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Natural Resources and Economic Growth: Some Theory and Evidence*

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We develop a one-sector endogenous growth model in which renewable natural resources are both a factor of production and measure of environmental quality. Along the balanced growth path, sustained economic growth and a non-deteriorating environment are shown to coexist. Moreover, steady-state economic growth and natural-resource utilization are positively related. Empirically, a cross-country growth regression that includes a broad measure of productive natural resources — the Ecological Footprint — provides strong support. Our estimation results also suggest conservation costs are minimal, and growth strategies based on greater physical capital formation and trade openness outperform those relying on more intensive utilization of the environment.

Key Words: Natural resources; Endogenous growth; Ecological footprint.
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1. INTRODUCTION

In response to high energy prices and the OPEC oil embargo during the 1970's, economists began to systematically examine the growth ef-

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fects of non-renewable natural resources within dynamic general equilibrium macroeconomic models. For example, using an exogenous-growth framework, Solow (1974) and Stiglitz (1974) show that sustained economic growth is possible so long as the reproducible factor of production (physical capital) can be substituted for exhaustible natural resources along the economy's balanced growth path.[1] This finding, while unquestionably essential, is somewhat restrictive in scope in that it ignores the impact of economic activities on the quality and state of the environment. As a result, economists began to broaden their focus and investigate the interrelations between economic growth and pollution emissions in the 1990's. Specifically, Stokey (1998) finds that continuing growth is possible despite ever tightening pollution restrictions that are met with costly abatement. More recently, Brock and Taylor (2005) demonstrate the co-existence of sustained economic growth and zero net pollution emissions (dubbed the "Kindergarten Rule") within an endogenous growth model in which the abatement technology improves through learning-by-doing. Although this latter branch of the literature implicitly discusses the relationship between economic development and environmental quality through the narrow lens of pollution, it neglects the additional role that natural resources play in the production of GDP and hence long-run economic growth. Motivated by this gap, we develop a stylized one-sector endogenous growth model that captures the environment's dual roles as (i) a provider of factors of production, and (ii) a stock of renewable natural resources that accumulates over time to preserve environmental quality as GDP continues to grow. Our main finding is that in the long run, the economy's output growth rate is positively related to the steady-state level of utilized natural resources. In addition, a panel cross-country growth regression, which includes a broad measure of productive natural resources, provides strong empirical support for this theoretical prediction.

The results of Solow (1974), Stiglitz (1974), and Stokey (1998), among others, together suggest that sustained economic growth is possible despite limitations on the productive availability of exhaustible natural resources, and that additional costs and restrictions associated with preserving environmental quality are not an insurmountable impediment to growth. By contrast, this paper focuses on the feasibility of a balanced-growth equilibrium with non-deteriorating environmental quality in a canonical one-sector endogenous growth model with renewable natural resources. In our model economy, households live forever, provide fixed labor supply and derive utility from consumption goods. On the production side, a continuum of identical, competitive firms produce output using natural resources, which

[1]Suzuki (1976) finds that continuing output growth can arise within environmental endogenous growth models as well.

are assumed to regenerate at a constant rate over time, as a factor of production. The economy's aggregate production function displays increasing returns-to-scale because of the presence of productive externalities generated by capital inputs. We show that along the balanced growth path (BGP), output, consumption, and physical capital all grow at a common positive rate, whereas the stock of total natural resources and the level of natural resources allocated to the firms' production process maintain their respective steady-state values.[2] It follows that the quantity of utilized natural resources per unit of GDP steadily declines in the economy's BGP equilibrium, a result that is also echoed in Solow (1974), Stiglitz (1974), and Stokey (1998) under non-renewable resources. Furthermore, we find that an increase of natural-resource utilization in production will raise the BGP's output growth rate.

Next, to empirically verify our main theoretical finding, we incorporate an inclusive measure of productive natural resources — the Ecological Footprint (EF) — into Barro's (1991) panel cross-country growth regression model. Formally speaking, natural capital includes all the productive resources that can be extracted from the earth, as well as all the biological processes and services that facilitate life such as the absorption of waste or the conversion of carbon-dioxide into oxygen. The EF series is based on this broader concept of natural capital. As described in Rees (1992) and Wackernagel and Rees (1996), the EF variable systematically measures the quantity of renewable natural resources and life-facilitating services demanded by each nation.[3] In order to overcome the inherent problem of aggregating over many disparate measures, the Ecological Footprint is constructed by first converting an exhaustive and comprehensive list of renewable natural resources and life-support services into standardized units of land area called global hectares. The resulting quantity, expressed in per-capita terms, offers a standardized measure of the land needed to support an average person's consumption expenditures (based on the country's current level of per-capita income), and to facilitate ecologically necessary life-facilitating services. To our knowledge, the EF series is the best available aggregate proxy for natural-resource utilization in the economy's production process for a large panel of countries.

In addition to the Ecological Footprint, our dataset consists of a broad international panel that includes 5-year growth spells of output, together with some standard conditioning variables such as initial per-capita GDP, an educational attainment proxy for human capital, government and invest-

[2]See Smulders (1999) for a survey of other mechanisms that also demonstrate the compatibility of continuing output growth and environmental preservation within the context of endogenous growth models.

[3]The Ecological Footprint does not include measures of mineral deposits extracted in a given year.

ment's shares of output, and trade openness. In order to obtain unbiased estimates from our dynamic panel regressions, Arellano and Bond's (1991) two-step GMM estimation procedure is employed. It is first shown that our empirical model passes the necessary specification tests whereby no second or higher-order serial correlations in the estimation residuals are present. We then show that the estimated coefficient on the Ecological Footprint is positive and statistically significant at the 1% level. This estimation result provides strong empirical support for the key prediction of our theoretical model, that is, more intensive utilization of natural resources in production leads to an increase in the economy's output growth rate. Moreover, the signs and statistical significance of the remaining regressors are generally in-line with neoclassical growth theory and previous empirical studies. We also perform a sensitivity analysis on our benchmark econometric specification by leaving out a variety of combinations of components from the footprint measure, or by including separate components of the EF series. As it turns out, the results from these alternative estimations broadly support our main empirical finding that natural-resource utilization positively contributes to future economic growth.

The remainder of this paper is organized as follows. Section 2 describes the theoretical model and analyzes the equilibrium conditions for the economy's balanced growth path. Section 3 employs an international panel dataset that includes the Ecological Footprint to empirically verify our main theoretical findings. Section 4 concludes.

