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ANALYSIS

Environmental Kuznets curve: threatened species and spatial effects

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Abstract

Several studies have found evidence of an environmental Kuznets curve (EKC) for various measures of environmental degradation such as pollution and deforestation. We estimate an EKC for threatened bird and mammal species for 113 countries in 2000. For both mammals and birds, our results indicate a possible EKC curve. Birds and mammals face a greater threat on islands and endemic species are more threatened. Both are threatened where freedom is limited. Birds are threatened where political turmoil exists, while mammals are more threatened in Muslim and communistic law countries. Spatial autocorrelation exists, with shocks spilling over into surrounding countries.

Keywords: Environmental Kuznets Curve; Threatened species; Spatial autocorrelation; Freedom

1. Introduction

The decline in extant species has prompted world-wide concern in recent years. Estimates of global rates of extinction for various species range from 10 to 1000 times the natural rate of extinction (Wilson, 1988). There is concern that the untapped value of many biological resources will be lost forever. Some species may be lost before their usefulness is ever known since only 1.4 million of an estimated 13 million have been identified (Heywood and Watson, 1995).

Rising concern over the loss of species has prompted researchers to analyze the possible causes (Brown and Shogren, 1998). In this regard, the insights from recent environmental Kuznets curve (EKC) research on environmental degradation may be enlightening. In the early 1990s several researchers presented evidence that pollution levels may exhibit an inverted-U-shaped curve with respect to per capita income (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993; and Selden and Song, 1995). According to this EKC theory, pollution levels first rise as income rises, then fall as

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income continues to rise. These models are often estimated using a cross section or panel data set of countries or localities that have measures of pollution concentrations. The results were interpreted, perhaps too hastily by some, as a justification for fostering growth in low-income countries. However, other researchers have criticized these conclusions (Arrow et al., 1995). In this paper we propose to further test this EKC hypothesis using data on threatened birds and mammals. Although income is the primary variable in the EKC theory, other variables must be included in the analysis. Population density, political rights, legal structure and other variables may be significant.

Our first task is to construct a measure of the dependent variable. The International Union for the Conservation of Nature and Natural Resources (IUCN)[2] is the pre-eminent authority on threatened species. We use the percentage of threatened bird and mammal species (as defined by the IUCN) in each country as our dependent variable.[3] Birds are useful empirically as an indicator of environmental health because they have been studied as much, or more than, any other class of organisms (Stattersfield and Capper, 2000) and all bird species have been reviewed by the IUCN. Mammals are also a useful indicator because they are the only other class for which all species have been reviewed by the IUCN (Hilton-Taylor, 2000). The IUCN defines a species as threatened if it is in one of the three categories of critically endangered, endangered, or vulnerable. In 1994 the IUCN established uniform criteria for evaluating the status of species in every country.[4] Prior to 1994 the criteria were somewhat subjectively determined by researchers in each country. Reptiles, amphibians and fish are not included in this analysis because they have not been comprehensively assessed.[5]

[2] The IUCN is also known as the World Conservation Union.

[3] We do not measure biodiversity loss per se. For a discussion of the issues see Solow et al. (1993), Weitzman (1992), and Nunes and van den Berg (2001).

[4] For a list of the criteria see http://www.redlist.org/info/categories_criteria.html.

[5] Several researchers have suggested improvements to the IUCN's criteria that might better account for the threat status of particular species. For a discussion of these issues, see for example Reyers and James (1999) and Harcourt and Parks (2003).

Our purpose is to examine the factors affecting the number of threatened bird and mammal species across all countries with available data for 2000. We briefly review the literature in the following section. In Section 3 we describe the empirical model and the data set. In Section 4 we discuss the critical issue of spatial autocorrelation. In Section 5 we present our results. In the final section we provide some conclusions.

2. Literature review

Grossman and Krueger (1991) were the first to posit a relationship between environmental quality and per capita income. They argued that as economic development proceeds, increasingly intensive and extensive economic activity initially leads to a sullying of the environment. Later, at higher income levels, changes in the composition and techniques of production may be strong enough to offset the greater level of economic activity, leading eventually to an improvement in environmental quality. Some have interpreted this to imply that countries might be able to outgrow environmental problems (Holtz-Eakin and Selden, 1995). Grossman and Krueger (1991) found that for a number of types of urban air pollution, concentrations first rise with per capita income, then fall. While there was some evidence of a second turning point, they considered it not to be especially compelling.

Very quickly a large EKC literature (Cavlovic et al., 2002 and Stern, 2004 provide comprehensive surveys) emerged. Much of this literature found evidence of EKC relationships between per capita income and toxic intensity of industrial production, national air quality, deforestation, various measures of water quality, solid wastes per capita, hazardous waste sites in the United States, automotive lead emissions, and protected areas. Simultaneously, several critiques of the EKC literature emerged, with researchers noting that earlier literature had ignored the possibility that environmental degradation is simply being transferred to middle-income countries and had failed to take international trade into account.

Although much of the early work in this area was empirical, a number of theoretical justifications (both production and consumption) for the environmental

Kuznets curve have emerged (John and Pecchenino, 1994; López, 1994; Selden and Song, 1995; Suri and Chapman, 1998; Munasinghe, 1999; Stokey, 1998; Andreoni and Levinson, 2001; Pasche, 2002; Roca, 2003). The debate over the existence and possible causes of the EKC continues to grow.

