Impacts of Population and Income Growth Rates

on Threatened Mammals and Birds

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Abstract

Per capita income and human population levels have direct influences on environmental outcomes of a country. Countries with same level of income (population size) may have a different rate of income (population) growth and vice versa, suggesting that the influence of the rate of income (population) growth on environmental outcomes could be different than that of income (population) level. We explore this empirical question using country-level data on threatened species published by International Union for Conservation of Nature for the year 2007. Controlling for other factors, including spatial dependency among countries, our model estimates the influences of the rate of income and population growth on threatened mammals and birds across 113 continental countries. The results suggest that, among other factors, the rate of population growth has a significant influence on number of threatened birds in a country.

Keywords: Income growth rate, Population growth rate, Spatial autocorrelation, Endemic species, Threatened species

JEL Codes: Q56, Q57

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1. Introduction

Accelerated biodiversity loss is one of the serious environmental challenges faced by the society today. Evidence indicates that, among a number of taxa groups, we are experiencing one of the worst episodes of mass extinction of species since dinosaurs roamed the earth 65 million years ago (CI, 2010; Hoffmann et al., 2010). In the past four decades (1970 to 2010), the sheer number of threatened species has grown dramatically, exceeding the normal *background rate* of extinction by a factor of two to three; and forecast scenarios for the 21st century consistently indicate that biodiversity will continue to decline (Pereira et al., 2010). A general consensus among scientists and policy makers is that both changes in natural habitat conditions and human activities are responsible for this extinction crisis (Balmford and Bond, 2005; Forester and Machlis, 1996; Kerr and Currie, 1995; Pereira et al., 2010; Sala et al., 2000). In addition, recent studies examining causal relationship between specific drivers and biodiversity loss highlighted five direct (i.e. habitat change, overexploitation, pollution, invasive alien species and climate change) and several indirect (i.e. demographic change, economic activity, levels of international trade, per capita consumption patterns, cultural and religious factors, and scientific and technological changes) drivers of biodiversity loss (NBL, 2010; SCBD, 2010; TEEB, 2010). To address these drivers, international agreements - such as Convention on Biological Diversity - have stressed the need to effectively tackle the indirect drivers of biodiversity loss to achieve global conservation goals, such as Aichi Biodiversity Targets (CI, 2010).

Both natural and anthropogenic pressure on the Earth's biodiversity is reflected by threatened species of flora and fauna (Dietz and Adger, 2003). The number of threatened species also serves as an important indicator of ecological impacts of direct and indirect drivers of biodiversity loss. Among indirect drivers, human population (population density) and economic activity (level of per-capita income) are the two most widely studied drivers of threatened species (Sodhi et al., 2008). In a cross-country context, human population density and per-capita income in a given year have been shown to influence the number (or percentage) of threatened species listed in International Union for Conservation of Nature (IUCN) Red Lists in that year (Asafu-Adjaye, 2003; Naidoo and Adamowicz, 2001; Pandit and Laband, 2007a). While the relationship between per-capita income and threatened species has been characterized by an Environmental Kuznets Curve (EKC) for some taxa, this relationship is not universal across taxa and studies. The relationship depends on several factors including the number of sample countries and functional forms used in the analysis (McPherson and Nieswiadomy, 2005; Naidoo and Adamowicz, 2001; Pandit and Laband, 2007b; Zibaei and Sheykh, 2009). Additionally, both McPherson and Nieswiadomy (2005) and Pandit and Laband (2007b) have demonstrated the importance of cross-border (or spatial) effects and its impact on empirical estimates of factors influencing species imperilment drawn from cross-section models.

These studies employed cross-section data to predict the impact of population density and per-capita income on either the number or percentage of threatened species of specific taxa. But the relationship between human population density and species imperilment and the relationship between per capita income and species imperilment may be more complex than suggested by an empirical analysis of *current levels* of these three variables. Among other things, putative impacts of population density and/or per capita income may only reveal themselves over time. Moreover, while current levels of population density and/or per capita income may exert significant impacts on country-level species imperilment, the time-path taken to reach such current levels may also be important. For example, consider 2 countries - A and B, which were identical in most respects in 1910, including measures of species diversity and species imperilment. Likewise, they were identical in 2010, in most respects, including population density and per capita income. However, country A's per capita income was considerably lower in 1910 than country B's, implying that the rate of growth in per capita income over this century was higher in country A than country B. The question is, 'would we expect the rate of species imperilment to be the same in countries A and B, given that the current level of per capita income is the same?' Or, is the rate of species imperilment sensitive to the time-pattern of growth in per capita income, controlling for its historical level? It is important to acknowledge that the difference in rate of species imperilment between countries is complex and depends on their biogeography and other environmental factors socio-economic factors such as income and population density. We used endemic species as a proxy to partly control for the differences due to biogeography and environmental factors in our analysis.