2. THE THEORETICAL MODEL

To provide the simplest possible analytical framework for motivating our empirical study, we modify Smulders' (1999, section 2.2) highly stylized one-sector environmental endogenous growth model in which the representative household lives forever, provides fixed labor supply, and derives utility from consumption goods. The economy's social technology exhibits increasing returns-to-scale because of the presence of productive externalities generated by capital inputs. For expositional simplicity, and to maintain consistency with the subsequent empirical work that employs the Ecological Footprint to measure environmental utilization, we assume that all natural resources are renewable (such as a forest or fishery) in our theoretical model. Moreover, some of the natural resources are used in the firm's production function to capture the environment's productive value. Our main objective is to explore the interrelations between the output growth rate and environmental quality along the economy's balanced growth path.

2.1. Firms

There is a continuum of identical, competitive firms in the economy, with the total number normalized to one. Each firm produces output Y_t using a constant returns-to-scale Cobb-Douglas production function

$$Y_t = K_t^{\alpha} H_t^{1-\alpha} X_t, \quad 0 < \alpha < 1, \tag{1}$$

where K_t and H_t are physical capital and harvested/utilized natural resources (or natural capital), respectively, and X_t represents productive externalities that are taken as given by individual firms.[4] In addition, X_t is postulated to take the form

$$X_t = A\overline{K}_t^{1-\alpha}, \quad A > 0, \tag{2}$$

where $\overline{K}_t$ denotes the economy-wide average level of the capital stock. In a symmetric equilibrium, all firms take the same actions such that $K_t = \overline{K}_t$. Hence, (2) can be substituted into (1) to obtain the following social production function that displays increasing returns-to-scale:

$$Y_t = AK_t H_t^{1-\alpha}. \tag{3}$$

Under the assumption that factor markets are perfectly competitive, the first-order conditions for the firm's profit maximization problem are given by

$$r_t = \alpha \frac{Y_t}{K_t}, \tag{4}$$

$$p_t = (1-\alpha)\frac{Y_t}{H_t}, \tag{5}$$

where r_t is the capital rental rate and p_t is the real price paid to utilized natural resources.

2.2. Households

The economy is populated by a unit measure of identical infinitely-lived households, each has perfect foresight and maximizes a discounted stream of utilities over its lifetime

$$\int_0^{\infty} \frac{C_t^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt, \quad \sigma > 0, \quad \sigma \neq 1, \tag{6}$$

[4]By contrast, Sumlders (1999) postulates that it is the stock of a broadly-defined capital, which includes physical capital as well as man-made knowledge (i.e. human capital), that enters the firm's production technology (1). None of our theoretical results are affected by this difference of modeling assumption.

where C_t is the individual household's consumption, $\rho \in (0, 1)$ is the subjective discount rate, and σ is the inverse of the intertemporal elasticity of substitution in consumption.

The budget constraint faced by the representative household is

$$C_t + \dot{K}_t + \delta K_t = r_t K_t + p_t H_t, \quad K_0 > 0 \text{ given}, \tag{7}$$

where $\delta \in [0, 1]$ is the capital depreciation rate. As is commonly specified in the environmental macroeconomics literature (see, for example, Smulders (1999) and references therein), the economy's ecological process or the law of motion for total renewable resources (as a proxy for environmental quality) N_t is given by

$$\dot{N}_t = f(N_t)N_t - H_t, \quad N_0 > 0 \text{ given}, \tag{8}$$

where $f(N_t)$ is the regeneration function that is often assumed to be strictly increasing in N_t. Without loss of any generality, we postulate that the rate of natural regeneration is independent of the environmental state, specifically $f(N_t) = \theta > 0$.[5] On the other hand, as pointed out by Smulders (1999, p. 612), H_t represents not only the extraction of natural resources, but also the disposal of wastes (i.e. pollution) because both activities reduce the environment's absorption capacity represented by $f(N_t)N_t$.

The first-order conditions for the representative household's dynamic optimization problem are

$$C_t^{-\sigma} = \lambda_{K_t}, \tag{9}$$

$$\lambda_{K_t}(r_t - \delta) = -\dot{\lambda}_{K_t} + \rho\lambda_{K_t}, \tag{10}$$

$$\theta\lambda_{N_t} = -\dot{\lambda}_{N_t} + \rho\lambda_{N_t}, \tag{11}$$

$$\lambda_{K_t} p_t = \lambda_{N_t}, \tag{12}$$

$$\lim_{t\to\infty} \lambda_{K_t} K_t e^{-\rho t} = 0, \tag{13}$$

$$\lim_{t\to\infty} \lambda_{N_t} N_t e^{-\rho t} = 0, \tag{14}$$

where λ_{K_t} and λ_{N_t} are shadow prices (or utility values) of capital stock and natural resources, respectively. Equation (9) states that the marginal benefit of consumption equals its marginal cost, which is the marginal utility of having an additional unit of physical capital. In addition, (10) and (11) are standard Euler equations that govern the evolution of K_t and N_t over time. Equation (12) shows that the firm utilizes natural resources to

[5]We also consider the formulation in which only the non-utilized natural resources are allowed to regenerate. In this case, the accumulation equation (8) becomes $\dot{N}_t = \theta N_t - (1 + \theta)H_t$. It turns out that all our theoretical results are qualitatively robust to this modification.

the point where the marginal value of more output is equal to the marginal cost of resource depletion. Finally, (13) and (14) are the transversality conditions (TVC).

2.3. Balanced Growth Path

In light of the household's CRRA utility formulation (6), together with the linearity of physical capital in the aggregate technology (3), the economy exhibits sustained endogenous growth whereby output, consumption, and physical capital all display a common, positive constant growth rate denoted by g. Moreover, the regeneration/depletion equation (8) implies that in the long run (or in an ecological equilibrium defined as $\dot{N}_t = 0$), total and utilized natural resources will reach their respective steady-state levels, N^* and H^*. This in turn imposes a sustainable long-run environmental quality constraint, as in Solow (1974), Stiglitz (1974), and Stokey (1998) under exhaustible natural resources, where a constant level of pollution exactly matches the environment's absorption capacity.

