic development (dummy variable for less-developed countries). These two variables were interacted with the area of forest cleared, thus allowing for the effect of forest clearance on economic growth to vary accordingly.

Data on forest product exports were taken from the Food and Agricultural Organization of the United Nations.[5] The

[3] (http://www.cid.harvard.edu/ciddata/ciddata.html). This Web site contains datasets used in publications by researchers affiliated with the Harvard Center for International Development.

[4] (http://www.wri.org). "Original forest cover" is defined as the forest cover that would have been present in a country about 8,000 years ago, before large-scale conversion by human societies occurred, assuming current climate conditions. Estimates were developed by the World Conservation Monitoring Center based on global and regional biogeographic maps.

[5] (http://www.fao.org). The FAO's FAOSTAT database contains data on forestry activities at the national and regional levels. "Forest products" refers to all finished and unfinished products derived from trees, including pulp and paper, charcoal, fibreboard, roundwood, and many others.

only year that these data overlapped with the economic growth time series was 1999, hence export data were from this year only. The less-developed countries dummy variable refers to countries in World Bank income categories 1–3, that is, those countries with an average per-capita income of less than $9,636 US in 1996 (also referred to as developing, underdeveloped, or Third World countries).

Geographical Effects

The influences of environmental variables such as land-use and geographical location of a country may be confounded with those of natural capital. Because forests are not uniformly distributed over the earth's surface, and because remaining forest area and agricultural land area may be inversely correlated, these factors should be accounted for in growth regressions using forest capital as an explanator. Accordingly, I obtained data on the area of domesticated land in a country,[6] and also coded each country with a dummy variable to represent the region of the world in which it is located.[7] Then, these variables were added to regressions explaining economic growth based on economic correlates and natural capital variables.

III. NATURAL CAPITAL AND ECONOMIC GROWTH

The empirical starting point was a regression including standard economic explanators, and variables used to assess the effect of forest clearance (Table 2, Model 1). While the literature on economic growth finds a wide array of variables to be significant explanators, the variables used in this initial regression model (excluding the natural capital variables) have been found robust to a wide variety of permutations in model specification, and are widely accepted as important to growth in cross-sectional studies (Sala-i-Martin 1997; Temple 1999). In this analysis, however, the coefficients on the number of assassinations per year, the number of revolutions per year, and average annual population growth from 1960–1999 were not significantly different from zero in the initial regression (Table 2, Model 1). All other variables in Model 1 were significant explanators of growth; their influences are discussed below with reference to Model 2 (Table 2). The regression model was highly significant (F = 10.4) and explained about 61% of the variance in national economic growth rates.

To more clearly examine the influence of natural capital depletion on economic growth, I removed non-significant variables from Model 1 and specified a reduced-form regression equation (Table 2, Model 2). I did, however, retain country area (non-significant in Model 1) in all reduced-form regression equations so that the forest area variables continued to be corrected for differences in country size across the sample.[8] The results from Model 2 (Table 2) show that proxies for initial human capital, physical capital accumulation, initial income, and economic openness were all highly significant explanators of economic growth in the expected direction. T-values ranged from 3.5 to 5.7 in absolute terms, well beyond the threshold for significance at the $p < 0.05$ level. The negative effect of initial income on growth is indicative of the "conditional convergence" effect, that is, that other things held constant, poorer countries tend to grow faster than richer countries (Barro 1991; Mankiw, Romer, and Weil 1992; Sachs and Warner 1995a; Sala-i-Martin 1997; Temple 1999). Positive effects

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[6] Domesticated land refers to land that is under either permanent pasture or crops. Data were obtained from the World Resources Institute: http://www.wri.org.

[7] Data are from the World Bank's Global Development Network Growth Database: http://www.worldbank.org/research/growth/GDNdata.htm Regions are East Asia and the Pacific (EAP), Eastern Europe and Central Asia (EECA), Middle East and North Africa (MENA), South America (SA), North America (NA), Sub-Saharan Africa (SSA), and Latin America and the Carribean (LAC).

