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Impacts of Population and Income Growth Rates on Threatened Mammals and Birds

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Abstract:

Per capita income and human population levels in a country have direct influences on its environmental outcomes. Countries with same level of income may have different rate of income growth and vice versa, suggesting that the influence of the rate of income growth on environmental outcomes could be different than that of income level. Similarly, the rate of population growth might have different impact in addition to the impacts of sheer number of population. We explore this empirical question using country-level data on threatened species published by IUCN for the year 2007. Controlling for other factors, our model estimates the influences of the rate of population and income growth on threatened mammals and birds across 113 continental countries. The results suggest that, among other factors, the rate of population growth has significant influences on number of threatened mammals and birds.

I Introduction

Accelerated biodiversity loss is one of the serious environmental challenges faced by the society today which is at its worst, 1 in 5 species are on the verge of mass extinction, since dinosaurs roamed the earth 65 million years ago (CI 2010; Hoffmann, Hilton-Taylor et al. 2010). The number of threatened species has grown dramatically in the past four decades, exceeding the normal *background rate* of extinction by a factor of two or three and the scenarios for 21st century consistently indicate that biodiversity will continue to decline (Pereira, Leadley et al. 2010). A general consensus among scientists and policy makers is that natural habitat conditions and anthropogenic factors – human population, economic growth etc - are responsible for this extinction crisis (Kerr and Currie 1995; Forester and Machlis 1996; Sala, Chapin et al. 2000; Balmford and Bond 2005; Pereira, Leadley et al. 2010). Recent reports that have examined the causal relationship between specific drivers and biodiversity loss highlighted two groups of factors responsible for the crisis: direct and indirect drivers (NBL 2010; TEEB 2010; SCBD 2010). The five principal drivers directly driving biodiversity loss are habitat change, overexploitation, pollution, invasive alien species and climate change which are either constant or increasing in intensity (SCBD 2010). The indirect drivers include demographic change, economic activity, levels of international trade, per capita consumption patterns, cultural and religious factors, and scientific and technological changes (SCBD 2010). The 10th Conference of Parties meeting on the Convention on Biological Diversity held in Nayoga Japan in 2010 has stressed on the need to effectively tackle the indirect drivers of biodiversity loss in order to achieve its conservation goals (CI 2010).

Although threatened species of flora and fauna truly represent natural and anthropogenic pressure on the Earth's biodiversity (Dietz and Adger 2003), it can also be modelled as an 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 in the published literature (Sodhi, Bickford et al. 2008). In cross-country studies, human population density and per-capita income in a given year have influences on a number or percentage of threatened species listed in IUCN Red Lists in that year (Naidoo and Adamowicz 2001; Asafu-Adjaye 2003; Pandit and Laband 2007a). The impact of per-capita income on threatened species has often been characterized by the Environmental Kuznets Curve (EKC) for some taxa; this relationship is not universal across taxa and depends on number of observations, functional forms and whether the analysis differentiate developed and developing countries (Naidoo and Adamowicz 2001; McPherson and Nieswiadomy 2005; Pandit and Laband 2007; Zibaei and Sheykh 2009). All of these studies have examined cross-sectional data to predict the impact of population density and per-capita income on a number or percentage of threatened species of specific taxa. Zibaei and Sheykh (2009) examined potential EKC for percentage of birds and mammals threatened with extinction, controlling for per capita income and population density between developed and developing countries and found that the EKC was observed only for developed countries. Lately, McPherson and Nieswiadomy (2005) and Pandit and Laband (2007b) have addressed the issue of cross-border effects, spatial autocorrelation in dependent variable or in model errors, and its impacts on status of threatened species which has practical implications for conservation policies as political boundaries are mere arbitrary lines in ecological sense.

While conjecturing the relationships between population and per capita income growth rates and threatened species in a cross country context, scientific guidance is limited particularly to link historical per capita income growth rate and its impact on threatened species. In the case of population growth rate, McKee et al. (2003) argue that human population growth rates determine future population sizes, and thus current growth rates do not appear to serve as good estimators of existing biodiversity threats. In a study comprises of 107 countries, Forester and Machlis (1996) found no significant correlation between biodiversity loss and national population change between 1980 and 1990. However, Kerr and Curie (1995) examined the relationship between human activities and extinction risks of mammals and birds in 90 countries and found that human population density was more closely related to proportion of threatened birds while per capita Gross National Product (GNP) was more closely related to proportion of threatened mammals. Mixed evidences are available on the relationships of human population growth rate and per capita income with status of threatened species across countries. The exact relationship is based on specific taxa examined and model specification used.