To derive a balanced growth path (BGP), we first make the variable transformation $X_t \equiv \frac{C_t}{K_t}$, and re-express the model's equilibrium conditions as the following autonomous differential equations:

$$\frac{\dot{X}_t}{X_t} = \frac{\alpha A H_t^{1-\alpha} - \delta - \rho}{\sigma} - A H_t^{1-\alpha} + X_t + \delta, \tag{15}$$

$$\frac{\dot{H}_t}{H_t} = \frac{1}{\alpha}\left[A(1-\alpha)H_t^{1-\alpha} - X_t + \theta\right], \tag{16}$$

$$\dot{N}_t = \theta N_t - H_t. \tag{17}$$

Given the above dynamical system (15)-(17), the balanced-growth equilibrium is characterized by a triplet of positive real numbers (X^*, H^*, N^*) that satisfy the condition $\dot{X}_t = \dot{H}_t = \dot{N}_t = 0$. It is straightforward to show that our model economy exhibits a unique balanced growth path along which the utilized natural resource maintains its steady-state level

$$H^* = \left[\frac{\sigma\theta - [\rho - (\sigma - 1)\delta]}{\alpha A(\sigma - 1)}\right]^{1/(1-\alpha)}, \tag{18}$$

which in turn leads to the expressions for X^* and N^* as follows:

$$X^* = A(1-\alpha)(H^*)^{1-\alpha} + \theta \quad \text{and} \quad N^* = \frac{H^*}{\theta}. \tag{19}$$

With (18) and (19), it follows that the common (positive) rate of economic growth g is given by

$$g = \frac{\theta - \rho}{\sigma - 1} \quad \text{or} \quad g = \alpha A(H^*)^{1-\alpha} - \theta - \rho. \tag{20}$$

As a result, the BGP's growth rate *ceteris paribus* is positively related to the steady-state level of utilized natural resources.[6] That is, a higher (lower) usage of services from the environment in production will raise (reduce) the economy's rate of growth in output, consumption, and physical capital. Moreover, the quantity of utilized natural resources per unit of GDP steadily declines along the economy's balanced growth path, a result that is also echoed in Solow (1974), Stiglitz (1974), and Stokey (1998), among many others.

3. THE EMPIRICAL MODEL

There are two interesting implications that follow from the above theoretical model. First, as mentioned earlier, the BGP's output growth rate rises with the productive utilization of natural resources $\frac{\partial g}{\partial H^*} > 0$. Second, the economy's long-run rate of economic growth increases with the reproduction rate of natural resources $\frac{\partial g}{\partial \theta} > 0$. The latter implication is difficult to verify empirically because of the need to access data on the *stock* of natural resources, whereas the former is more easily testable given that it requires the *flow* of natural resources used in production. As a result, we restrict our empirical analyses to the output-growth effect of natural-resource utilization. In particular, we incorporate natural-resource usage into Barro's (1991) specification and examine the following panel cross-country growth regression model:

$$\begin{aligned} \text{growth}_{it+1} &= \beta_1 \text{income}_{it} + \beta_2 \text{education}_{it} + \beta_3 \text{gov}_{it} + \beta_4 \text{inv}_{it} \\ &\quad + \beta_5 \text{trade}_{it} + \beta_6 \text{footprint}_{it} + \alpha_i + \eta_t + \varepsilon_{it+1} \qquad (21) \end{aligned}$$

where the dependent variable (growth_{it+1}) measures the average annual growth in real GDP per capita of country i over the next 5-year period (between t and $t+1$). To account for conditional convergence, our model includes income_{it}, which is the natural log of PPP-adjusted, chain-weighted per-capital GDP at period t. Human capital is controlled by way of the proxy education_{it}, which equals the average years of education for the entire population aged 15 and above. To account for differences in fiscal policies across countries, we include gov_{it}, which measures public expenditures on goods and services relative to GDP (i.e. G_{it}/Y_{it}), as a conditioning variable. To control for the rate of capital formation, the investment share in output (i.e. I_{it}/Y_{it}), denoted as inv_{it}, is also included. The openness of a nation is captured by trade_{it}, which is the ratio of total trade to GDP, i.e. $(IM_{it} + EX_{it})/Y_{it}$. To control for the natural-resource utilization in production, we include footprint_{it}, which equals the natural log of the per-

[6]To ensure that the BGP's output growth rate g is positive, we impose the following parametric restriction: $\theta > (<)\rho$ when $\sigma > (<)1$.

capita quantity of renewable natural resources, in our panel estimation. Finally, α_i is a country-specific effect, η_t is a period-specific effect, and ε_{it+1} is an i.i.d. stochastic shock with zero mean and standard deviation σ_ε^2.

3.1. The Data

Our international panel dataset is constructed from three sources. Output growth, income, government and investment's shares of GDP, and trade openness are taken from the Penn World Table v. 6.2 (Heston, Summers, and Aten, 2006). These variables are expressed as percentages with the exception of income, which is expressed (prior to taking the natural log) in constant (2000) international dollars ($I). The education series comes from Barro and Lee (2000), and measures the average years of schooling for the entire population aged 15 and above. Finally, the natural-resource series — the Ecological Footprint (EF) — is obtained from the Global Footprint Network (2005).[7] This variable measures the quantity of renewable natural resources, in standardized global hectares (gha), needed to produce a nation's current level of per-capita consumption. Specifically, the EF series is equal to the sum of seven underlying components: the land required to produce crops for both human and animal consumption (henceforth denoted as "crops"); the land required to maintain pasture-grazing animals (denoted as "pasture"); the land required to harvest forest products, which is sub-divided between wood for fuel (denoted as "fuelwood") and all other forest products (denoted as "timber"); the freshwater and oceanic surface area required to produce fishing harvests (denoted as "fish"); the land required to sequester carbon dioxide emissions from the burning of fossil fuels (denoted as "CO2"); and the land that has been developed for commercial and residential uses (denoted as "built"). Since the value of permanent improvements to land and to the structures placed on land are generally considered as parts of a nation's stock of physical capital, including them in a flow measurement of renewable resources is not appropriate. Therefore, we remove the developed-land component (i.e. "built") from the total EF series in our empirical estimations.[8]

Although the Ecological Footprint possesses the obvious attractiveness of being a single statistic designed to capture the aggregate utilization of renewable natural resources, it suffers the same drawback of any aggregated measure: strong assumptions are required in its construction. For example, it lumps together the input and environmental effects, i.e. unwanted outputs like waste and the damage from CO2; and it confuses flow

[7]See Haberl, Erb, and Krausmann (2001) for a good introduction on how ecological footprints are calculated.