There has been relatively little empirical attention paid to the impact of the time-pattern of changes in population density and per capita income on species imperilment. McKee et al. (2003) argued that current rates of human population growth determine future population sizes, and thus the current growth rates do not appear to serve as good estimators of existing biodiversity threats. In a study comprised of 107 countries, Forester and Machlis (1996) found no significant correlation between biodiversity loss and national population change between 1980 and 1990. While this might seem like a relatively short period of time to measure population growth rates, the simple fact is that we do not know whether species imperilment is sensitive to population growth rates and what time frames may be critical with respect to establishing such a relationship.

We do know that there is considerable diversity across countries with respect to population and income growth patterns. For example, Ghana and Greece had identical populations (8.7 million) in 1970 which had increased by 162% and 27%, respectively, by 2007. The populations of both South Korea and South Africa were just over 48 million in 2007 but this reflected a 118 percent increase in South Africa's population since 1970, whereas South Korea's population growth rate over that same period was only about 51 percent (WB, 2010). In the case of per capita income growth, Guyana ($567) and Thailand ($560) had almost identical real per capita income in 1970 that increased 3.6 times and 17.4 times, respectively, by 2007. Similarly, real per capita income in Lebanon ($8228) and China ($8271) was virtually the same in 2007 but this income was 1.87 and 41.37 times the respective per capita income of these countries in 1970 (Heston et al., 2009). Do these different rates of increase in population and per-capita income have different level of impacts on species imperilment in these countries? Does a country with higher (lower) rates of population- and per capita income-growth have a higher (lower) rate of species imperilment? There are important policy implications of disentangling these linkages, particularly in the context of developing countries where rich biodiversity exists alongside increased pressure from population growth and economic growth.

We tend to agree with McKee et al. (2003) who argue that there should be a lagged or temporal effect of these drivers on threatened species. For example, among other drivers, the threatened status of mammals in a country in 2007 could have been the result of economic activities and population growth during earlier decades. Because of the difficulties in obtaining statistically sufficient longitudinal data, empirical researchers examining factors that influence species imperilment have tended to use cross-sectional data, (substituting space for time). A few recent studies have considered a specific time in the past to examine the lagged effects (e.g., Mikkelson et al., 2007; Pandit and Laband, 2009) but they differ with respect to modelling and estimation techniques. In this paper we explore whether species imperilment is statistically sensitive to long-term impacts of population growth and economic activity by examining the relationship between the average rates of population and per-capita income growth from 1970-1990 and the number of threatened mammals and birds listed in IUCN's Red List in 2007 among 113 non-island countries. In what follows, we describe our models - including the model to control for spatial effects - data and methods in section 2, estimation results and discussion in sections 3 and 4, and concluding remarks in section 5.

2. Model, Data, and Methods

2.1. Model

We posit a taxa-specific reduced form model from the conceptual model presented in Eq. 1 to investigate country specific impacts of the *rate* of population and per-capita income growth on the number of threatened mammals and birds. The conceptual model can be expressed as

Threatened species = f (total species, endemic species, land area, human population density, gross national income, rates of population and income growth) (Eq. 1)

The reduced form model in Eq. 2 links the number of threatened mammals and birds in a country with hypothesized determinants (**X** matrix) represented by the model as $y_{ij} = x_{ij}^{'}\beta + \varepsilon_{ij}$, i= countries (1 to 113), j = taxa (1 for mammal and 2 for bird). In a matrix form, the model is

$$\mathbf{y} = \mathbf{X}\beta + \boldsymbol{\varepsilon} \qquad \text{(Eq. 2)}$$

where **y** is an n x 1 vector of independent variable (number of threatened species – mammals or birds); **X** is a n x k matrix of explanatory variables that include number of endemic species, country area, population density, per capita income, population growth rate, and income growth rate; $\boldsymbol{\beta}$ is a k x 1 vector of regression coefficients; and **ε** is the n x 1 vector of error terms.

The number of threatened species refers to the number of *critically endangered, endangered, and vulnerable* species of mammals and birds for 113 countries, as listed in the 2007 IUCN Red Lists of Threatened Species (IUCN, 2007). We included land area, human population density and per capita income levels as predictor variables in the model to control for the effect of available space for all species as well as human-induced pressure on other species by virtue of sheer population size relative to area and economic activities. Earlier studies have indicated that the number of endemic species, species with limited distributional range, in a country is a significant predictor of the number of threatened/endangered species (McKee et al., 2003; Pandit and Laband, 2007a). We include this variable in the model, but we do not include the total number of species as a predictor variable due to significantly high correlation ($p > 0.001$) between endemic and total number of species for the taxa we analysed.

A priori, we expect that the number of endemic species in a country, the human population density, and the per capita income will be positively related to the number of threatened species of mammals and birds in that country. Further, we expect that, controlling for historical population density and per capita income levels, the rate of population and per-capita income growth in earlier periods will be related positively to the number of threatened species in a later period.