Arguably, increased human population and economic activity in the past have impacts on threatened species in later years suggesting a potential lagged effect of population and per-capita income. However, only limited guidance exists in literature to link any lagged effect of factors impacting threatened species. Pandit and Laband (2009) studied the influences of logged population density and per-capita income of 1990 on percentage of threatened mammals, birds, reptiles, amphibians, and vascular plants in 2007 and found that population density has a significant lagged effect on threatened mammals and vascular plants. In addition, their findings suggest a positive influence of lagged income inequality variable threatened vascular plants while finding negative influences on threatened mammals and reptiles which are at odd with the findings of the taxa-aggregated analysis of Mikkelson et al. (2007).

Additionally, when linking human population and per-capita income to threatened species in a cross-country setting, it is plausible that the *rates* of population and per-capita income growth may have additional impacts on top of country specific impacts of population and per-capita income *levels*. The empirical question is that if we control the population and income levels, do the rate of population growth and the rate of per-capita income growth have any impacts on threatened species in a country? It is plausible in a sense that a higher population and per-capita income growth rates could have potential impacts on intensive and extensive use of its natural resources, shared by other species, leading to severe pressure and adverse effects on other species. A close examination of population and income growth patterns among countries suggest quite contrasting figures between 1970 and 2007. For example: Ghana and Greece had identical populations (8.7 million) in 1970 which were increased by 162% and 27% in 2007; the population of South Korea and South Africa were just over 48 million in 2007 but it was just about 51% and 118% increases in these countries' 1970 population levels respectively (WB 2010). Similarly, Guyana ($567) and Thailand ($560) had almost identical real per capita income in 1970 that was increased by a respective factor of 3.6 and 17.4 in 2007 while the real per capita income in Lebanon ($8228) and China ($8271) were almost the same in 2007 but this income was just about 1.87 and 41.37 times the respective per capita income of these countries in 1970 (Heston, Summers et al. 2009). Do these differential rates of increase in population and per-capita income have differential impacts on threatened species in these countries? In other words, does a country with higher (lower) rates of population and per-capita income-growth have a higher (lower) rate of threatened species? 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.

Clearly, a species become threatened as a result of the cumulative effect of direct and indirect drivers (SCBD 2010). As McKee et al. (2003) argues that there should be a lagged 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. Generally, empirical studies have used cross-sectional data, space for time approach, to link threatened species to its determinants. A few recent studies have considered a specific time in the past to examine the lagged effects (Mikkelson, Gonzalez et al. 2007; Pandit and Laband 2009) but they differ in the modelling techniques. However a compelling case would be to examine a continuing impact of these factors to explain threatened species phenomena. Therefore, in this paper we aim to discern the continuing impacts of population growth and economic activity by examining the relationship between average rates of population and per-capita income growth and the status of threatened species. Controlling for spatial effect in the modelling process and considering 1970 as a base year, our analysis focuses on the continuing impacts of population and income growth rates on documented threatened mammals and birds in 2007 from 113 continental countries.

II Model, Data, and Methods

Model

We posit a taxa-specific reduced form model from a conceptual model presented in equation 1 to investigate country specific impacts of the *rate* of population and per-capita income growth on its threatened species. The reduced form model in equation 2 links the number of threatened mammals and birds with their determinants. We included land area, human population and per capita income levels as predictor variables in the model to control the effect of available space for all species and human induced pressure on other species by its sheer population size and economic activities. Earlier studies have indicated endemic species, species with limited distributional range, as a significant predictor of threatened species (McKee, Sciulli 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 both of the taxa we analysed. We added the rates of per-capita income and population growth as explanatory variables in the model to examine the impact of these variables on number of threatened mammals and birds. Finally, we augmented spatial control variable for spatial lag and error models in equation 2 to estimate taxa-specific spatial models.