[8]The nuclear power component (which is a sub-component of the "CO2" series) is removed from the footprint indicator used in the subsequent estimations as well.

versus stock effects, e.g. the cost of cleaning up soils is imputed. Moreover, Ayers (2000) takes issue with the underlying assumptions with regard to the carbon dioxide sequestering and the conversion of energy consumption into land usage areas. Van Kooten and Bulte (2000) highlight the EF inability to tackle important ecological topics such as soil erosion and carbon absorption. In order to alleviate these concerns, we perform robustness checks (in section 3.5) — leaving out a variety of combinations of components from the footprint measure, or including separate components of the EF indicator — on our benchmark empirical model that uses the modified (six-component) EF series as a regressor.

In sum, our dataset consists of an unbalanced panel of 93 countries over 9 five-year time periods (1961, 1966,..., 2001), for a total of 794 observations. Table 1 lists the nations and periods covered in the dataset, and Table 2 presents summary statistics of the raw, untransformed data on the Ecological Footprint, together with its correlation with each country's per-capita GDP. It turns out that 35 countries exhibit a negative co-movement between the EF and output (Australia has the lowest correlation of -0.88), whereas the remaining 58 nations display a positive relationship (China has the highest correlation of 0.99). For the entire sample of 93 countries, the average correlation coefficient between the EF and per-capita GDP is 0.25, and the corresponding median value is 0.44. The fact that this relationship, on balance, is positive is also reflected in the scatter plot of Figure 1, which shows that the correlation coefficient between the country-specific average Ecological Footprint and average output is 0.84. In addition, we calculate the mean levels of the EF and GDP per person over all available countries for each year of our sample period (from 1961 to 2001), and plot the resulting time series in Figure 2. While the EF is a more volatile series than output, both variables have exhibited an upward trend with a correlation coefficient of 0.85. The above-mentioned evidence, albeit descriptive in nature, provides empirical support for the presence of a positive linkage between natural-resource utilization and the economy's per-capita GDP.

3.2. Estimation Method

It is well known in the empirical growth literature that using standard fixed- or random-effect methods to estimate a dynamic panel model such as (21) generates biased estimates. Typically, this deficiency is resolved by use of a Generalized Method of Moments (GMM) estimator along with suitable instruments. Within this family of estimation procedures, Arellano and Bond's (1991) two-step estimator is one of the most popular methods, and is also the estimator of choice for this paper. The first step of Arellano and Bond's estimation procedure is to take the first difference of (21),

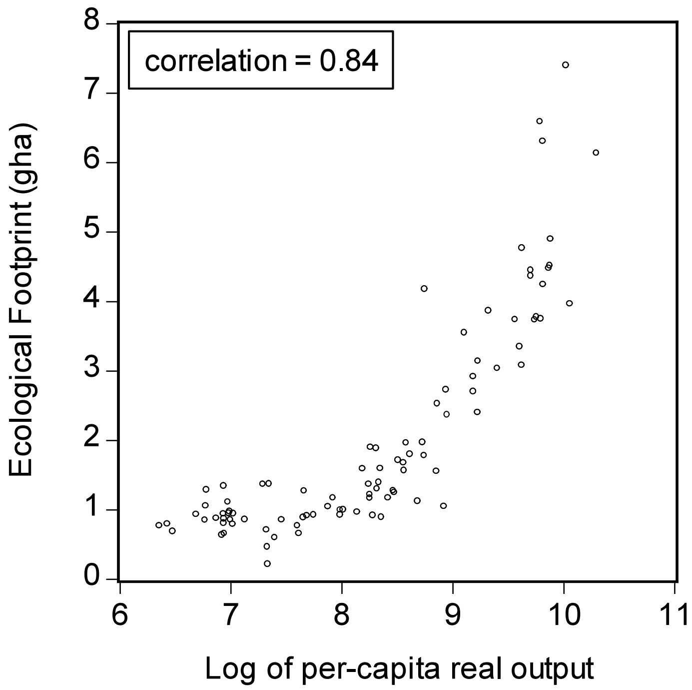
TABLE 1.

Countries and Periods

Country	Observations	Range	Country	Observations	Range
Afghanistan	7	1971-2001	Lesotho	9	1961-2001
Algeria	9	1961-2001	Liberia	7	1971-2001
Argentina	9	1961-2001	Malawi	9	1961-2001
Australia	9	1961-2001	Malaysia	9	1961-2001
Austria	9	1961-2001	Mali	9	1961-2001
Bangladesh	6	1976-2001	Mauritius	9	1961-2001
Benin	9	1961-2001	Mexico	9	1961-2001
Bolivia	9	1961-2001	Mozambique	9	1961-2001
Botswana	7	1971-2001	Nepal	9	1961-2001
Brazil	9	1961-2001	Netherlands	9	1961-2001
Cameroon	9	1961-2001	New Zealand	9	1961-2001
Canada	9	1961-2001	Nicaragua	9	1961-2001
Central African Republic	7	1971-2001	Niger	9	1961-2001
Chile	9	1961-2001	Norway	9	1961-2001
China	6	1976-2001	Pakistan	9	1961-2001
Colombia	9	1961-2001	Panama	9	1961-2001
Congo, Republic of	4	1986-2001	Papua New Guinea	7	1971-2001
Costa Rica	9	1961-2001	Paraguay	9	1961-2001
Denmark	9	1961-2001	Peru	9	1961-2001
Dominican Republic	9	1961-2001	Philippines	9	1961-2001
Ecuador	9	1961-2001	Poland	7	1971-2001
Egypt	6	1976-2001	Portugal	9	1961-2001
El Salvador	9	1961-2001	Rwanda	9	1961-2001
Finland	9	1961-2001	Senegal	9	1961-2001
France	9	1961-2001	Sierra Leone	7	1971-2001
Gambia, The	9	1961-2001	South Africa	9	1961-2001
Germany	7	1971-2001	Spain	9	1961-2001
Ghana	9	1961-2001	Sri Lanka	9	1961-2001
Greece	9	1961-2001	Sudan	7	1971-2001
Guatemala	9	1961-2001	Swaziland	7	1971-2001
Guinea-Bissau	9	1961-2001	Sweden	9	1961-2001
Haiti	6	1971-1996	Switzerland	9	1961-2001
Honduras	9	1961-2001	Syria	9	1961-2001
Hungary	7	1971-2001	Tanzania	9	1961-2001
India	9	1961-2001	Thailand	9	1961-2001
Indonesia	9	1961-2001	Togo	9	1961-2001
Iran	9	1961-2001	Trinidad &Tobago	9	1961-2001