[8] Some might argue that the logarithm of country area should be removed from the reduced-form regression equations, since it was insignificant in the full-form model. I re-ran Models 2, 3, and 4 of Table 2 without country area, and the results were nearly identical to those presented here.

TABLE 2
REGRESSION COEFFICIENTS (t-VALUES BENEATH) FOR MODELS OF ECONOMIC GROWTH, 1960–1999, INCLUDING NATURAL CAPITAL, ECONOMIC SCALE/STRUCTURE, AND LAND USE

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	0.01319	0.00229	0.0281	−0.0208	0.01202	−0.0005
	(0.8890)	(0.8523)	(1.5255)	(−0.5712)	(1.0656)	(−0.0411)
ASS	0.00149	–	–	–	–	–
	(0.5211)					
REV	−0.0087	–	–	–	–	–
	(−1.3285)					
POPGRWTH	−0.0014	–	–	–	–	–
	(−0.7152)					
LNAREA	0.00155	0.00145	0.00158	0.00152	−0.0012	0.00162
	(1.1653)	(1.0959)	(1.1485)	(1.1129)	(−0.7079)	(0.6949)
LNORGFOR	−0.0058	−0.006	−0.0061	−0.0042	–	−0.0059
	(−2.6983)	(−2.7804)	(−2.6247)	(−1.6738)		(−2.3362)
LNAREACUT	0.0055	0.00567	0.00525	0.00843	–	0.00699
	(2.6980)	(2.8050)	(2.4878)	(2.4164)		(2.9824)
LIFEEX60	0.00089	0.00099	0.00095	0.00108	0.00104	0.00099
	(3.8101)	(4.4633)	(4.2376)	(4.7070)	(4.6835)	(4.5246)
SAV6099	0.00098	0.00103	0.00118	0.00117	0.00092	0.00106
	(5.2893)	(5.6609)	(6.2509)	(6.2389)	(5.4972)	(5.9113)
LOGGDP60	−0.0107	−0.0104	−0.0123	−0.0129	−0.0112	−0.0102
	(−5.4263)	(−5.3404)	(−5.6661)	(−5.9734)	(−5.7550)	(−5.3131)
YRSOPEN	0.00044	0.00042	0.00032	0.00031	0.00045	0.00039
	(3.3624)	(3.4205)	(2.4536)	(2.3725)	(3.7659)	(3.1868)
LDC	–	–	−0.0097	−0.0283	–	–
			(−1.7545)	(−1.4884)		
LDC × LNAREACUT	–	–	–	0.00201	–	–
				(0.9872)		
LNFPDGDP	–	–	8.2E-05	−0.0093	–	–
			(0.1132)	(−1.9327)		
LNFPDGDP × LNAREACUT	–	–	–	0.00104	–	–
				(1.9559)		
LNDOMES	–	–	–	–	0.00169	−0.0014
					(1.0809)	(−0.7485)
N	77	77	71	71	80	75
F	10.4	14.6	12.2	10.8	18.2	13.5
R^2	0.61	0.60	0.64	0.67	0.60	0.62
Adjusted R^2	0.55	0.56	0.59	0.61	0.58	0.58

of physical capital, human capital, and an economy's openness on economic growth are robust findings consistent with previous reviews (Sala-i-Martin 1997). These results are therefore similar to those of earlier studies that used shorter time periods and various measures of economic growth.

In addition to these expected economic correlates, there was strong evidence that countries that liquidated their natural capital fastest had higher rates of economic growth than those with greater remaining levels (Table 2, Model 2). As mentioned, country area was not significant, therefore economic growth did not depend on the geographical size of a country, a result noted by Reynolds (1985). Original forested area had a negative effect on growth in the reduced-form models, suggesting that countries with less original forest have grown faster than heavily forested countries. Additionally, countries that had cleared more of their original forest have also grown faster than those more original forest remaining (Figure 1). The standardized regression coefficient on this variable (0.546) fell within the range of those for the economic correlates (0.389–0.944 in