A few recent studies have examined the relationship between per capita income and threatened species, a line of research originally suggested by Grossman and Krueger (1995), and our paper falls into this area. Kerr and Currie (1995) found that the percentage of species under threat decreases with per capita income (especially for mammals), but they do not allow for a non-linear relationship (i.e., the EKC). Naidoo and Adamowicz (2001) examined the determinants of the total number of threatened bird and mammal species and found some evidence of an EKC. Asafu-Adjaye (2003) argued that because the process by which species become extinct proceeds markedly more rapidly than that by which new species are created, there can be no turning point in the relationship between biodiversity and per capita income. That is, the decline in biodiversity is essentially irreversible and monotonic. This is undoubtedly true given that Asafu-Adjaye's (2003) measure of biodiversity is the total number of species in a country. Although Dietz and Adger (2003) used as their dependent variable a different measure of species richness, their argument is similar to Asafu-Adjaye's (2003). Our dependent variable amounts to the percent of a country's mammal or bird species that is threatened, and so an EKC relationship is certainly possible.

Our paper distinguishes itself from all previous literature by directly addressing the issue of spatial autocorrelation (SA). SA exists when events occurring in one place in one cross sectional unit affect or are affected by events in another. In the present context, threats to species in one country can easily spill over to neighboring countries. The consequences of failing to correct for SA are serious: certainly ordinary least squares estimates will not be efficient, and (depending on the form in which SA manifests itself) may be biased. Kerr and Burkey (2002) correctly note that SA is a typical problem in biodiversity data, and make an attempt to address the problem by adjusting the degrees of freedom in their statistical analysis. While an improvement over all previous literature, the Kerr and Burkey (2002) treatment of SA only addresses the efficiency issue in an indirect way, and leaves the possibility of bias untouched. Our paper is the first to consider the problems surrounding SA in a comprehensive manner. We also consider variables not often considered in the previous EKC literature, such as the legal structure of a country and measures of political stability and civil rights.

3. Empirical specification and data

Data on threats to bird and mammal species have been collected for approximately 30 years by the IUCN. But only recently (since 1996) have all bird and mammal species been assessed in all countries. A problem common to all similar studies of changes in stocks of species or forests is that the number of endangered species or the rate of deforestation may be low in countries where there has been much extinction or deforestation in the past and therefore fewer species or forests remain to be destroyed.[6] Because it is not possible to model all the factors that have impacted species for the last 500 (or more) years, we focus on the threats that species face today based on factors that they have faced over the last 20 years. In essence, we are modeling how the current generation is protecting the stock of species that it has inherited. To adjust for this problem we focus on the percent, not number, of species that are threatened today. So for example suppose a country started with 100 species 500 years ago and lost only 10 species (now having 90). If it now has 10% of its remaining species threatened, then 9 species are threatened. Suppose another country has extirpated 90% of its species (going from 100 down to 10). If only one of its species is threatened, it will have 10% of its species threatened. So countries with few species need to have only a small number of species threatened to have a relatively high percent threatened. Thus our dependent variables, PTHRTBRD and PTHRTMAM, are the percentage of bird or mammal species that were classified by IUCN as threatened in 2000.

Several adjustments to the raw data were made. First, since the IUCN only counts a species as threatened in 2000 if it is extant, a country would

[6] We thank an anonymous referee for this comment.

Table 1
Descriptive statistics

Variable	Mean	Minimum	Maximum	Standard deviation
PTHRTBRD [% threatened birds (2000)]	0.031	0	0.320	0.040
PTHRTMAM [% threatened mammals (2000)]	0.115	0	0.457	0.074
MAMENDPR (% endemic mammals)	0.06	0	0.79	0.14
BIRDENPR (% endemic birds)	0.03	0	0.47	0.07
ISLAND (1 if island, 0 otherwise)	0.142	0	1	0.350
PPP8100 (per capita income in 1995$ purchasing power parity, 1981–2000 average)	$6,633	$463	$26,003	$7,219
POPD8100 (persons per square kilometer, 1981–2000 average)	83.3	1.3	770.9	115.6
POLC8100 (political rights and civil liberties, 1981–2000 average)	7.80	2	13.75	3.59
DEMO8100 (antigovernment demonstrations, per year, 1981–2000 average)	0.72	0	5.05	1.01
CIVIL (1 if civil law, 0 otherwise)	0.54	0	1	0.50
COMMON (1 if common law, 0 otherwise)	0.27	0	1	0.45
COMMUN (1 if communist law, 0 otherwise)	0.05	0	1	0.23
MUSLIM (1 if Muslim law, 0 otherwise)	0.13	0	1	0.34
Number of Countries	113			

appear to have less of a problem if it has recently extirpated a species. As an additional adjustment for this issue, we count any species that became extinct in the previous ten years (1990–1999) as a threatened species.[7] Both the numerator (threatened species) and the denominator (the number of extant species) are increased by one in each case. Second, since island species are especially vulnerable (as mentioned below) it is problematic to include them in the count for countries that have a significant number of threatened species on small islands and far fewer threatened species on its mainland. For example, most of the threatened birds in the United States live on the Hawaiian Islands. Thus for any country that has threatened species on its outlying islands, we do not use these island species in calculating the percent threatened in the country. Third, cetaceans are not counted in the percent threatened for mammals since Groombridge and Jenkins (1994; the authorities on total identified species) do not count these wide-ranging species. Fourth, only the percent threatened of a country's breeding bird species is examined because a country has more of an impact on species that breed within its borders than on species that breed in other countries.[8]