Country	Observations	Range	Country	Observations	Range
Iraq	7	1971-2001	Tunisia	9	1961-2001
Ireland	9	1961-2001	Turkey	9	1961-2001
Israel	9	1961-2001	Uganda	9	1961-2001
Italy	9	1961-2001	United Kingdom	9	1961-2001
Jamaica	9	1961-2001	United States	9	1961-2001
Japan	9	1961-2001	Uruguay	9	1961-2001
Jordan	9	1961-2001	Venezuela	9	1961-2001
Kenya	9	1961-2001	Zambia	9	1961-2001
Korea, Republic of	9	1961-2001	Zimbabwe	9	1961-2001
Kuwait	7	1971-2001			

FIG. 1. Scatter Plot of Real Output and the Ecological Footprint



Note: Diagram includes 93 observations, each consisting of country-specific averages over all available time periods.

which, after some algebraic manipulation, can be expressed as (22)

$$\begin{aligned}\Delta\text{income}_{it+1} \;=\; & (1+\beta_1)\Delta\text{income}_{it} + \beta_2\Delta\text{education}_{it} + \beta_3\Delta\text{gov}_{it} + \beta_4\Delta\text{inv}_{it} \\ & +\beta_5\Delta\text{trade}_{it} + \beta_6\Delta\text{footprint}_{it} + \Delta\eta_t + \Delta\varepsilon_{it+1} \qquad (22)\end{aligned}$$

TABLE 2.

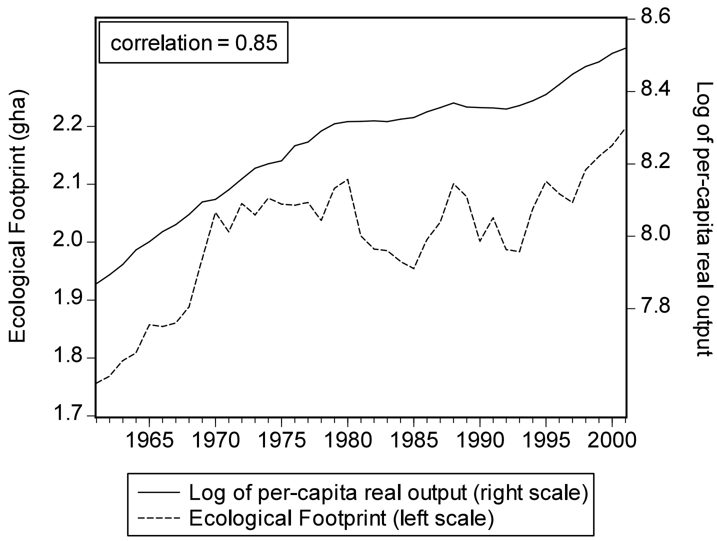
Summary Statistics of the Ecological Footprint

Country	Avg	Std.Dev.	Correlation with GDP	Country	Avg	Std.Dev	Correlation with GDP
Afghanistan	0.22	0.06	0.86	Lesotho	0.96	0.15	−0.82
Algeria	1.21	0.27	0.86	Liberia	0.80	0.11	0.37
Argentina	2.70	0.21	−0.17	Malawi	0.69	0.19	−0.87
Australia	6.60	1.06	−0.88	Malaysia	1.58	0.51	0.73
Austria	3.77	0.70	0.95	Mali	0.94	0.14	−0.67
Bangladesh	0.45	0.07	−0.53	Mauritius	1.02	0.32	0.89
Benin	0.93	0.12	−0.39	Mexico	1.94	0.35	0.96
Bolivia	1.14	0.09	0.36	Mozambique	0.66	0.06	−0.41
Botswana	1.37	0.47	0.56	Nepal	0.64	0.06	−0.84
Brazil	1.80	0.15	0.74	Netherlands	3.71	0.69	0.90
Cameroon	0.94	0.14	−0.46	New Zealand	4.43	0.56	0.55
Canada	6.19	0.80	0.54	Nicaragua	1.30	0.21	0.90
Central African Republic	0.89	0.07	0.52	Niger	1.32	0.15	0.62
Chile	1.50	0.21	0.24	Norway	4.40	1.01	0.78
China	1.23	0.25	0.99	Pakistan	0.58	0.04	−0.73
Colombia	1.16	0.06	0.79	Panama	1.67	0.11	−0.07
Congo, Republic of	0.67	0.16	−0.56	Papua New Guinea	1.48	0.29	0.63
Costa Rica	1.84	0.48	0.59	Paraguay	1.89	0.09	−0.06
Denmark	5.01	0.85	0.54	Peru	0.90	0.14	0.48
Dominican Republic	1.16	0.20	0.77	Philippines	0.92	0.07	−0.35
Ecuador	1.18	0.16	0.41	Poland	4.16	0.61	−0.39
Egypt	1.14	0.09	0.90	Portugal	2.87	0.69	0.80
El Salvador	0.91	0.13	0.66	Rwanda	0.81	0.11	−0.29
Finland	4.68	0.50	0.76	Senegal	1.38	0.17	0.50
France	3.67	0.39	0.58	Sierra Leone	0.85	0.13	0.60
Gambia, The	1.08	0.12	−0.20	South Africa	2.50	0.41	0.47
Germany	4.45	0.34	−0.69	Spain	2.93	0.66	0.93
Ghana	0.87	0.12	−0.28	Sri Lanka	0.76	0.05	−0.51
Greece	3.09	1.03	0.82	Sudan	0.95	0.10	0.13
Guatemala	0.93	0.05	−0.06	Swaziland	1.03	0.21	−0.61
Guinea-Bissau	0.80	0.07	0.19	Sweden	4.29	0.56	−0.16
Haiti	0.66	0.09	0.67	Switzerland	3.88	0.50	0.81
Honduras	1.26	0.26	−0.86	Syria	1.36	0.24	0.94
Hungary	3.57	0.46	−0.33	Tanzania	0.77	0.09	−0.47
India	0.71	0.05	−0.27	Thailand	1.00	0.25	0.73
Indonesia	0.90	0.07	−0.07	Togo	0.94	0.17	0.49