We consider population and per capita income growth rates from 1970 to 1990 to capture the temporal effect of these variables on the number of threatened mammals and birds in 2007. The use 1970 as a base year for the analysis is partly because this pushes the limit on how far back in time we can go while still guaranteeing availability of satisfactory data on key model variables for a large number of countries and the emergence of environmental conservation movement in different parts of the world (e.g. establishment of national environmental protection agencies in a number of countries, including the United States). The use of year 1990 is to allow some time lag to reflect the effect of these variables on number of threatened species in 2007 and also to coincide roughly with the first Earth Summit (5 June 1992) that opened the Convention on Biological Diversity for signature among parties which came to effect on 29 December 1993.

To capture the spatial effects or spill-over effects on species imperilment from neighbouring observations, the model in Eq. 2 is further modified based on the nature and the significance of spatial dependency among observations. If $\mathbf{y}$ (number of threatened species) is endogenously determined, i.e. the threatened species in a country depends on the number of threatened species in neighbouring countries, then the Eq. 2 takes a form of spatial lag model (Eq. 3) that captures the spatial effect in the model by augmenting lagged value of independent variable ($\mathbf{Wy}$) as a predictor, where $\mathbf{W}$ is a spatial weight matrix based on a particular type of spatial dependency (e.g. simple binary contiguity or inverse distance) among observations and ρ is the spatial lag parameter. If the errors among observations in Eq. 2 are correlated, i.e. $\boldsymbol{\varepsilon} = \lambda \mathbf{W} \boldsymbol{\varepsilon} + \boldsymbol{\upsilon}$, then the Eq. 2 takes the form of spatial error model (Eq. 4) where λ is the spatial error parameter and $\boldsymbol{\upsilon}$ is a vector of normally distributed error terms (for detail on spatial model and weight matrices, refer to Anselin 1988; Anselin 2010).

$$\mathbf{y} = \rho \mathbf{W y} + \mathbf{X}\beta + \boldsymbol{\varepsilon} \qquad \text{(Eq. 3)}$$

$$\mathbf{y} = \mathbf{X}\beta + \lambda \mathbf{W} \boldsymbol{\varepsilon} + \boldsymbol{\upsilon} \qquad \text{(Eq. 4)}$$

We restrict our empirical analysis to continental countries to avoid the statistical difficulties associated with island nations (e.g., the absence of weights for island countries when developing a contiguity matrix to control for spatial autocorrelation, and the distinct ecological characteristics of islands - higher species endemism).

2.2. Data and methods

Data on threatened, endemic and total number of mammals and birds in each country was obtained from IUCN (IUCN 2007). Country-specific data on population size and land area was from the World Bank (WB, 2010); the purchasing power parity converted data on per capita income was from the Penn World Table (Heston et al., 2009). Using the population and per capita income data for the years 1970 and 1990, we derived the country-specific population growth rate and per capita income growth rate variables for analysis considering 1970 as a base year.

Descriptive statistics for the model variables are presented in Table 1. These statistics reveal that in 2007 there were more threatened mammals and birds in each country than their respective endemic numbers. Based on the total number of identified species, on average about 18 mammals (9.85%) and 18 birds (2.47%) were threatened with extinction in each sample country while 10 mammals (3.2%) and 15 birds (1.68%) were categorized as endemic per country.

[Table 1 about here]

On average, the sheer number of human population in each sample country increased by about 12.12 million between 1970 and 1990 from the mean population size of 26.03 million in 1970. Compared to 1970 population, the rate of population growth during this 20-year period varied widely from 2.205% (Germany) to 731.108% (United Arab Emirates) with the average rate of 70.828%. The purchasing power parity based mean per-capita income was about $1,513 in 1970, $6,027 in 1990 and $13,525 in 2007. The average per capita income growth from 1970 to 1990 was about 3.12 times that of the 1970 income. During this period, South Korea and Lebanon were the countries with highest (11.87 times) and lowest (0.41085 times) rates of per capita income growth, respectively compared to their 1970 income levels of $721 and $2,872.

We transformed all model variables into natural log form as models in the level form are plagued with over-dispersion. A value of 0.01 was assigned to each observation with a recorded value of 'zero' in the raw data to avoid the problem of undefined values. Then we estimated a multiple regression model (Eq. 2) with a square term for per capita income to examine the effect of factors (by considering space for time) on imperilment of mammals and birds by using 2007 data (Table 3, columns – b and e). Then we estimated the same model using 1970 and 1990 data on predictor variables to examine the effect of temporal lag (1970-1990) of population and per capita income growth rates on threatened mammals and birds in 2007, while controlling population density and per capita income in 1970. To examine spatial effects (i.e. influences from neighbouring observations) on species imperilment, we then employed spatial econometric techniques to test and control for spatial dependency using the 'spdep' package in R (R, 2010). The spatial dependency between observations was characterised using two types of spatial dependency structures, i.e. weight matrices **W**, – simple neighbourhood contiguity and inverse distance between centroids of the observations within a threshold distance that allows to have at least one neighbour for each observation (for details on weight matrices and their construction, refer to Bivand *et al.* 2008). Based on these weight matrices, Moran's I (Moran, 1950) and Lagrange Multiplier tests on model residuals were used to detect and analyse nature of spatial dependency among observations.