Summary statistics on threatened species are shown in Table 1. The threatened bird species variable ranges from 0% to 32% for birds with a mean of 3.1%. The percent of mammal species that is threatened ranges from 0% to 45.7%, with an average of 11.5%. The 113 countries included in this study are shown in Appendix A.

Following the literature, we hypothesize that the percentage of threatened species in a country is a function of the level of real per capita income as well as its square and cube. We hypothesize that there exists an inverted-U-shaped (or possibly N-shaped) relationship between per capita income and the percent of species threatened. As countries undergo the structural changes that are part of the economic development transition, they may substitute towards industrial and agricultural technologies that are less damaging to the environment. In addition, wealthier countries are better able to afford policies designed to protect threatened species. Our income variable, PPP8100, is real per capita income in 1995 U.S. dollars in purchasing power parity (PPP) terms, averaged over the 1981–2000 period. The data are from the World Bank. As shown in Table 1, this variable ranges from $463 to $26,003, and averaged $6,633. Figs. 1 and 2 give a crude view of the possible EKC effect. To aid in the visual display, island countries have been omitted from the graph because they tend to have much higher percentages of threatened species. Of course other factors affect endangered species, as will be modeled in this paper. As a result, it is not possible to visually show in two

[7] The data source for extinct mammals is the Committee on Recently Extinct Organisms (CREO; http://creo.amnh.org). Extinct bird data are from various IUCN action plans.

[8] The threatened non-breeding species number (Stattersfield and Capper, 2000) is subtracted from the total number of threatened species on the IUCN Red List (Hilton-Taylor, 2000).

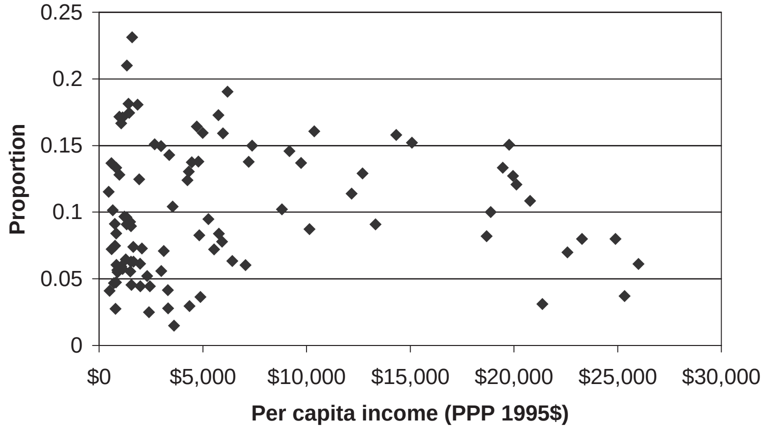

Fig. 1. Percent of mammal species threatened: 2000 (excludes island countries).

dimensions a perfect Kuznets curve. Nonetheless, there appears to be some inverted-U shape, more so for mammals.

Besides income, we hypothesize that population density (persons per square kilometer) in a country is directly related to the percent of bird and mammal species under threat, since presumably encroachment of human beings almost surely leads to habitat loss and perhaps an increase in hunting by humans. Cropper and Griffiths (1994) also found that population density had a significant effect on deforestation rates, and Kerr and Currie (1995) found such a relationship with respect to percent of mammal and bird species under threat. The variable, POPD8100, is the average population density for 1981–2000 for each country, as reported by the World Bank. As Table 1 shows, this variable (POPD8100) ranges from 1.3 to 770.9 persons per square kilometer, with a mean of 83.3 for 1981–2000.

Following Torras and Boyce (1998), we include measures of political rights and civil liberties. Torras and Boyce (1998, p. 148) speculated that higher degrees of freedom within a society may lead to "an induced policy response in the form of more stringent and more strictly enforced environmental standards, driven by citizen demand..." López and Mitra (2000) argued theoretically that corruption might affect the EKC. In a similar vein, we use Freedom House's

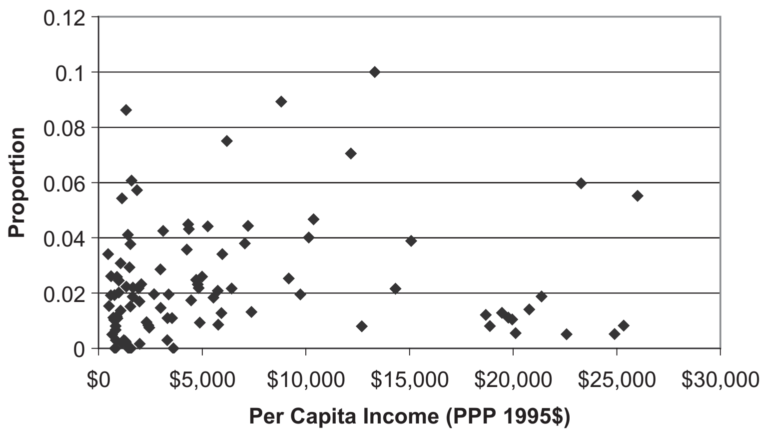

Fig. 2. Percent of bird species threatened: 2000 (excludes island countries).