Country	Avg	Std.Dev.	Correlation with GDP	Country	Avg	Std.Dev	Correlation with GDP
Iran	1.53	0.29	0.43	Trinidad &Tobago	2.37	0.87	0.32
Iraq	0.85	0.14	0.22	Tunisia	1.26	0.12	0.80
Ireland	3.84	0.65	0.89	Turkey	1.88	0.11	−0.21
Israel	4.05	1.83	0.74	Uganda	1.30	0.27	0.44
Italy	2.98	0.63	0.97	United Kingdom	4.29	0.50	0.83
Jamaica	1.56	0.33	−0.14	United States	7.21	1.19	0.89
Japan	3.27	0.71	0.82	Uruguay	3.40	2.66	−0.03
Jordan	1.40	0.26	−0.11	Venezuela	2.34	0.33	0.87
Kenya	0.86	0.12	−0.43	Zambia	0.77	0.19	0.23
Korea, Republic of	1.95	0.81	0.96	Zimbabwe	1.00	0.22	−0.47
Kuwait	5.41	1.97	0.00				

Note: Footprints are measured in standardized global hectares (gha)

FIG. 2. Time Series Plots of Real Output and the Ecological Footprint



Note: Diagram includes equal period averages from 1961 to 2001 over all available countries.

thus the country-specific term α_i is removed. The next step is to construct an appropriate set of instruments. Generally speaking, the strictly exogenous variables in (22) can serve as their own instruments, as well as lagged observations of the remaining predetermined, untransformed endogenous variables. In the current context, we follow previous studies (see, for example, Barro (2000) and Forbes (2000), among others) and postulate both the series of income and investment's share of output to be endogenous regressors.

Moreover, since it is conceivable that a higher rate of economic growth boosts the productive usage of the environment, we make the cautious modeling decision and treat the natural-resource utilization as an endogenous conditioning variable as well. As a result, our instrument set consists of all lagged values of income, investment's share of output, and ecological footprints, expressed in levels $\{\text{income}_{it-1}, \ldots, \text{income}_{i1}, \text{inv}_{it-1}, \ldots, \text{inv}_{i1}, \text{footprint}_{it-1}, \ldots, \text{footprint}_{i1}\}$, together with the remaining (exogenous) regressors, expressed in differences $\{\Delta\text{education}_{it}, \Delta\text{gov}_{it}, \Delta\text{trade}_{it}\}$, serving as their own instruments.[9]

3.3. Specification Tests

Arellano and Bond (1991) state that the following two conditions must be satisfied for their two-step GMM estimator to be consistent and efficient: (i) all of the regressors (apart from the lagged dependent variable) must be predetermined by at least one period, i.e. $E(X'_{it}\varepsilon_{is}) = 0$ for all $s > t$, where $X_{it} \equiv \{\text{education}_{it}, \text{gov}_{it}, \text{inv}_{it}, \text{trade}_{it}, \text{footprint}_{it}\}$ in this paper; and (ii) the model's estimation errors cannot be autocorrelated, i.e. $E(\varepsilon_{it}\varepsilon_{is}) = 0$, for all $s \neq t$. The first condition cannot be tested as a formal testing method does not exist. However, Arellano and Bond (1991) propose two serial-correlation tests: the m_2 test for second-order serial correlation, and the Sargan test for overidentifying restrictions.[10] Before reporting estimation results in the next subsection, we first conduct these specification tests on our empirical model as in (22).

The m_2 test for second-order autocorrelation in the residuals of (22) is crucially important because lagged values of the right-hand side regressors are used as instruments in the estimation procedure. Under the null hypothesis that there is no second-order autocorrelation, the test statistic has an asymptotic standard normal distribution

$$m_2 = \frac{\Delta\varepsilon'_{-2}\Delta\varepsilon_*}{\sqrt{\nu}} \underset{a}{\sim} N(0,1), \tag{23}$$

where $\Delta\varepsilon_{-2}$ is the vector of residuals from (22) lagged twice, $\Delta\varepsilon_*$ is the vector of residuals from the same model trimmed to match $\Delta\varepsilon_{-2}$, and ν is

[9]The one exception is the time-period effects, which (as is customary) enter the instrument matrices in levels, not in differences.

[10]As a third test, Arellano and Bond (1991) also suggest a Hausman specification test. However, using Monte Carlo experiments, these authors show that the Hausman test lacks power and is very susceptible to outliners. For this reason, Hausman specification tests are not commonly employed to test for serial correlation.

a scalar that is defined as

$$\nu \equiv \sum_{i\in N} \Delta\hat{\varepsilon}'_{i(-2)}\Delta\hat{\varepsilon}_{i^*}\Delta\hat{\varepsilon}'_{i^*}\Delta\hat{\varepsilon}_{i(-2)} - 2\Delta\hat{\varepsilon}'_{-2}X_*(X'ZA_NZ'X)^{-1}X'ZA_N \times \left(\sum_{i\in N} Z'_i\Delta\hat{\varepsilon}_i\Delta\hat{\varepsilon}'_{i^*}\Delta\hat{\varepsilon}_{i(-2)}\right) + \Delta\hat{\varepsilon}'_{-2}X_*av\hat{a}r(\hat{\delta})X'_*\Delta\hat{\varepsilon}_{-2}, \qquad (24)$$

where X includes all the right-hand side conditioning variables, $\hat{\delta}$ includes all the estimated coefficients, Z is the matrix of instruments, and A_N is the weighting matrix used in the Arellano-Bond procedure. It turns out that for model (22), the m_2 test statistic is equal to 0.33, with a corresponding p-value of 0.7415, yielding no evidence of second-order autocorrelation.

As another check of our model's estimation residuals, the Sargan test for overidentifying restrictions is employed to confirm the validity of the moment restrictions implied by the instruments. Under the null hypothesis that the moment restrictions are valid (which implies the absence of second or higher-order autocorrelations), the test statistic, denoted as s, is asymptotically chi-square distributed with $q-k$ degrees of freedom (i.e. χ^2_{q-k}):

$$s = \Delta\hat{\varepsilon}'Z\left(\sum_{i\in N} Z'_i\Delta\hat{\varepsilon}_i\Delta\hat{\varepsilon}'_iZ_i\right)^{-1} Z'\Delta\hat{\varepsilon} \underset{a}{\sim} \chi^2_{q-k}, \qquad (25)$$

where q is the number of moment restrictions, and k is the number of coefficients estimated in the model.