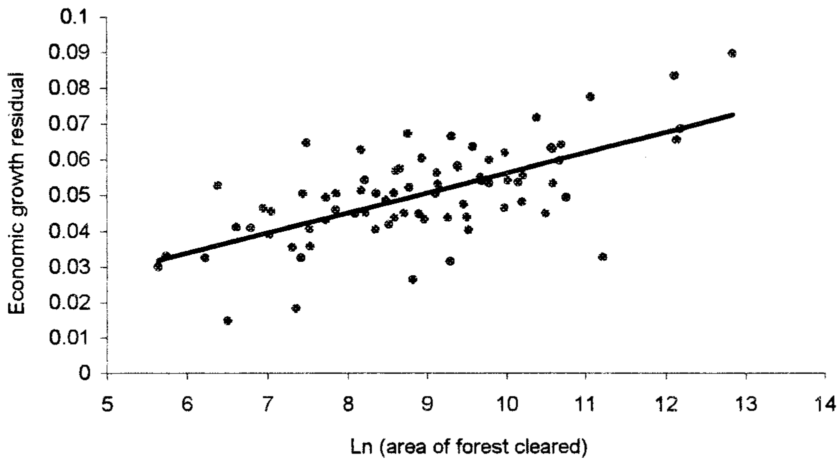

FIGURE 1
THE PARTIAL ASSOCIATION BETWEEN ECONOMIC GROWTH AND AREA OF ORIGINAL FOREST CLEARED (LN TRANSFORMED) (R = 0.66, N= 77, P = 0.0049. PARTIAL ASSOCIATIONS MEASURE THE CORRELATION BETWEEN AN INDEPENDENT VARIABLE IN A MULTIPLE REGRESSION AND THE DEPENDENT VARIABLE, HAVING CONTROLLED FOR THE EFFECTS OF OTHER INDEPENDENT VARIABLES IN THE MODEL.)

absolute value), indicating an impact on economic growth of similar magnitude to these more commonly-held explanatory factors. These results suggest that natural capital does have an important effect on national economic growth rates, despite having received little attention in the empirical growth literature.

The regression equation of Model 2 was highly significant, with a higher F-value than Model 1 (F = 14.6), and explained a similar amount of variance in economic growth (60%). I therefore take Model 2 to be the "core" model for sections that follow, in which I assess the effects of various additional explanatory variables on the robustness of the natural capital relationships.

IV. NATURAL CAPITAL, ECONOMIC GROWTH, AND SCALE/STRUCTURE OF THE ECONOMY

Model 3 of Table 2 shows the results of a regression including all variables of Model 2, as well as the logarithm of the importance of forest product exports, and a dummy variable for less-developed countries. The dummy variable was negative and marginally significant, providing weak evidence that less-developed countries grew more slowly than developed countries, after controlling for other variables. The majority of less-developed countries are located in the tropics, and others have postulated that these countries may grow more slowly because of the prevalence of virulent tropical diseases, erratic rainfall, and poor soils for agriculture (Perkins et al. 2001; Gallup and Sachs 1998). I address this geographical hypothesis on economic growth in more detail in Section 5. The forest exports variable was insignificant, suggesting no effect of the importance of forest product exports to the economy on economic growth. The direction, significance, and magnitude of the coefficients on all variables held over from Model 2, including those representing natural capital and its liquidation, were similar. The regression was also once again significant, explaining 60% of the variance in economic growth.

Next, I added interaction terms of the forest area cleared variable to the LDC dummy and the forest exports variable. The results are presented in Model 4 of Table 2. The LDC dummy variable, along with its interaction term, were this time not significant. These results thus provide no evidence to support the notion that poor, resource-rich countries rely more on natural capital depletion for economic growth than richer countries, as has been suggested (Sachs and Warner 1995b). However, the forest exports variable coefficient is now negative and marginally significant (Table 1, Model 3), suggesting that countries with a greater share of forest exports in their economies grew more slowly than those with a lesser share. Evidence that countries with a greater share of primary product exports grow more slowly than those countries with less of a dependence on natural resource exports has previously been provided by Sachs and Warner (1995b). The interaction between the importance of forest exports and area of forest cleared was positive and also marginally significant. This indicates that the effect of the area of forest cleared is conditional on the value of the forest exports variable, and vice-versa. Coefficients on the variables in Model 3 changed slightly from previous models, but their direction and significance as explanators of economic growth remained the same (marginally significant in the case of original forest cover). The regression equation of Model 4 was again highly significant (*F*-value of 10.8), and explained a greater share of the variance than Models 1 and 2 (67%).