(2002) annual index of freedom. This survey uses checklists for political rights and civil liberties to determine the degree of freedom present in each country. The raw scores for the two checklists are converted to two seven-category scales, with 1 representing the most free and 7 the least free. We sum the two variables to create POLC8100, which ranges from 2 to 14. We hypothesize that the percent of species under threat will be higher when POLC8100 is higher (i.e., lower political rights and civil liberties). As shown in Table 1, the mean for POLC8100 is 7.80 for 1981–2000.

Following Deacon (1994), Smith et al. (2003), and O'Connor et al. (2003), we consider the effect on the environment of political unrest. We use the number of antigovernment demonstrations per year (DEMO8100) averaged over the 1981–2000 period as our measure of political unrest. Deacon (1994) has shown that deforestation has occurred more rapidly in countries facing political unrest or that have nonrepresentative governments. He surmises that these factors tend to reduce the security of property rights, thereby causing individuals to focus on the short run benefits while ignoring long run consequences. We expect that species will be more threatened where political turmoil exists. The data are from the Cross National Time-Series Data Archive (Banks, 2002).[9] As shown in Table 1, the mean number of demonstrations is 0.72 per year.

We also test for the impact of the type of legal system. Several studies (Mahoney, 2001; La Porta et al., 1998) have found that countries that have a legal structure based on British common law have more secure property rights than those that are based on French civil law.[10] These studies tend to find that the GDP in common law counties has grown faster than in civil law countries. Less attention has been focused on the impact of communistic and Islamic law. We use three dummy variables to categorize these four types of legal structures [CIVIL, COMMUN (for Communism), and MUSLIM]. The legal system classification is based on Reynolds and Flores (1989), as is commonly relied upon in the literature. It is expected that communistic countries will have more threatened species than common law countries since communistic countries have not protected the environment well. We do not include the countries of the former U.S.S.R. due to lack of data for them before 1991. We classify three countries as communist that have become more democratic since 1991: Poland, Bulgaria and Hungary. The impact of Muslim law on threatened species has not been analyzed. However, Barro (1999) has found that countries with larger Muslim populations have less freedom. Thus, we hypothesize that Muslim countries may have more endangered species than common law countries due to less secure property rights. Furthermore, Muslim (and communistic) countries' citizens may not have the freedom to demand protection of species by their government (United Nations Development Programme, 2002, p. 48). It is not clear, a priori, whether civil law countries will have more threatened species than common law countries. The legal structures for the countries in this study are shown in Appendix A.

Another causal factor, related to human encroachment, is that island species are more vulnerable to pressures. About 75 percent of the mammals and birds that have become extinct in recent history were island-dwelling species (Frankel and Soule, 1981). Extended isolation in a confined area (such as an island) may eventually predispose some species to extinction because they become so specialized that they cannot adapt rapidly enough to environmental changes. We include a dummy variable (ISLAND) equal to one for island countries and zero otherwise. As shown in Table 1, 14.2 percent of the countries in the data set are islands.

A final possible factor that has been identified in the literature is the presence of endemic species (Naidoo and Adamowicz, 2001). Since endemic species occur exclusively within a country's borders, they possibly are more vulnerable. As shown in Table 1, on average six percent of mammal species are endemic and three percent of bird species are endemic.

[9] We tested several other variables mentioned by Deacon (1994) that were not significant such as assassinations, strikes, guerilla warfare, crises, military executions and purges. Two variables that we did find significant were riots and no legislature. These variables show a positive effect on threatened species. Since these variables are collinear with other variables in the model, we do not show these results but they are available upon request. We also tried a tropical country dummy variable, but it was found to be statistically insignificant.

[10] Civil law is sometimes subclassifed into other categories. We use only the one category.

We estimate reduced form models for birds and mammals as follows:

$$
\begin{aligned}
\%\mathrm{THREAT}_i = \beta_0 &+ \beta_1 \mathrm{PPP8100}_i \\
&+ \beta_2 \mathrm{PPP8100}_i^2 + \beta_3 \mathrm{ENDEMIC}_i \\
&+ \beta_4 \mathrm{ISLAND}_i + \beta_5 \mathrm{POPD}_i \\
&+ \beta_6 \mathrm{POLC}_i + \beta_7 \mathrm{DEMO}_i \\
&+ \beta_8 \mathrm{CIVIL}_i + \beta_9 \mathrm{COMMUN}_i \\
&+ \beta_{10} \mathrm{MUSLIM}_i + \varepsilon_i \qquad (1)
\end{aligned}
$$

where ε_i is a disturbance term (to be discussed below). A finding that β_1>0 and β_2<0 would indicate an EKC exists. (We will also include a cubic term to determine if the EKC is N-shaped, with a second turning point). In accordance with the discussion above, we further hypothesize that β_3>0, β_4>0, β_5>0, β_6>0, β_7>0, β_8 ?0, β_9>0, and β_{10}>0. Since past socioeconomic events may have lagged effects on threatened species we estimate our models with lagged averages of 20 years.[11]