The Sargan test statistic for model (22) is equal to 82.86, with a corresponding p-value of 0.44, hence we cannot reject the null hypothesis that the overidentifying restrictions are valid. The above test results indicate that (22) lacks second or higher-order serial correlations in the estimation residuals. Therefore, the two-step GMM estimator that we report below is both consistent and efficient.

3.4. Estimation Results

Before discussing our estimation results, it is instructive to examine the coefficient estimates within a benchmark specification that excludes the footprint series from model (22). Table 3 shows that the coefficient estimates from this standard formulation are generally in-line with the existing empirical growth literature. In particular, the estimated coefficient on initial income is negative and statistically significant at the 1% level, indicating the presence of growth convergence, i.e. more developed nations, *ceteris paribus*, grow more slowly than their less developed counterparts. The coefficients on education, investment's output share, and the degree of openness are all positive and statistically significant. These results conform to the neoclassical growth theory where increased accumulation of physical and human capital or higher volumes of international trade will raise a nation's output growth rate. Finally, the estimated coefficient on government expenditures is positive but marginally insignificant, with a p-value of 0.156.

Turing to a full estimate of model (22) with the footprint variable included, Table 3 shows that the estimated coefficients are very similar to those in the benchmark specification.[11] However, the coefficient on government's share in GDP is now positive and statistically significant, which is at odds with the findings of other researchers (see, for example, Levine and Renelt (1992) and Barro (2000), among others). On the other hand, consistent with the key prediction of our theoretical model, the estimated natural-resource coefficient is positive and statistically significant at the 1% level. In other words, when more natural resources (as measured in standardized global hectares) are utilized in production within a nation, its subsequent 5-year growth rate in output will rise.

TABLE 3.

Two-Step GMM Estimation Results

Variable	Benchmark	Model (22)
income	−0.0493	−0.064
	(0.0012)***	(0.0010)***
education	0.0099	0.013
	(0.0025)***	(0.0011)***
government	0.0241	0.057
	(0.0170)	(0.0080)***
investment	0.1054	0.106
	(0.0241)***	(0.0122)***
trade	0.0174	0.017
	(0.0063)***	(0.0033)***
footprint		0.017
		(0.0027)***
Sargan test	64.44	82.86
Sargan p-value	0.156	0.422
Observations	608	608

White robust (period) standard errors in parenthesis ***,**,* — statistically significant at the one, five, and ten percent levels respectively

[11] Both the benchmark specification and model (22) include period dummies, whose estimated coefficients are not reported in Table 3. In addition, the Sargan test fails to reject the null hypothesis that the overidentifying restrictions are valid at any standard level of statistical significance in either formulation. See Table 3 for the respective test statistics and p-values.

Since the footprint series has been transformed by taking the natural log, the estimated coefficient is interpreted as a growth elasticity measure. Specifically, a ten percent increase in natural-resource utilization leads to a 0.17% rise in the annual growth rate of per-capita GDP over the next 5-year period. Given the relatively small magnitude of this effect, it would be inadvisable for an underdeveloped nation to rely too heavily on natural resource extraction as a means of promoting economic growth. Instead, the estimation results in Table 3 suggest that promoting domestic capital accumulation produces a much larger quantitative impact on an economy's future growth. In particular, a ten percent increase in investment's share of GDP would boost the rate of output growth by almost 1.1%. Moreover, we note that a ten percent expansion in trade openness would enhance economic growth by the same magnitude as the corresponding increase in natural-resource usage. Therefore, our analysis offers some empirical support for adopting mainstream growth strategies, such as promoting foreign direct investment and reaping the gains from international trade, that are more economically rewarding and less harmful to the environment. These results also suggest that developed nations should not be overly opposed to well-reasoned conservation programs designed to slow down the rate of natural-resource extraction because they appear to generate little drag on the economy. In addition, anti-globalization efforts, i.e. opposition to the free flow of capital and goods and services, may leave impoverished nations with few growth-promoting options. Environmental degradation, be it for internal consumption (e.g. deforestation for small homesteads) or external consumption (e.g. the export of raw commodities), is often the result. This implies that anti-globalization, anti-poverty, and pro-environmental goals are likely to be internally inconsistent.

3.5. Sensitivity Analysis

To explore the sensitivity of the above estimation results, we examine two alternative specifications whereby model (22) is re-estimated using (i) measures of the EF series with a single component (CO2, crops, fish, fuelwood, pasture or timber) removed; and (ii) measures of the EF indicator consisting of only a single component, i.e. all but one component is removed. As it turns out, the results from these alternative estimations broadly support our main empirical finding that natural-resource utilization positively contributes to future economic growth.[12]

Table 4 presents the estimation results when one footprint component is removed from the EF. With the exception of removing carbon dioxide, all of the remaining footprints continue to possess positive and statistically

[12]We have also estimated model (22) with two, or three or four of the EF components removed, and obtained the same qualitative result. These estimation results are available from the authors upon request.

significant coefficients at the 1% level. This result is perhaps not too surprising because the carbon component (CO2) has steadily trended upward as a percentage of the EF series — it rose from 8.1% in 1961 to 48.3% in 2001.[13] On the other hand, Table 5 reports the estimation results when all but one of the EF components are removed. The results turn out to be mixed, with negative and statistically significant coefficients on the EF component in three of the six regressions. Overall, the results in Tables 3, 4, and 5 show that aggregated measures of natural-resource utilization exhibit a strong, positive relationship with the growth rate of real output, but that highly disaggregated EF series do not uniformly behave in this manner. Although a formal test is beyond the scope of this paper, we note that the estimation results in Table 5 are not inconsistent with the "resource curse" literature, which finds that nations with substantial natural-capital endowments, measured as the value of the stock of crop, pasture, and forest land plus subterranean resources (such as mineral and fossil fuels), tend to grow more slowly than their lesser-endowed peers. For example, Masanjala and Papageorgiou (2008) find that primary commodity exports have a negative effect on global growth, with resource-rich African nations suffering twice the growth penalty as the rest of the world.[14] While the overlap between the Ecological Footprint and natural-capital is somewhat limited, and the corresponding units of measurement are not identical (standardized land area versus imputed value), Table 5 shows that the components common to both variables (i.e. crops, fuelwood, and timber), all exert a negative effect on economic growth.[15]