Finally, we ran two additional sets of spatial regression models specified by Eqs. 3 and 4 (spatial lag and spatial error) using a row standardized weight matrices (total sum of weights in a row equals 1) derived from a simple contiguity relationship between countries. We used model diagnostic criteria, including Akaike Information Criteria (AIC), to indicate the superiority of alternative models we analysed.

3. Results

In Table 3, columns b and f, we present linear model results using 2007 data on population density and per capita income for specification described in Eq. 2. These results suggest that, as expected, population density and per capita income are highly significant predictors of threatened mammals and birds based on cross-section analyses. They also verify that the number of threatened mammals and birds is highly related to the number of endemic mammals and birds in continental countries. However, our interest in this paper is to examine the impact of population and per capita income growth rates on imperilment of mammals and birds. Thus deviating slightly from cross-section analysis by allowing temporal lag effects to be reflected on, in Table 3 - columns c and g, we present linear model results by including population and per capita income growth rates during 1970 to 1990 controlling for 1970 population density and per capita income. The use of 1970 as a base year allows us to model the temporal lagged effect of predictor variables on the imperilment of mammals and birds reported in 2007. In addition to the significant and sizable impact of endemic species and country area, these latter results also suggest that population density of 1970 is a significant predictor of mammals and birds imperilment in 2007.

Per capita income in 1970 is a significant predictor of the number of threatened birds but not the number of threatened mammals. The relationship between per capita income and threatened number of birds appears to be characterized as an inverted U - - the so-called Environmental Kuznets Curve relationship. However, the rate of per capita income growth has no discernible impact on either the number of threatened mammals or birds, in these models that do not control for spatial effects (Table 3 – columns c and g).

In Table 2, we report the results of the Moran's I tests for spatial effects (or spatial autocorrelation) on linear model residuals of models in column c and g for both mammals and birds. The tests indicate significant spatial autocorrelation on the number of threatened mammals and birds in a country. The Lagrange multiplier tests on spatial dependency strongly indicate the presence of spatial lag and error dependency based on two types of weight matrices (simple contiguity and inverse distance) used to characterise the spatial relationship among observations. It is worth noting that except the robust version of the Lagrange Multiplier tests based on simple contiguity matrix for spatial lag and error dependences for mammals and birds, rest of the tests are consistent for both taxa for both types of weight matrices.

[Table 2 about here]

In response to the compelling results from the Moran's I tests and Lagrange multiplier tests, we estimated two sets of spatial regressions (spatial lag and spatial error) for both mammals (Table 3 – columns d and e) and birds (Table 3 – columns h and i) following the model specified in Eqs. 3 and 4. We used row-standardized simple contiguity based weight matrix and Maximum Likelihood estimation technique to estimate these models. The model results vary slightly between spatial lag and error specifications for both the taxa as the spatial control variable differs in its formation between the two types of models.

One important and consistent aspect of our estimation results of spatial models is the influence of the number of endemic mammals and birds on the number of threatened mammals and birds. Depending on the spatial models (d, e, h, and i), a 1% increase in the number of endemic mammals is associated with a 0.15% (or 0.16%) increase in the number of threatened mammals. Birds are relatively more sensitive to endemism compared to mammals - - a 1% increase in the number of endemic birds is associated with a 0.22% (or 0.23%) increase in the number of threatened birds. Land area appears to be highly significant predictor of threatened mammals and birds across all model specifications, suggesting that an increase in land area could provide additional habitat for these taxa but also increases the number of threatened mammals and birds. Likewise, human population density in 1970, a measure of human footprint, has a statistically significant and consistent impact on threatened mammals and birds in all models.

The per capita income in 1970 has a model-specific influence on the number of threatened mammals and birds in 2007. Among spatial models (d, e, h, and i), both the linear and quadratic terms are statistically significant (to indicate EKC type relationship) only in the model where the spatial effect is controlled by the lag of correlated errors (for mammals) and the lag of the number of threatened birds (for birds). This is further reinforced by the model selection diagnostics. For mammals, both Akaike Information Criteria (AIC) and Log likelihood (LL) values as well as residual autocorrelation tests on spatial lag model (Table 3) indicate superiority of spatial error model. Whereas for birds, despite similar AIC and LL values for both spatial models, spatial lag model is marginally preferred as no significant residual autocorrelation is found in this model. The spatial control variables, row weighted lagged dependent variable (rho) and lagged error (lambda), are consistently significant across models indicating that control for spatial effects is important in examining imperilment of mammals and birds. The parameter estimates of the spatial control variable also suggest that the lagged correlated errors (0.51 vs. 0.48) and lagged number of threatened species (0.21 vs. 0.13) have relatively high influence on the number of threatened mammals and birds, respectively. For example, a 1% increase in the weighted average of the threatened birds in the adjoining countries is associated with a 0.21% increase in the number of threatened birds in the referent country.