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

Number of Threatened Species$_{ij}$ = β_0 + β_1 Number of Endemic Species$_{ij}$ + β_2 Land Area$_i$

$+ \beta_3$ Population Size 1970_i + β_4 Rate of Population $Growth_i$ + β_5 Per Capita Income 1970_i
$+ \beta_6$ Rate of Per Capita Income $Growth_i + \upsilon_{ij}$ (Eq. 2)

Where threatened species refers to the critically endangered, endangered, and vulnerable mammals and birds in each of 113 sample countries as listed in 2007 IUCN RedList of Threatened Species (IUCN 2007). v_{ij} is country and taxa specific model error term. As a priori, we expect that endemic species, human population, and per-capita income are positively related with threatened mammals and birds. Further, we expect that controlling for population and per-capita income levels, the rate of population and per-capita income growth may have a positive influence on threatened species.

We used 1970 as a base year to examine impacts of population and per-capita income growth rates on threatened species in the year 2007. There are no specific reasons to choose 1970 as a base year other than the availability of data for key model variables for large number of countries for the longest years of interval possible. One loosely related aspect with 1970 is that it is also the early phase of the environmental conservation movement partly contributed by Rachel Carson's 1962 Silent Spring and the subsequent establishment of the national Environmental Protection Agency (EPA) in several countries, such as US EPA. In this study we focused only on continental countries to isolate island specific characteristics in the modelling process i.e. 1) no weights for islands when controlling for spatial autocorrelation based on contiguity weight matrix, 2) distinct ecological characteristics of islands – higher species endemism and greater sensitivity of native species (Czech, Krausman et al. 2000), and 3) high human population densities and severe ecological disruption (McKinney 2001).

Data and methods

Data on model variables for 113 mainland countries were collected from different sources. The data on threatened, endemic and the total number of mammals and birds were obtained from The World Conservation Union (IUCN 2007). Country specific data on population size and land area are from World Bank (WB 2010), and the purchasing power parity converted data on per capita income are from the Penn World Table (Heston, Summers et al. 2009). Using the population and per capita income data for the years 1970 and 2007, we derived the country specific population growth rate and per capita income growth rate variables for analysis considering 1970 as a base year.

We first 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 "zero' record in the raw data to avoid the problem of undefined values. Then we employed spatial econometric techniques to analyse the data using 'spdep' package in R (R 2010) to test and control the spatial dependency in the models. The spatial dependency between observations is defined based on neighbourhood contiguity as this form of simple binary adjacency relationship was adequate to represent spatial dependency structure in earlier analysis (Pandit and Laband 2007b). All adjacent neighbour countries are included in constructing a weight matrix for a referent country. The row-standardized weight matrix (W) created in GeoDa, spatial analysis software, was used to test spatial dependency using Moran's I statistic (Moran 1950) on both dependent variable and linear model residual.

We ran three sets of regression models: linear, spatial lag, and spatial error controlling for the 1970 levels of per-capita income and population. These models include the variables that represent the rate of per-capita income growth and the rate of population growth between 1970 and 2007. For all models, we report Akaike Information Criteria (AIC) to indicate the superiority of alternative models we analysed.

III Results

Descriptive statistics

The descriptive statistics for model variables are presented in Table 1. The statistics are based on 113 continental countries analysed in this study. The descriptive statistics indicate that there are more threatened mammals and birds in each country than their endemic numbers. Based on the total number of identified species, on average about 18 mammals (9.85%) and 18 birds (2.47%) are threatened with extinction in each country while 10 mammals (3.2%) and 15 birds (1.68%) are categorized as endemic per country.

Table 1. Descriptive statistics: Threatened mammals and birds in 2007 and factors (n=113)

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	31.80	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 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 2007 (person/sq.km)	153.23	622.78	1.67 to 6555.14
Population growth 1970-2007 (in 10,000)	2283.70	7278.55	5.47 to 57721.80
Rate of population growth 1970-2007 (%)	150.45	192.63	5.85 to 1842.54
Average Rate/year	4.07	5.21	0.16 to 49.80
Real per-capita income 1970 (int. $)	1512.53	1887.01	149.75 to 13748.79
Real per-capita income 2007 (int. $)	13524.69	17665.40	414.04 to 104707.45
Per-capita income growth 1970-2007 (int. $)	12012.17	15959.36	44.35 to 90958.66
Per-capita income growth rate 1970-2007 (x)	8.40	8.34	0.12 to 59.72
Average rate/year	0.227	0.225	0.003 to 1.6