4. Spatial autocorrelation models

4.1. Methodology

Cross sectional data may have interesting relationships that are not always modeled with standard econometrics procedures. The essence of many cross sectional relationships is captured by Tobler's (1979) first law of geography: "everything is related to everything else, but near things are more related than distant things." For example, if crime is high in one district of a city, it is likely that crime in neighboring districts may be affected. In our case, the threats to a species in one country may spill over to neighboring countries' species. Two types of spatial regression models have been used most often: spatial lag models and spatial error models. The spatial lag model (also known as the mixed regressive–spatial autoregressive model) is written as:

$$y = \rho \mathbf{W} y + \mathbf{X}\beta + \varepsilon \qquad (2)$$

where ρ is the coefficient of the spatially lagged dependent variable, $\mathbf{W}$ is a spatial weights matrix (to be discussed below), $\mathbf{X}$ is an N by K matrix, β is a K by 1 vector of parameters associated the exogenous variables X, and ε is a normally distributed disturbance term with a diagonal covariance matrix.

The spatial error model (also known as the linear regression model with a spatial autoregressive disturbance) is written as:

$$y = \mathbf{X}\beta + \varepsilon \qquad (3)$$

$$\varepsilon = \lambda \mathbf{W} \varepsilon + \mu$$

where λ is the autoregressive coefficient, $\mathbf{W}$ is a spatial weights matrix, and μ is a well behaved (i.e., homoskedastic and uncorrelated) disturbance term (Anselin, 1988, pp. 34–35).

There are serious consequences of ignoring these spatial correlations. If spatial lag dependence is ignored, ordinary least squares (OLS) estimators will be biased and inconsistent. If spatial error dependence is ignored, OLS estimators will be unbiased but inefficient and the standard errors of the estimators will be biased (Anselin, 1988, pp. 58–59). Ours is the first empirical EKC research to address spatial autocorrelation in a direct fashion.

4.2. Spatial weights

The original measures of spatial dependence were based on the binary contiguity matrix of Moran (1948) and Geary (1954). If two entities share a common border they are considered to be neighbors and a 1 is assigned to the weights matrix; if they do not share a common border a value of 0 is assigned.[12] A contiguity matrix is N by N. For example, in our case of 113 countries, the contiguity matrix has 12,769 cells of zeros or ones. Cliff and Ord (1981)

[11] Given that the dependent variable ranges between zero percent and 100 percent, we also consider a two-limit Tobit model. Since no one has developed a two-limit Tobit model in a spatial autocorrelation setting, we estimate a two-limit Tobit model without spatial autocorrelation correction. The results (partial effects) were very similar; this is unsurprising given that there was only one zero percent observation for mammals and only seven for birds. These results are available from the authors on request.

[12] We use the queen criterion, as defined in the literature (Anselin, 1988).

considered a more general form of spatial dependence with the use of a Cliff-Ord weights matrix. Several forms of the matrix have been developed. We will utilize one common form of the weights matrix in which each cell contains the length of a given country's border that is shared by another country. Spatial weights matrices are usually row standardized such that each row sums to one.

Two of the best-known summary statistics to test for spatial association are Moran's I (Moran, 1948) and Geary's c (Geary, 1954). Moran's I is calculated as:

$$I = ((N/S_0)\Sigma_i\Sigma_j w_{ij}(x_i - \mu)(x_j - \mu))/\Sigma_i(x_i - \mu)^2$$

where w_{ij} is the element in the weights matrix corresponding to observation pair i, j, x_i and x_j are observations for locations i and j (with mean μ), and S_0 is a scaling constant equal to the sum of the weights such that:

$$S_0 = \Sigma_i\Sigma_j w_{ij}$$

When the weights matrix is row standardized (where each row sums to one and thus $S_0=N$) Moran's I is calculated as:

$$I^* = \Sigma_i\Sigma_j w_{ij}(x_i - \mu)(x_j - \mu)/\Sigma_i(x_i - \mu)^2$$

The theoretical mean of Moran's I is$-1/(N-1)$. A Moran's I coefficient larger than its expected value indicates positive spatial autocorrelation and a coefficient less than its expected value indicates negative spatial autocorrelation. Inference is usually based on a standardized z-value. For Moran's I, the z-value is:

$$Z_I = (I - E(I))/(\mathrm{SD}(I))$$

Where $E(I)$ is the theoretical mean and SD(I) is the theoretical standard deviation. The standard deviation depends on the stochastic assumptions. Three assumptions are often used: normal, randomization and permutation. A positive and significant z-value for I indicates positive spatial autocorrelation (Anselin, 1995).

Geary's c is calculated as:

$$c = \left(((N-1)/2S_0)\Sigma_i\Sigma_j w_{ij}(x_i - x_j)^2\right)/\Sigma_i(x_i - \mu)^2$$

The theoretical mean of c is 1. A value of c less than 1 indicates positive spatial autocorrelation, while a value larger than 1 indicates negative spatial autocorrelation. A negative and significant z-value for c indicates positive spatial autocorrelation (Anselin, 1995).