An understanding of the effects of an interaction in a multiple regression model can be improved by calculating the regression coefficient of each variable at various levels of the other. Figure 2A shows the relationship between the coefficient on LNAREACUT and the value of LNFPDGDP, and Figure 2B the relationship between the coefficient on LNFPDGDP and the value of LNAREACUT. The coefficient on LNAREACUT is positive for values of LNFPDGDP above –8.1 (Figure 2A). Since this is relatively close to the minimum value of LNFPDGDP (–10.7), the relationship between LNAREACUT and economic growth is positive over most values of forest export importance. The coefficient on LNFPDGDP is negative at most values below the mean of LNAREACUT (8.6), and positive at most values above (Figure 2B), indicating strong conditionality in its effect on economic growth.

Overall, results from Models 3 and 4 provide weak evidence for the following. For most countries, the effect of forest clearance on economic growth is positive. Only in countries with very low ratios of forest product exports to GDP will forest clearance have had a negative effect on growth. On the other hand, the direction of the effect of forest exports on economic growth is more strongly conditional on forest clearance: economic growth in countries with a greater-than-average area of forest cleared is positively affected by the increasing importance of forest exports in the economy, while the reverse is true in countries below the mean area of forest cleared. There is some evidence to indicate that developing countries may have grown more slowly than developed countries, but this is not a strong effect.

V. NATURAL CAPITAL, ECONOMIC GROWTH, AND GEOGRAPHY

A common problem in the empirical growth field is the uncertainty surrounding the regression specification, in terms of omitted variables, explanatory variables that may be correlated with unspecified variables actually driving a relationship, and reverse causality. By using variables for which both theoretical and empirical relationships with economic growth have already been demonstrated, I hope to have reduced the likelihood of these problems with the economic explanators. For the natural capital variables, however, it is possible that unspecified variables correlated with original forest cover and the area of forest cleared are actually driving economic growth. The direction of the relationship between economic growth and forest clearance is also an issue; increased economic growth may result in more forest cleared, not vice-versa.

One approach to addressing reverse causality problems involves the use of instrument variables (Hayashi 2000). There are many variables that have been correlated