In terms of number, the highest and least numbers of threatened mammals are found in India (89) and Qatar (1) respectively while the corresponding numbers for endemic mammals are in Mexico (155) and 37 other countries including Qatar (0). Brazil has the highest number of both threatened (122) and endemic (207) birds, while Luxembourg is one of the two, the other one is Suriname, and one of the 21 other countries without threatened and endemic birds. On average, human population in each sample country increased by about 22.84 million between 1970 and 2007 which is about 150% growth in 1970 mean population size (26.03 million). The rate of population growth compared to the 1970 population during this 37 years period is very different among continental countries. Five countries with the least population growth in this period include Germany (5.8%), Romania (6.4%), Guyana (7.7%), Belgium (10.2%) and Italy (10.3%) with the respective population size of 77.72 million, 20.25 million, 0.709 million, 9.638 million and 53.822 million in 1970. The countries with the highest population growth between 1970 and 2007 are United Arab Emirates (1842.5%) from 224,650 to 4,363,913, Qatar (921.8%) from 111,330 to 1,137,553, Djibouti (416.3%) from 161,584 to 834,291, Saudi Arabia (321.9%) from 5,744,737 to 24,236,361 and Ivory Coast (284.6%) from 5,232,558 to 20,122,796.

The mean purchasing power parity based per-capita income in international dollars was about $1,513 in 1970 and $13,525 in 2007. The average per capita income growth from 1970 to 2007 was about 8.4 times to that of the 1970 income. Compared to the 1970 income, five countries that are at the lower end of this income growth include The Democratic Republic of Congo (0.12 times), Somalia (1.14 times), Djibouti (1.17 times), Nicaragua (1.25 times), and Zambia (1.46 times). The 1970 per capita income in these countries was $370, $229, $2,143, $1,023, and $934 respectively. Countries at the upper end of this income growth include Equatorial Guinea, China, South Korea, Botswana, and Singapore. The income growth rates of these countries were 59.72 times, 41.37 times, 33.60 times, 31.92 times, and 30.38 times higher in 2007 compared to 1970 income. The 1970 incomes of these countries were about $291, $195, $721, $309, and $1,545 respectively.

Regression results

In table 3, column b and e, we present log transformed linear model results for specifications described in equation 2. Linear model result suggests that the 1970 population size is a highly significant predictor of threatened mammals and birds. It also indicates that higher number of endemic mammals and birds significantly influences their threatened numbers. The 1970 human population level significantly impacts the number of threatened mammals and birds in 2007, but the population growth rate in this period, weighted by the 1970 population size, only impacts threatened birds. Per capita income of 1970 has influences on number of threatened birds but not on mammals. For birds, the relationship between per capita income and threatened number appears to follow EKC relationship. However, the rate of per capita income growth has no discernible impacts either on number of threatened mammals or on birds while estimating the model without spatial control variable.

One modelling issue in linear model results presented in table 3 (column b and e) is that these results are obtained without controlling for spatial effect either on dependent variable or on model residuals. To detect spatial dependency structures Moran’s I tests on dependent variables and on linear model residuals was used. This test of spatial dependency is based on row standardized weight matrix which is derived from a simple contiguity relationship between countries. If a country borders to a referent country then it gets a proportionate share out of the total weight 1, otherwise it gets ‘0’ weight. The weight matrix is row standardized, so the sum of weight shared by all countries equals 1. In table 2 we report the results of Moran's I test on dependent variables and linear model residuals for mammals and birds. The test indicates significant spatial autocorrelation on both dependent variable and linear model residuals.

Table 2. Moran's I test for dependent variable and regression residual based on simple contiguity based row-standardized weight matrix

Models	Moran's I statistic	Standard deviate	p value
Logged dependent variable:			
# threatened mammals	0.336	4.497	8.885E-06
# threatened birds	0.492	6.534	6.391E-11
Linear model residual:			
# threatened mammals	0.228	3.488	0.0004
# threatened birds	0.210	3.300	0.0009

Taking insights from Moran's I tests, we ran two sets of spatial regressions – spatial lag and error - following the model specifications of equation 2 for both mammals and birds. The spatial lag and error models are different on how we control the spatial effect in the modelling process. Spatial lag model has spatially weighted dependent variable as spatial control, while spatial error model uses spatially weighted residuals of the linear model as spatial control variable. In columns c, d, f and g of table 3 we report spatial regression results based on Maximum Likelihood estimation for both spatial lag and error models. The model results vary slightly between spatial lag and error specifications for mammals but the results are entirely consistent for birds.