[Table 3 about here]

Contrary to our expectation, the average rate of per capita income growth during 1970 to 1990 has no significant impacts on the number of threatened mammals and birds in 2007, i.e. the lagged effect of income growth rate has no direct impact on threatened mammals and birds listed in IUCN RedList in 2007. Similarly, the average rate of population growth has no discernible impacts on the number of threatened mammals; but it has uniform and highly significant impact on the number of threatened birds (models g, h, and i). On average, a 1% increase in the mean population growth rate between 1970 and 1990 is associated with 0.46%, 0.49% and 0.56% increase in the percentage of threatened birds based on spatial error, spatial lag and linear (g) model results, respectively. One potential reason for different results between lag and error models for a given variable is due to the strong correlation of the variable with the lagged error term i.e. the spatial control variables used in the error models.

The partial-regression plots in Figure 1 also reinforce our findings of only significant impact of population growth rate during 1970 to 1990 on the number of threatened birds in 2007. These plots are drawn using regression residuals from two types of linear models where y-axis represents the residuals of a model where dependent variable (log-transformed number of threatened mammals (lnTM) and birds (lnTB) is regressed on explanatory variables excluding the variable of interest - - lnPopRate97, lnIGRate97); and x-axis represents the regression residuals when the variable of interest is regressed against all other explanatory variables. Besides figure 1.c, we didn't find a strong correlation between these two types of residuals in Figure 1.

[Figure 1 about here]

4. Discussion

The possibility that imperilment of mammals and birds may be affected by the rate of population and per capita income growth in addition to population density and per capita income level is not supported consistently across the taxa and models we examined. Irrespective of model formulations, we find a consistent positive relationship between population growth rates and the number of threatened birds, indicating that birds are more sensitive to population growth rate than mammals. However, we find that the 1970 population density in a country and the rate of population growth during 1970 to 1990 are more influential factors to predict the number of threatened birds, but not mammals, in 2007 than the 1970 per capita income level and its growth rate during the same period of two decades.

In a study that looked at the influence of raising population size on threats to birds and mammals, McKinney (2001) found that, for continental countries, the log of population explains 16-33% of the variation in the threat level of birds and mammals. The pattern of the continental population-threat correlation indicates that per capita human impacts is initially very high and asymptotically diminish with increasing population size (McKinney 2001). Our findings are consistent with the sizable impact of human population density on the number of threatened species reported by McKee et al. (2003).

With respect to the impacts of 1970 income and income growth rate during 1970 to 1990 on threatened mammals and birds, our results depends on model specifications. The impact of income on threatened mammals and birds show a strong EKC type relationship when we analyse the cross-section data by considering space for time (models b and f) without controlling for any temporal and spatial effects. With the control for such effects in the model, the relationship is sensitive to the model formulations. For example, controlling for correlated errors among observation we find expected influence of 1970 per capita income on the number of threatened mammals; and the similar influence of per capita income on the number of threatened birds is observed while we control for the spatial lag, i.e. the average number of the threatened birds in neighbouring countries. A detailed discussion on EKC type relationship between income and environmental indicators is beyond the scope of this paper, but a good review on this topic can be found in Torras and Boyce (1998) and Stern (2004).

For income growth rate we find no significant result for mammals and birds irrespective of model specifications. In an earlier U.S.-based study, Chambers et al. (2008) found no significant impacts of per capita income growth between 1972 and 2004 on threatened and endangered species listings in the States. However, their study differs from ours in two respects: 1) they used time series data while we used cross-sectional data and 2) they did not check and control for spatial effects in their model while we do so; and therefore the results are not directly comparable.

The explanations for why the rate of per capita income growth in earlier period (1970-1990 in this case) does not seem to matter much in explaining threatened species could be numerous. One possible reason could be an increase in cleaner service sectors as economies grow (Kongsamut et al., 2001). Increase in per capita income growth as a result of growth in service sectors may have little or no negative impacts on the environment. Further, the increased income might result in greater demand for programs and policies that protect species. This seems plausible in the case of developed countries where significant emphasis has been given in the last 4 decades to improve the environment by introducing new legislation and programs. We still observe economic growth at the cost of a deteriorating environment in developing countries (i.e. tropical deforestation, increased air and water pollutions due to industrial development etc.), but our model failed to detect the impact of per capita income growth expressed in terms of these latter trends on threatened species in this analysis.

In addition to the introduction of environmental legislations among countries in the past 4 decades, the insignificant relationship between per capita income growth rate and threatened mammals and birds could also be due to the impact of environment friendly technological progresses. Undoubtedly, since the 1970s polluting technologies have been replaced by more environment friendly technologies in order to advance economic growth in many nations, particularly in developed countries, that could have potentially reduced the conflict between per capita income growth rate and the status of threatened species.