It should be noted that Moran's I and Geary's c test provide only a general measure of spatial correlation. Spatial lag and spatial error models must be estimated to determine the impact of spatial correlation in association with the explanatory variables.

5. Results

Moran's I and Geary's c tests for spatial autocorrelation (under the normality assumption) in percent of bird and mammal species threatened are shown in Table 2. (The results using randomization and permutations were nearly identical.) For the Moran I, the z-values are positive and highly significant. This indicates the presence of positive spatial autocorrelation in threatened species for both mammals and birds. For the Geary's c, the z-value is negative and highly significant. This also indicates the presence of positive spatial autocorrelation.

In Table 3 we present the spatial lag results for the models for mammals. For all models, the evidence

Table 2
Spatial autocorrelation tests

Moran's I test for spatial autocorrelation for mammals (%threatened; normal approximation)

Weight	I	Mean	Standard deviation	Z-value	Prob
Distance	0.301	−0.009	0.0092	3.359	0.001

Geary C test for spatial autocorrelation for mammals (%threatened; normal approximation)

Weight	c	Mean	Standard deviation	Z-value	Prob
Distance	0.285	1.0000	0.115	−6.199	0.0000

Moran's I test for spatial autocorrelation for birds (%threatened; normal approximation)

Weight	I	Mean	Standard deviation	Z-value	Prob
Distance	0.1880	−0.009	0.092	2.139	0.032

Geary C test for spatial autocorrelation for birds (%threatened; normal approximation)

Weight	c	Mean	Standard deviation	Z-value	Prob
Distance	0.118	1.000	0.115	−7.648	0.0000

Weights matrix DISTANCE is row standardized.

Table 3
Spatial lag model—maximum likelihood estimation percent threatened mammals in 2000 (1981–2000 lagged averages of independent variables)

Variable	Model 1	Model 2	Model 3	Model 4
Constant	0.0173 (0.69)	0.0188 (0.76)	−0.0105 (−0.46)	0.0475*** (3.79)
Island	0.0359** (2.28)	0.034** (2.21)	0.035** (2.33)	0.0317** (2.05)
MAMENDPR	0.3663*** (9.69)	0.3725*** (10.38)	0.3766*** (10.19)	0.3690*** (10.22)
POPD8100	9.171 E-05** (2.37)	9.886 E-05*** (2.73)	1.141 E-04*** (3.10)	8.808 E-05** (2.48)
PPP8100	5.156 E-06** (1.94)	5.416 E-06** (2.08)	7.579 E-06*** (3.00)	3.631 E-06* (1.61)
$PPP8100^2$	−2.125 E-10** (−2.04)	−2.262 E-10** (−2.24)	−2.926 E-10*** (−2.90)	−1.865 E-10* (−1.92)
POLC8100	0.0028 (1.38)	0.0027 (1.33)	0.0050*** (2.79)	
DEMO8100	0.0024 (0.52)			
Civil	−0.0059 (−0.60)	−0.0060 (−0.60)		−0.0048 (−0.48)
Muslim	0.0169 (1.10)	0.0168 (1.09)		0.0265* (1.92)
Commun	0.0476** (2.34)	0.0485** (2.39)		0.0569*** (2.92)
Lag%threat	0.2253*** (3.78)	0.2235*** (3.72)	0.255*** (4.13)	0.2164*** (3.59)
Income at Peak	$12,129	$11,972	$12,952	$9738
N	113	113	113	113
R^2 (Buse)	0.6697	0.6690	0.6405	0.6643
Likelihood	197.600	197.467	193.092	196.598

t-statistics are in parentheses.
* Indicates *p*-value less than 0.10.
** Indicates *p*-value less than 0.05.
*** Indicates *p*-value less than 0.01.

indicates that the spatial lag effect is highly significant. We also found evidence that spatial error dependence may be present (in models not reported). However, since spatial lag dependence has been detected it is more critical to adjust for this problem because all other methods (such as OLS and spatial error dependence) yield biased and inconsistent results. With current techniques, it is not possible to adjust for both spatial lag dependence and spatial error dependence (Anselin, 1995). Thus we only present results for the spatial lag dependence models. We present four models. Model 1 includes all of the variables. However, since there is some multicollinearity among POLC8100, DEMO8100 and the legal system dummies (CIVIL, MUSLIM, and COMMUN), we also present models that include only some of these variables to see if some of these variables are significant. In Model 1 we note the linear and squared income variables are significant. (The cubed income term was not significant in any of the models.) This indicates that a Kuznets curve may exist for threatened mammals. The turning point is at approximately $12,000. That is, the threat to species appears to rise up to $12,000 in per capita income, thereafter declining. The island dummy is highly significant, indicating a 3.6 percentage points higher threat for mammals in island countries, ceteris paribus. The endemic percentage (MAMENDPR) is highly significant. A one percent higher amount of endemic mammals leads to a 0.36 percentage points higher amount of threatened mammal species. The population density variable (POPD8100) has a significant positive effect on threatened species. Each 100 person increase in population density increases the threat by approximately one percentage point. The POLC8100 variable is not quite statistically significant, but has the expected positive sign. The demonstration variable (DEMO8100) is not significant. Of the legal systems variables, the Communism dummy variable has a positive impact on threatened species, with a 4.76% more threatened species than in common law countries, ceteris paribus. The lagged dependent variable (Lag%threat) is highly significant. It indicates that a one percent increase in threatened mammals in an adjoining country leads to a 0.23% increase in threatened mammals in the home country. In other words, threats to mammals spill over into adjoining countries. Another reason that the lagged effect is significant is that if the IUCN identifies a species as threatened, it is considered threatened in every country in which it exists, even if the particular country has enacted successful protective measures. Thus the IUCN classification method provides another reason for the use of a spatial autocorrelation model.