One important aspect of these results is the influence of endemic mammals and birds on their threatened status. Depending on the models, 1% increase in endemic mammals is associated with a 0.15% increase in percentage of threatened mammals. Birds are relatively more sensitive to endemism compared to mammals; 1% increase in endemic birds is associated with 0.21% increase in threatened birds. Land area appears to be marginally significant for mammals when correlated error is used as spatial control, suggesting that increase in land area could provide additional habitat for mammals but also increases the number of threatened mammals. On average, an increase of 8,585 sq km of area (1% of mean area) in a country increases the number of threatened mammals by about 0.07%. However, we did not find any significance of area on imperilment of birds. Human population of 1970 has significant and consistent impact on threatened mammals and birds in all models. On average, 1% increase on 1970 human population (i.e. 260,283 persons) in a country increases the number of threatened mammals by about 0.12 to 0.17% and the number of birds by about 0.25% to 0.29%. The rate of population growth has model-specific impacts on number of threatened mammals; but it has uniform and highly significant impacts on number of threatened birds. On average a 1% increase in mean population growth between 1970 and 2007 (i.e. on average i.e. 228,370 persons) is associated with 0.12% increase in percentage of threatened mammals, whilst the percentage increase in number of threatened birds is substantially high at the range of 0.31% to 0.44%. One potential reason for different results between lag and error models for a given variable is due to the strong

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

	Models for Mammals			Models for Birds		
Variables	*Linear*	*Lag*	*Error*	*Linear*	*Lag*	*Error*
(a)	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**
Intercept	-1.986 (2.071)	-3.124 (1.964)	-4.190** (1.821)	-9.311*** (2.916)	-10.252*** (2.652)	-6.602** (2.596)
Ln Endemic species (#)	0.151*** (0.028)	0.143*** (0.026)	0.152*** (0.027)	0.258*** (0.036)	0.211*** (0.034)	0.205*** (0.042)
Ln Land Area (sq. km)	0.044 (0.037)	0.030 (0.035)	0.070* (0.038)	0.086* (0.049)	0.049 (0.045)	0.050 (0.050)
Ln Population 1970	0.162*** (0.037)	0.173*** (0.035)	0.122*** (0.035)	0.246*** (0.056)	0.285*** (0.251)	0.251*** (0.052)
Ln Population growth rate 1970-2007	0.086 (0.054)	0.080 (0.050)	0.115** (0.059)	0.507*** (0.076)	0.437*** (0.070)	0.315*** (0.088)
Ln Per capita income 1970	0.604 (0.561)	0.803 (0.526)	1.266** (0.517)	1.919** (0.818)	1.982*** (0.738)	1.291* (0.752)
Ln Per capita income 1970^2	-0.058 (0.040)	-0.071** (0.038)	-0.099*** (0.037)	-0.143** (0.059)	-0.148*** (0.053)	-0.095* (0.054)
Ln Per capita income growth rate 1970-2007	0.080 (0.053)	0.083* (0.050)	0.042 (0.048)	-0.103 (0.080)	0.090 (0.072)	-0.011 (0.071)
Spatial control variable		0.134** (0.052)	0.527*** (0.084)		0.238*** (0.059)	0.613*** (0.073)
Adj. R^2	0.68			0.68		
Log Likelihood		-62.47	-57.82		-103.21	-101.60
AIC	149.44	144.94	135.64	238.10	226.43	223.20
Number of countries	113	113	113	113	113	113

correlation of the variable with lagged error term i.e. the spatial control variables used in error models.