Our analyses raise issues regarding how the link between threatened species and its determinants in a cross-country context is modelled. For example, how temporal effects and spatial effects are captured in the model; what would be the reasonable temporal lag for a causal relationship between independent and dependent variables; and what type of spatial effect is more important for a given research context. To model spatial effects, the choice between the two spatial models commands further consideration depending on the empirical questions in hand. If the concern is on spill-over effect of threatened species from neighbouring countries, obviously lag models would be favored. However, if researchers are exploring the effect of factors that are not included in the model then error models would be favored. We find better performance of the error model for mammals and the lag model for birds based on the model selection criteria used in this analysis – higher Log Likelihood and lower AIC. Thus, depending upon the empirical questions in hand, both type of models need to be considered in the analysis.

However, we are cautious with respect to the findings that there are no lagged effects of population growth rate on mammals and per capita income growth rates on both threatened mammals and birds. These findings should be viewed in light of the data availability and timeframe under investigation. The available data on all model variables for large number of countries doesn't go far earlier than 1970; therefore the potential questions and empirical results about what if we would have examined the effects of these growth rate variables based on a longer time period is unanswered. But we do acknowledge that this is an important question that needs further investigation.

There are some limitations in our study that need to be pointed out as well. First of all, we are limited by the comparable time series data on threatened mammals and birds between any two periods. Analysis based on the time series data would be more informative than the cross-sectional data that we used in this analysis, however to the best of our knowledge no consistent time series data are available on threatened mammals and birds for the period we have considered. Secondly, we have not been able to capture the potential roles of legislation and programs that have impacted the country-specific population and per capita income growth rates and thereby the status of threatened species over the years. Our analysis only provides a general overview of the relationship between the status of threatened mammals and birds and the population and per capita income growth rates across continental countries. Since species imperilment is a complex process and additional empirical studies would benefit to disentangle this process further and to improve our understanding to take potential actions to slow down or revert this process.

5. Conclusion

We found mixed results in examining the relationship between the population and per capita income growth rates in earlier period (1070-1990) and the number of threatened mammals and birds in a later period (in 2007) among 113 continental countries. Despite significant effect of population density, the increase in population growth rates during the decades of 1970s and 1980s increases the number of threatened birds in 2007. But no significant effect on both threatened mammals and birds is found as a result of increase in per capita income growth rates during the same period. The lack of statistical significance between per capita income growth rate and the number of threatened mammals and birds is an interesting finding in itself, but it demands cautions. It needs further research with varying length of the temporal lag covering longer periods and using updated data on the status of threatened mammals and birds in future studies.

In the context of our analysis, the population growth rate is more sensitive to species imperilment than the per capita income growth rates. The implied meaning of our finding is that not only the human population density but also the human population growth rate is important for conservation policy. In other words, everything else equal, countries with high population growth rates at present may face higher number of threatened species, particularly birds, in the future. Other than increased competition for space/habitat due to increased human population size as a result of high population growth rate, the causal mechanism of the effect on the number of threatened species is not quite clear to us; but it is imperative that current conservation policies should also aim to deal with human population density and the population growth rate to achieve conservation goals in a distant future.

From an analytical perspective, we conclude that a control for spatial effects on cross country studies is essential to accurately estimate the model parameters. As Tobler's (1970) first law of geography states that "*everything is related to everything else, but near things are more related than distant things"*, species imperilment has also been influenced by this law. The significance of this law can be seen based on the model performance (AIC) that both the spatial lag and spatial error models performed better than the identical model without any control for spatial effects. Incorporating spill-over effects in cross-country conservation practices such as landscape level conservation or trans-boundary conservation is important for conservation of threatened species that have wider home range, i.e. extending into neighbouring countries, or are affected by human activities in neighbouring countries.

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Table 1. Descriptive statistics for model variables (n=113 countries[©])

Variable	Mean	Std. Deviation	Range
Threatened mammals (#)	18.65	16.24	1 to 89
Endangered mammals (#)	10.54	24.49	0 to 155
Total mammals (#)	190.73	117.88	8 to 578
Threatened birds (#)	18.18	21.29	0 to 122
Endangered birds (#)	15.22	31.8	0 to 207
Total birds (#)	649.47	317.29	151 to 1851
Population in 1970 (in 10,000)	2602.83	9386.49	11.13 to 81831.50
Population in 1990 (in 10,000)	3814.87	13444.30	18.9 to 113518.50
Population in 2007 (in 10,000)	4886.52	16446.27	31.15 to 131788.50
Country area (in 10,000 sq km)	85.85	177.76	0.07 to 998.47
Population density 1970 (person/sq.km)	77.29	284.82	0.80 to 2964.29
Population density 1990 (person/sq.km)	111.74	416.56	1.42 to 4352.86
Population density 2007 (person/sq.km)	153.23	622.78	1.67 to 6555.14
Population growth from 1970 to 1990 (in 10,000)	1212.04	4145.46	3.44 to 31687
Average rate of population growth per annum 1970-1990	0.7083	0.7779	0.02205 to 7.31108
Real per-capita income 1970 (int. $)	1512.53	1887.01	149.75 to 13748.79
Real per-capita income 1990 (int. $)	6027.00	7016.52	423.73 to 31851.19
Real per-capita income 2007 (int. $)	13524.69	17665.40	414.04 to 104707.45
Per-capita income growth from 1970 to 1990 (int. $)	4514.48	5526.60	102.07 to 26374.27
Average rate of per-capita income growth per annum 1970-1990	3.1172	2.0773	0.1093 to 13.7812