In Model 2, the demonstration variable is dropped. The results are similar to Model 1's results. Since there is some collinearity between POLC8100 and the legal dummies, Model 3 reports results that exclude the legal dummies. In this model, the POLC8100 variable is highly significant, indicating that threats to mammals are greater in countries with less freedom. This is consistent with Torras and Boyce's (1998) findings that greater political freedom was associated with less environmental degradation. In Model 4, the legal system dummies are included, but POLC8100 is dropped. Both Muslim and Communistic legal systems are associated with greater threats to mammals. (Note that common law is the base case.) The civil law dummy is insignificant. Both the Muslim law and communistic law dummies are positive and significant. Muslim law countries have 2.65 percentage points higher threatened mammals than common law countries, while communistic law countries have 5.7 percentage points higher threat.

In Table 4, we present the spatial lag model for birds. As was the case for mammals, the results indicate that a spatial lag model is likely the most appropriate model. We again present four models for the same reasons given above. Model 1 includes all of the variables. In Model 1 we note the linear and squared income variables are significant, as they were for mammals. (The cubed income term was not significant in any of the models.) This indicates that a Kuznets curve may exist for threatened birds. The turning point is in the $12,000 to $14,000 range. The threat to species appears to rise up to $12,000 to $14,000 in per capita income, then declines. The island dummy is highly significant, indicating a 2.04 percentage points higher threat for birds on island, ceteris paribus. The endemic percentage (BIRDENPR) is highly significant. A one percent higher amount of endemic birds leads to a 0.26 percentage points higher amount of threatened bird species. The population density variable (POPD8100) is not significant in this model. The POLC8100 variable is not quite statistically significant, but, as for mammals, has the expected positive sign. The demonstration variable (DEMO8100) is significant,

Table 4
Spatial lag model—maximum likelihood estimation percent threatened birds in 2000 (1981–2000 lagged averages of independent variables)

Variable	Model 1	Model 2	Model 3	Model 4
Constant	−0.0173 (−1.04)	−0.0145 (−0.87)	−0.0165 (−1.12)	0.0065 (0.86)
Island	0.0204* (1.92)	0.0178* (1.67)	0.0196* (1.93)	0.0163*** (1.52)
BIRDENPR	0.2614** (5.60)	0.2805*** (6.11)	0.2779*** (6.10)	0.2749*** (5.96)
POPD8100	3.186 E-05 (1.19)	4.736 E-05* (1.86)	4.627 E-05* (1.86)	3.901 E-05 (1.56)
PPP8100	4.072 E-06** (2.19)	4.692 E-06** (2.55)	4.596 E-06*** (2.67)	3.349 E-06** (2.10)
$PPP8100^2$	−1.441 E-10** (−1.98)	−1.756 E-10** (−2.46)	−1.724 E-10** (−2.51)	−1.454 E-10** (−2.12)
POLC8100	0.0022 (1.59)	0.0020 (1.41)	0.0020* (1.62)	
DEMO8100	0.0053* (1.71)			
Civil	−0.0037 (−0.54)	−0.0036 (−0.52)		−0.0026 (−0.38)
Muslim	−0.0014 (−0.13)	−0.0017 (−0.15)		0.0054 (0.56)
Commun	−0.066 (−0.46)	−0.0043 (−0.30)		0.0019 (0.14)
lag%threat	0.1558* (1.83)	0.1650* (1.89)		0.1639* (1.87)
Income at Peak	$14,130	$13,361	$13,333	$11,513
N	113	113	113	113
R^2 (Buse)	0.4502	0.4354	0.4333	0.4255
Likelihood	239.352	237.907	237.759	236.917

t-statistics are in parentheses.

* Indicates *p*-value less than 0.10.

** Indicates *p*-value less than 0.05.

*** Indicates *p*-value less than 0.01.

indicating a 0.53% higher threat for each additional demonstration. These results are consistent with Deacon's (1994) findings that greater legal instability is associated with more environmental degradation. None of the legal systems variables are significant. The lagged dependent variable (Lag%-threat) is highly significant. It indicates that a one percent increase in threatened birds in an adjoining country leads to a 0.156% increase in threatened birds in the home country. In other words, threats to birds spill over into adjoining countries.