4. CONCLUSION

In examining long-run economic growth within the context of dynamic environmental macroeconomic models, most of the existing literature has developed along the following two strands: (i) the environment is a source of non-renewable factors of production, and (ii) the state of the environment's quality is measured by pollution emissions. In this paper, we incorporate both of these environmental concerns, but from a different perspective, into an otherwise standard one-sector endogenous growth model. Specifically, the environment is postulated to be a storehouse of renewable natural resources, some of which are used in the firm's production process, that accu-

[13]In 2001, the breakdown of the total EF series (net of built land and the nuclear component) was 48.3% for CO2, 23.2% for crops, 5.9% for fish, 3.6% for fuelwood, 8.4% for pasture, and 10.5% for timber.

[14]For other examples of the resource curse literature, see Gylfason (2001), Isham et al. (2005), Robinson et al. (2006), Sachs and Warner (1999), among many others.

[15]The one exception is pasture, which has a positive and statistically significant coefficient in Table 5.

TABLE 4.

Robustness Estimation Results (with one footprint component removed)

Variable						
income	−0.0393	−0.0684	−0.0668	−0.0620	−0.0640	−0.0605
	(0.0007)***	(0.0015)***	(0.0009)***	(0.001)***	(0.0008)***	(0.0008)***
education	0.0152	0.0121	0.0135	0.0127	0.0144	0.0124
	(0.0009)***	(0.0013)***	(0.0012)***	(0.0012)***	(0.001)***	(0.0012)***
government	0.0018	0.0502	0.0647	0.0523	0.0498	0.0570
	(0.0071)	(0.0079)***	(0.0088)***	(0.0106)***	(0.0119)***	(0.0088)***
investment	0.1803	0.0617	0.1004	0.1131	0.0852	0.1165
	(0.0123)***	(0.0111)***	(0.0129)***	(0.0112)***	(0.0099)***	(0.0106)***
trade	−0.0048	0.0285	0.0161	0.0153	0.0162	0.0142
	(0.0045)	(0.0045)***	(0.0046)***	(0.0046)***	(0.0039)***	(0.0045)***
footprint less CO2	−0.0540	—	—	—	—	—
	(0.0029)***					
footprint less crops	—	0.0164	—	—	—	—
		(0.002)***				
footprint less fish	—	—	0.0192	—	—	—
			(0.003)***			
footprint less fuelwood	—	—	—	0.0147	—	—
				(0.0034)***		
footprint less pasture	—	—	—	—	0.0054	—
					(0.0026)**	
footprint less timber	—	—	—	—	—	0.0158
						(0.002)***
Sargan test	84.87	84.71	84.76	82.16	84.27	81.68
Sargan p-value	0.33	0.34	0.34	0.41	0.35	0.43
Observations	608	608	608	608	608	608

White robust (period) standard errors in parenthesis ***,**,* – statistically significant at the one, five, and ten percent levels respectively

mulate over time to maintain environmental quality while output continues to grow. We show that sustained economic growth and a non-deteriorating environment can be simultaneously present along the economy's balanced growth path. Moreover, we find that the BGP's output growth rate is positively related to the steady-state level of natural-resource utilization in production.

To verify the empirical veracity of our theoretical findings, we estimate a panel cross-country growth regression that includes the Ecological Footprint, a broad measure of productive natural resources, as one of the conditioning variables. The estimation results from various econometric specifications provide strong empirical support for the positive relation-

TABLE 5.

Robustness Estimation Results (with all but one footprint component removed)

Variable						
income	−0.0403	−0.0604	−0.0685	−0.0755	−0.0544	−0.0124
	(0.0005)***	(0.0008)***	(0.0014)***	(0.0015)***	(0.0006)***	(0.0001)***
education	0.0104	0.0151	0.0021	0.0097	0.0109	0.0025
	(0.0013)***	(0.0014)***	(0.0014)	(0.0029)***	(0.0016)***	(0.0015)*
government	0.0630	−0.0167	0.0069	−0.0219	0.0718	0.0685
	(0.0092)***	(0.013)	(0.011)	(0.0161)	(0.0119)***	(0.0177)***
investment	0.0682	0.1730	0.0514	0.0105	0.1519	0.0911
	(0.0087)***	(0.0106)***	(0.0132)***	(0.0126)	(0.0156)***	(0.0136)***
trade	0.0056	−0.0074	0.0315	0.0312	0.0050	0.0131
	(0.0044)	(0.0049)	(0.003)***	(0.0053)***	(0.0039)	(0.0058)**
CO2	0.0020	—	—	—	—	—
	(0.0011)*					
crops	—	−0.0590	—	—	—	—
		(0.0027)***				
fish	—	—	−0.0107	—	—	—
			(0.0013)***			
fuelwood	—	—	—	−0.0003	—	—
				(0.003)		
pasture	—	—	—	—	0.0213	—
					(0.0017)***	
timber	—	—	—	—	—	−0.0051
						(0.0025)**
Sargan test	82.95	84.92	61.68	71.93	81.82	83.35
Sargan p-value	0.36	0.33	0.63	0.41	0.42	0.35
Observations	542	607	474	529	597	591

White robust (period) standard errors in parenthesis ***,**,* – statistically significant at the one, five, and ten percent levels respectively

ship between the utilization rate of natural resources in production and subsequent output growth. However, this finding needs to be interpreted carefully since our empirical results also suggest that the costs of environmental conservation are fairly minimal, and that growth strategies based on greater physical capital formation and openness to trade appear to outperform those depending on more intensive use of the environment. In addition, it is important to underscore that the BGP's output growth rate is positively related to the stationary, long-run value of natural-resource utilization. Hence, higher usage of natural resources today may boost economic growth in the short run, but will likely decrease its steady-state level, thus permanently reducing the economy's long-run rate of output growth. In light of this short- vs. long-run growth tradeoff, and the fact that the short-run costs of environmental conservation are relatively low, it is perhaps advisable that nations not rely too heavily on environmentally-intensive economic growth strategies.

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