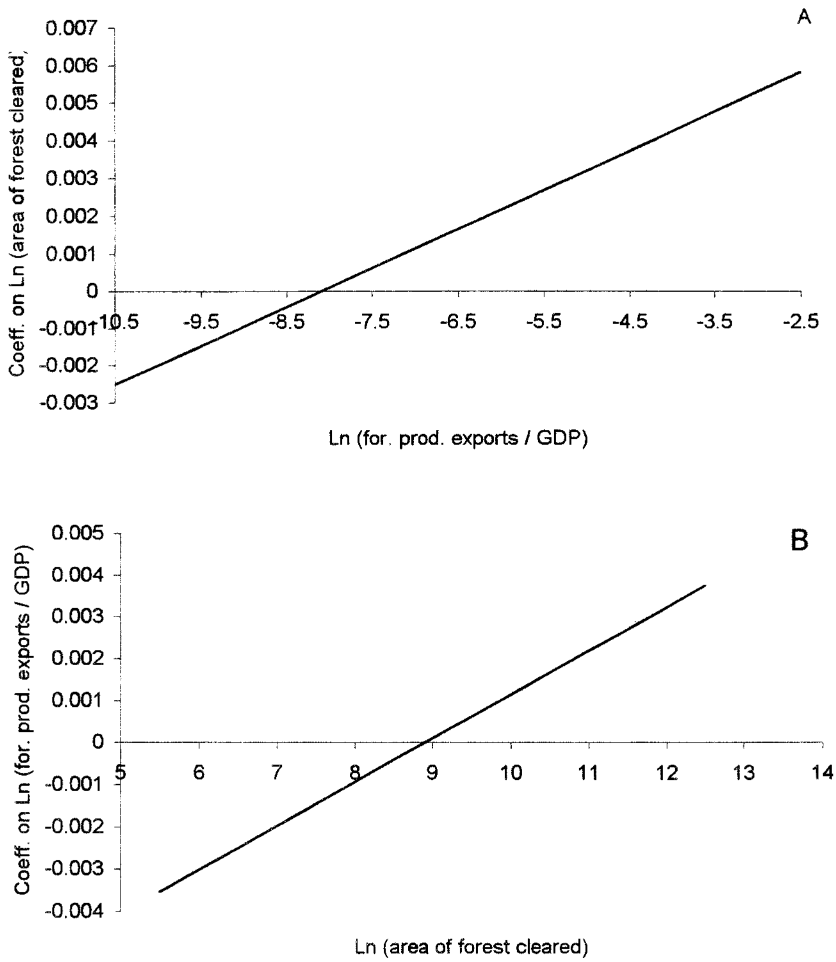

FIGURE 2
THE INTERACTION BETWEEN AREA OF FOREST CLEARED AND THE IMPORTANCE OF FOREST EXPORTS, AS REPRESENTED BY: (A) THE RELATIONSHIP BETWEEN THE COEFFICIENT ON LNAREACUT AND LNFPDIVGDP; AND (B) THE RELATIONSHIP BETWEEN THE COEFFICIENT ON LNFPDIVGDP AND LNAREACUT.

with deforestation (Angelsen and Kaimowitz 1999), and hence many possible instruments for forest clearance. Variables such as the length of the road network and off-farm employment are strong correlates of deforestation (Angelsen and Kaimowitz 1999), and may not be as strongly related to economic growth as the explanators I have specified in the growth equations. However, because forest clearance has occurred at different times in different countries, appropriate instruments would need to be temporally coincident with forest clearance in a country. Since data on the timing of forest clearance in different countries is scarce or non-existent, the instrument variable approach is probably not feasible in this case.

I have attempted to address the concerns raised above in two ways. The first involves investigating the effects of land-use that may be correlated with liquidation of forest capital. Because decreasing the area of forest may result in an increase in land used for agricultural production, agricultural land area has obvious potential as an unobserved correlate of economic growth. To explore this possibility, I specified models (Table 2, Models 5 and 6) that include the logarithm of the area of a country under domestication. Model 5 replaces original forest cover and area of forest cover cleared with domesticated area, while Model 6 includes both forest variables and the area under domestication. In both models, the coefficient on LNDOMES was insignificant, indicating that this variable was unrelated to economic growth rates. The magnitude and significance of coefficients on the economic explanators did not change, while the country area variable remained insignificant. Both forest variables remained significant with the addition of LNDOMES in Model 6 (the strength of the relationship between forest area cleared and economic growth actually increased with this specification). Model 5 and Model 6 were significant regression models, explaining 60% and 62% of the variance in economic growth, respectively. Results from these two models suggest that the area of forest cleared does not appear to be acting simply as the inverse of productive agricultural land, in its effect on economic growth.

As a second exploration of potential confounding factors, I assessed the role of geographical variables on economic growth models that included measures of natural capital liquidation. Because not all geographic regions on the earth's surface have equal suitabilities for forest ecosystems, forests and their depletion may just be surrogates for unobserved geographical effects that influence a country's potential for economic growth. For example, humid tropical African countries may be disadvantaged economically by virtue of their high prevalence of virulent diseases. But this area is also naturally heavily forested, and includes the Congo basin, an area that retains much of its original forest cover (Myers 1992). Because sub-Saharan countries have grown very slowly in recent years, it might appear that a high degree of original forest cover and low forest clearance have led to low economic growth in these countries, whereas, this may in fact be due to unobserved factors such as those mentioned above.