In Model 2 of Table 4, the demonstration variable is dropped. The results are similar to Model 1's results. POLC8100, CIVIL, MUSLIM, COMMUN are not significant. We note that population density is significant in this model, with a 100 person increase in population density increasing the threat by approximately 0.5 percentage points. Since there is some collinearity between POLC8100 and the legal dummies, Model 3 reports results that exclude the legal dummies. As was the case with mammals, in this model the POLC8100 variable is significant, indicating that threats to birds are greater in countries with less freedom. In Model 4, the legal system dummies are included, but POLC8100 is dropped. None of the legal system variables are significant.

6. Conclusions

The loss of species is an issue that has concerned experts from many disciplines, and this concern has spawned a substantial amount of research into its causes. In the early 1990s, a literature emerged that examined the so-called environmental Kuznets curve. In its simplest manifestation, the EKC relates environmental degradation to per capita income levels in an inverted-U pattern; that is, as per capita income levels rise, environmental degradation first increases, and then decreases. In some cases, evidence of a second turning point was found (an N-shaped curve), in which case economic growth is ultimately associated with greater degrees of degradation.

Our paper considers the relationship between threatened bird and mammal species and per capita PPP income levels (1995 US$) using 113 countries in 2000. For both birds and mammals, our results indicate that an EKC curve may exist: as per capita income levels increase up to around $10,000 to $15,000, the percent of bird and mammal species classified as threatened rises. At higher income levels, the percent threatened falls.

Several other variables are found to have statistically significant impacts. First, as hypothesized, both bird and mammal island species face a greater threat. Second, endemic species are more likely to be threatened. Third, greater population density poses greater threats. Fourth, our measure of freedom is significant for both mammals and birds; more mammal and bird species are threatened where political rights and civil liberties are weak. This finding is consistent with Torras and Boyce (1998). Fifth, threats to birds are greater when legal instability (demonstrations) is greater. This is consistent with Deacon's (1994) study. Sixth, we find that both communistic and Islamic law countries have more threatened mammal species (and civil law countries were not statistically different) than common law countries.

The results indicate that spatial autocorrelation (in the form of spatial lag dependence) is present in our data on threatened birds and mammals. This causes the OLS estimators to be biased. This paper is the first to adjust for spatial autocorrelation in the EKC context. Given that spatial autocorrelation is present in threatened species across countries, it may be interesting to analyze other environmental indicators to determine if spatial autocorrelation is a significant problem.

This paper is the first to examine the EKC hypothesis for threatened species using a spatial autocorrelation framework. The results indicate that the EKC effect for threatened species may exist. The turning point is around $10,000 to $15,000 (1995$ PPP) in per capita income. We emphasize that our results do not imply that today's developing countries will inevitably follow these patterns. Furthermore, other factors such as political rights and civil liberties, political instability, and legal institutions may also impact species. These effects also must be considered when constructing environmental policies for achieving sustainable economic growth.

Appendix A. Countries included in the sample

Algeria (M)	Egypt (M)	Lebanon (F)	Senegal (F)
Angola (F)	El Salvador (F)	Lesotho (B)	Sierra Leone (B)
Argentina (F)	Equatorial Guinea (F)	Madagascar (F)	South Africa (B)
Australia (B)	Ethiopia (F)	Malawi (B)	South Korea (F)
Austria (F)	Finland (F)	Malaysia (B)	Spain (F)
Bahamas (B)	France (F)	Mali (F)	Sri Lanka (B)
Bangladesh (M)	Gabon (F)	Mauritania (F)	Sudan (F)
Belgium (F)	Gambia (M)	Mexico (F)	Suriname (F)
Benin (F)	Ghana (B)	Mongolia (F)	Swaziland (B)
Bhutan (B)	Greece (F)	Morocco (F)	Sweden (F)
Bolivia (F)	Guatemala (F)	Mozambique (F)	Switzerland (F)
Botswana (B)	Guinea (F)	Namibia (B)	Tanzania (B)
Brazil (F)	Guinea-Bissau (F)	Nepal (B)	Thailand (F)
Bulgaria (C)	Guyana (B)	Netherlands (F)	Togo (F)
Burkina Faso (F)	Hispaniola (F)	New Zealand (B)	Trinidad and Tobago (B)
Burundi (F)	Honduras (F)	Nicaragua (F)	Tunisia (F)
Cameroon (F)	Hungary (C)	Niger (F)	Turkey (F)
Canada (B)	Iceland (F)	Nigeria (B)	Uganda (B)
Central African Republic (F)	India (B)	Norway (F)	United Arab Emirates (M)
Chad (F)	Indonesia (M)	Oman (M)	United Kingdom (B)
Chile (F)	Iran (M)	Pakistan (M)	United States (B)
China (C)	Ireland (B)	Panama (F)	Uruguay (F)
Colombia (F)	Israel (B)	Papua New Guinea (B)	Venezuela (F)
Congo, D. R. (Zaire) (F)	Italy (F)	Paraguay (F)	Vietnam (C)
Congo, Republic of (F)	Jamaica (B)	Peru (F)	Zambia (B)
Costa Rica (F)	Japan (F)	Philippines (F)	Zimbabwe (B)
Côte d'Ivoire (F)	Kenya (B)	Poland (C)	
Denmark (F)	Kuwait (M)	Rwanda (F)	
Ecuador (F)	Laos (C)	Saudi Arabia (M)	

Legal structure is in parentheses: B (British Common) F (French Civil), C (Communism), M (Muslim).

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