[©] Afghanistan, Albania, Algeria, Angola, Argentina, Austria, Bangladesh, Belgium, Belize, Benin, Bhutan, Bolivia, Botswana, Brazil, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Colombia, Congo, Democratic Republic of Congo, Costa Rica, Cote d'Ivoire, Denmark, Djibouti, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Finland, France, Gabon, Gambia, Germany, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Honduras, India, Iran, Iraq, Israel, Italy, Jordan, Kenya, Kuwait, Laos, Lebanon, Lesotho, Libya, Luxembourg, Malawi, Malaysia, Mali, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Namibia, Nepal, Netherlands, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Poland, Portugal, Qatar, Romania, Rwanda, Saudi Arabia, Senegal, Sierra Leone, Singapore, Somalia, South Africa, South Korea, Spain, Sudan, Suriname, Swaziland, Sweden, Switzerland, Syria, Tanzania, Thailand, Togo, Tunisia, Turkey, Uganda, United Arab Emirates, United States, Uruguay, Venezuela, Viet Nam, Zambia, and Zimbabwe.

Figure 1. Partial regression plots (added-variable plots: a, b, c and d) for threatened mammals and birds in 2007 by population (lnPopRate97) and per capita income (lnIGRate97) growth rates during 1970-1990

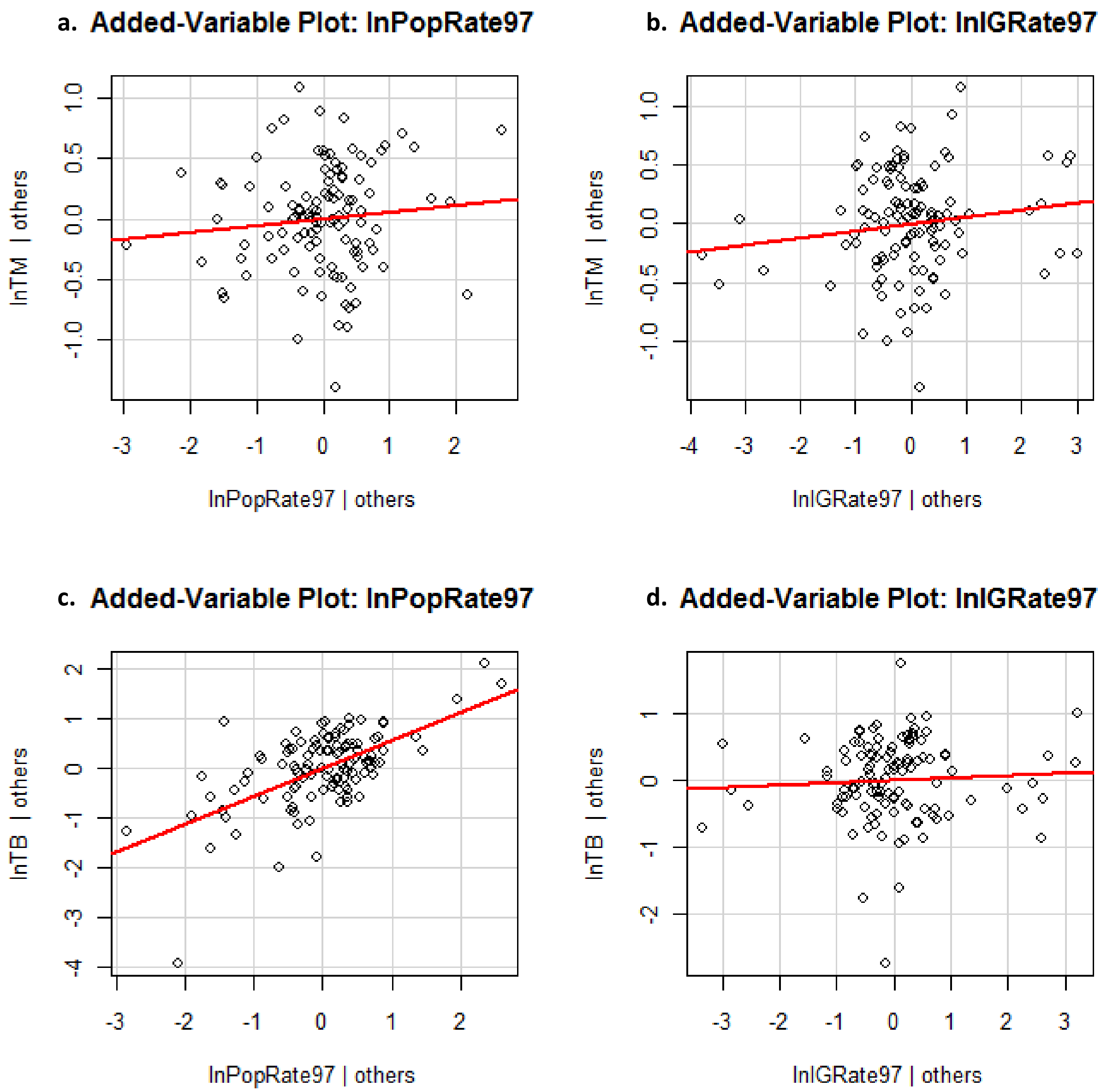

Table 2. Moran's I (spatial autocorrelation) and spatial dependency tests on regression residuals of threatened mammals and birds (linear model 2s in Table 3) by weight matrix