I attempted to control for such possibilities by adding dummy variables for geographic region to the regression equation of Model 2, and examining whether regions that had significantly higher or lower economic growth differed in their effect of natural capital liquidation on growth. Because of small sample sizes (less than 10 countries in each region), dummies for Eastern Europe and Central Asia, North America, South America, and Middle East and North Africa were excluded from the analysis. Model 7 of Table 3 shows the results of a regression model including economic, natural capital, and geographic variables. As with previous additions to the "core" model, the direction and significance of the economic and natural capital variables remain unchanged, although the area of forest cleared drops to marginally significant, with a t-value of 1.92, slightly below the $p < 0.05$ threshold of $t = 1.96$. The coefficient values on all variables remain similar to those in previous models. The regression was highly significant ($F = 12.2$), and explained 67% of the variance in economic growth.

Dummy variables for Sub-Saharan Africa and Latin America and the Caribbean were negative and significant, indicating that these regions had lower economic growth rates than others, after correcting for the rest of the explanatory variables. Both of these regions occur almost entirely within the tropics, and their component countries have low (in some cases extremely low) per-capita incomes. Slow economic growth has been noted in these regions before (Gallup and Sachs 1998). To determine whether the effect of natural capital liquidation was different for countries in these regions, I specified another regression model, that included variables from the core model, as well as the significant regional dummy variables and their interactions with the area of forest cleared variable (Model 8, Table 3). Neither of these interactions was significant, and indeed the

TABLE 3

REGRESSION COEFFICIENTS (*t*-VALUES BENEATH) FOR MODELS OF ECONOMIC GROWTH, 1960−1999, INCLUDING NATURAL CAPITAL AND GEOGRAPHY VARIABLES

Variable	Model 7	Model 8
Intercept	0.02239	0.02094
	(1.7406)	(1.3164)
LNAREA	0.00115	0.00059
	(0.9202)	(0.4903)
LNORGFOR	−0.0048	−0.0045
	(−2.2174)	(−2.1688)
LNAREACUT	0.00385	0.0043
	(1.9174)	(2.0560)
LIFEEX60	0.00065	0.00067
	(2.7260)	(2.9339)
SAV6099	0.00086	0.00091
	(4.8538)	(5.404)
LOGGDP60	−0.0081	−0.0082
	(−4.0730)	(−4.3293)
YRSOPEN	0.00026	0.00022
	(2.0550)	(1.8301)
EAP	0.00423	–
	(0.9209)	
WE	5.3E-05	–
	(0.0101)	
SSA	−0.0131	0.01205
	(−3.0445)	(0.6843)
LAC	−0.0083	−0.0267
	(−2.1884)	(−1.6834)
SSA × LNAREACUT	–	−0.003
		(−1.5637)
LAC × LNAREACUT	–	0.00204
		(1.1542)
N	77	77
F	12.2	13.7
R^2	0.67	0.70
Adjusted R^2	0.62	0.65

significance of the dummy variables themselves disappeared in this model. However, all other economic and natural capital variables retained their significant effects on economic growth (marginally so for the number of years an economy has been open), with near-identical coefficient values for these explanators. This regression model explained 70% of the variance in economic growth, and was highly significant ($F = 13.7$). I conclude from this analysis that although evidence for geographical variation in growth rates is found in the lower growth of countries in Sub-Saharan Africa and Latin America and the Caribbean, these variables do not diminish the importance of natural capital liquidation on economic growth.

VI. CONCLUSION

The negative consequences of forest clearance and logging to biodiversity conservation and ecosystem functioning have been well-documented (Lawton et al. 1998; Putz et al. 2001; Siegert et al. 2001). Forest ecosystems, particularly tropical forests, are thought to be the most species-rich ecosystems on earth (World Resources Institute 2000), and are also thought to play important roles in the regulation of watersheds and the global carbon cycle (Daily 1997). Recent attempts to calculate the economic value of standing forests have argued that conserving forests can have economic as well as environmental benefits (Adger et al. 1995; Godoy et al. 2000; Kremen et al. 2000). Economic valuation of such items as carbon storage, biodiversity option value, and ecotourism have emphasized that leaving an area under forest may have as much or more economic value as clearing it (Kremen et al. 2000; Adger et al. 1995; Chase et al. 1998; Adamowicz et al. 1996).

In contrast, this paper has shown that economic growth over a large cross-section of countries is generally accelerated by the clearance of forested areas. Using standard methods from the empirical growth field, I have demonstrated that economic growth rates of over 70 countries were affected by an original stock of natural capital and its subsequent liquidation. Countries that initially had a great deal area of their surface area covered in forests have grown more slowly than those having fewer original forests. In addition, countries that have cleared large areas of their original forests have grown faster than those countries that retain much of their forested land.

These results are robust to many changes in model specification. Level of economic development, the area of land under domestication, and the geographical position of a country do not influence how forest clearance impacts economic growth, though each of these variables has their own effect on economic growth. The importance of forest exports to a country's economy did modify the impact of forest clearance on economic growth, but its main effect was to change the degree, and not the direction, of the relationship. Forest clearance was still a positive contributor to economic growth for most countries; only those countries having tiny levels of forest export importance were negatively influenced by forest clearance.

Forest clearance in countries has occurred at very different times throughout history; most of western Europe's forests were cleared many centuries ago (World Resources Institute 2000), whereas countries in the Amazon and Congo basins still retain much of their original forest cover (Myers 1992). For this reason, it is difficult to determine the reasons behind the relationship between natural capital and its liquidation, and national economic growth rates. To investigate this linkage more thoroughly, an ideal data set would be comprised of the variables utilized here, but over a time series dating to the time when countries first started large-scale clearance of their forests. Despite the lack of this information, I will speculate that countries have made productive investments from the dividends of the clearance of forests, and that these investments have contributed to growth from 1960 to 1999. For slow-growing natural assets such as forests, overexploitation and investment in alternative assets with faster growth potential is often the economically rational pathway (Clark 1973). The logic is thus that countries with more forests were disadvantaged because they needed to clear their forests so that more productive investments to the land under forests could be made. The earlier countries have started clearing forests, the greater the area has been cleared, resulting in a greater time for alternative assets to grow, and hence greater economic growth.

The results from these analyses are somewhat disconcerting from the point of view of sustainable development, as they suggest that liquidating one's natural capital will contribute to higher economic growth rates. Remedial policy measures can be suggested under both weak and strong sustainability paradigms. Assuming substitutability of different capital types exists, the dual policy goals of preservation of natural capital and continued economic growth would require investments in substitutes for forest clearance. For example, the average growth rate of countries from 1960 to 1999 was 1.4%/yr. Had initial life expectancy averaged 58 years instead of 53 and the average savings rate 21% instead of 18%, this same growth rate could have been achieved while clearing only 18% of original forest area, instead of the 56% that has actually been cut in the sample of countries used in this analysis. This example indicates that at a broad scale, investments in alternative types of capital could potentially offset growth losses due to natural capital preservation.

From a strong sustainability perspective, the liquidation of forest assets leads to a reduction of wealth and the illusion of economic growth, rather than true increases in well-being. Studies in Indonesia and Costa Rica have illustrated that the depletion of natural capital such as forests and soils results in inflated estimates of per-capita income, and that when the depreciation of these natural assets is accounted for, actual income and economic performance are much lower than conventional estimates (Repetto 1992; Repetto et al. 1989). The results presented here show that earlier case studies and more recent work regarding unsustainable economic growth and the liquidation of natural capital may apply for forest clearance in a wide cross-section of countries (Hamilton and Clemens 1999; Pearce, Hamilton, and Atkinson 1996; Repetto et al. 1989). Unless accounting procedures that correct for the depreciation of natural assets are adopted, the desire for sustained economic growth as traditionally-defined may well lead to continuing liquidation of forests, with the attendant consequences for the environment and sustainable development.

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