Tests for spatial correlation in OLS residuals	Mammals				Birds			
	Contiguity		Inverse distance		Contiguity		Inverse distance	
	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
Moran's I	0.228	0.0020	0.119	0.0002	0.204	0.0055	0.087	0.0051
(Standard deviate)	(3.086)		(3.727)		(2.777)		(2.802)	
Spatial error dependence:								
Lagrange multiplier test	9.127	0.0025	10.549	0.0012	7.325	0.0068	5.672	0.0172
Robust Lagrange multiplier test	4.403	0.0359	2.681	0.1016	0.928	0.3354	0.040	0.8409
Spatial lag dependence:								
Lagrange multiplier test	6.209	0.0127	10.816	0.0010	11.176	0.0008	20.044	0.00001
Robust Lagrange multiplier test	1.485	0.2230	0.086	0.0860	4.779	0.0288	14.412	0.0001
Spatial lag and error dependence (SARMA):								
Lagrange multiplier test	10.612	0.0050	13.496	0.0012	12.104	0.0024	20.084	0.00004

Table 3. Linear and spatial regression results for Ln number of threatened mammals and birds in 2007

	Mammals				Birds			
Variables (a)	Linear 1‡ (b)	Linear 2 (c)	Spatial lag (d)	Spatial error (e)	Linear 1‡ (f)	Linear 2 (g)	Spatial lag (h)	Spatial error (i)
Intercept	-4.6641**	-0.8772	-2.6208	-3.6194**	-10.7031***	-6.6363**	-8.4523***	-6.0764**
	(2.0763)	(2.0312)	(1.9364)	(1.8038)	(3.3204)	(2.7500)	(2.5334)	(2.5672)
Ln Endemic species (#)	0.1593***	0.1655***	0.1485***	0.1597***	0.2508***	0.2776***	0.2196***	0.2278***
	(0.0274)	(0.0274)	(0.0258)	(0.0268)	(0.0396)	(0.0339)	(0.0335)	(0.0399)
Ln Country area (Sq. Km)	0.2018***	0.1847***	0.1969***	0.1806***	0.3126***	0.3019***	0.3253***	0.2984***
	(0.0400)	(0.0392)	(0.0364)	(0.0372)	(0.0541)	(0.0460)	(0.0414)	(0.0422)
Ln Population density 1970‡	0.1758***	0.1487***	0.1630***	0.1136***	0.2313***	0.2362***	0.2821***	0.2391***
	(0.0379)	(0.0370)	(0.0344)	(0.0347)	(0.0623)	(0.0532)	(0.0481)	(0.0504)
Ln Population growth rate 1970-1990		0.0559	0.0487	0.0836		0.5607***	0.4940***	0.4570***
		(0.0538)	(0.0496)	(0.0596)		(0.0748)	(0.0686)	(0.0830)
Ln Per capita income 1970‡	1.0706**	0.4075	0.7920	1.2194**	2.0132***	1.3866*	1.6416**	1.2160
	(0.4603)	(0.5631)	(0.5351)	(0.5305)	(0.7426)	(0.7857)	(0.7214)	(0.7593)
Ln Per capita income 1970^2‡	-0.0682**	-0.0445	-0.0702*	-0.0962**	-0.1233***	-0.1029*	-0.1191**	-0.0887
	(0.0261)	(0.0404)	(0.0383)	(0.0381)	(0.0420)	(0.0564)	(0.0517)	(0.0545)
Ln Per capita income growth rate 1970-1990		0.0503	0.0528	0.0349		0.0151	0.0220	0.0000
		(0.0649)	(0.0375)	(0.0342)		(0.0914)	(0.0521)	(0.0499)
Spatial control variable (ρ for lag and λ for error)			0.1253**	0.5122***			0.2089***	0.4771***
			(0.0521)	(0.0850)			(0.0580)	(0.0886)
Adj. R2	0.6575	0.6712			0.5944	0.6971		
Akaike Information Criteria		150.2	146.63	137.13		225.76	216.53	216.82
Log Likelihood			-63.32	-58.56			-98.26	-98.41
LM test for residual-autocorrelation			4.92**				2.48	
Number of countries	113	113	113	113	113	113	113	113

*, **, and *** represent significance of estimated coefficient at 10%, 5%, and 1% levels, respectively.

‡ represents the use of 2007 data for population density and income variables in linear 1 model for mammals and birds.