In terms of income variables, the number of threatened mammals and birds in 2007 were significantly influenced by the lagged income of 1970. An EKC relationship has been observed between 1970 per capita income and the number of threatened mammals and birds in 2007. Clearly, we find the lagged and non-linear effects of income on imperilment of mammals and birds. Increase in 1970 per capita income is associated with an increase in number of threatened mammals and birds up to a certain income level then any increase in income is associated with decrease in number of threatened mammals and birds. This quadratic relationship is well explained by the data for birds than for mammals. However the effect of per capita income growth is observed only for mammals when the spatial effect is controlled by the lag of the number of threatened mammals. A 1% increase in income differential between 1970 and 2007 (1% of $12,012) is associated with a 0.08% increase in the number of threatened mammals. The spatial control variables, row weighted lagged dependent variable and lagged error, are consistently significant across all models indicating that control for spatial effect is important in examining imperilment of mammals and birds. The parameter estimates for spatial control variable suggests that birds are more sensitive than mammals with respect to neighbourhood impacts. For example, 1% increases in weighted average of the threatened mammals (birds) in the adjoining countries is associated with 0.13% (0.24%) increase in threatened mammals (birds) in the referent country.

IV Discussion

The notion that there might be some additional effects of the rate of population and per capita income growth in addition to the effects of the 1970 population and per capita income levels does not seem to bear empirical support universally across the taxa and models we examined in this study. Irrespective of model formulation and spatial models used, we find consistent impact of population growth rates on threatened birds indicating that birds are more sensitive to population growth rates than mammals. However, we find some model sensitive results for mammals. For example, increased population growth rate significantly increases the number of threatened mammals in spatial error model. Despite this model sensitivity, we find that the 1970 population level and the rate of population growth since then are more influential factors to predict the number of threatened species in 2007 than the 1970 per capita income level and its growth rate during this period. 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, log 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 finding is consistent with the significant effect of the human population density on the number of threatened mammals and birds among 114 countries found by McKee et al. (2003).

With respect to the impacts of 1970 income and income growth rate on threatened mammals and birds, most of our results follow general expectations. The impact of income on threatened mammals and birds show EKC relationship in all formulations. For income growth rate we find expected results only for mammals when the model is specified in spatial lag formulation. In an earlier US based study of this nature, 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 any spatial effects in their model while we do so.

The explanations for why the rate of per capita income growth beyond 1970 does not seem to matter much in explaining threatened species could be varied. One possible reason could be increase in cleaner service sectors as economies grow (Kongsamut, Rebelo 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 and also, the increased income could have impact on a greater demand for programs and policies that protect species. This seems plausible in the case of developed countries where significant emphasis was given in the last 4 decades to improve the environment by introducing new legislations and programs. For example: establishment of the Environmental Protection Agency in the US in 1970. We still observe deteriorating environment at the cost of economic growth 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 fuelled by these latter trends on threatened species in this analysis except for mammals.

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. As Czech (2008) argues that if we acknowledge the conflict between economic growth and biodiversity conservation, technological progress could partly reconcile it through the innovations that increase technical efficiency. Undoubtedly, since the 1970s polluting technologies have been replaced by more environment friendly technologies in order to prosper economic growth in many nations, particularly in developed countries, that could have potentially mitigated the conflict between per capita income growth rate and the status of threatened species. However, we are cautious to this linkage as it is not universal between the models and taxa groups we examined. This finding implies a couple of issues in modelling the link between threatened species and its determinants in a cross-country context. Firstly, how we define dependent variables could play a role on model performance and the significance of predictor variables. Dependent variables can be defined in several ways: sheer number of threatened species or by weighing the number of threatened species either by total number of species or by area of the country. Secondly, the choice between the two spatial models, need further consideration depending on the empirical questions in hand. If the concern is on the lag effect of threatened species from neighbouring countries, obviously the lag models are the choices, if the question is to explore the effect of factors that are not included in the model then obviously the error model is the choice. We find better performance of lag model for mammals and error 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.

There are some limitations in our study that need to be pointed out. 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 replaced time by space by using cross-sectional analysis that could have potentially limited the 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.

V Conclusion

In examining the relationship between threatened mammals and birds in 2007 and the factors that influence their status among 113 continental countries we found that a control for spatial autocorrelation is essential from a modelling perspective. The model performance has been enhanced by the use of both types of spatial autocorrelation control measures, lagged dependent variable or lagged error term. The variable that captures the country specific environment in the form of endemic species is found to be a significant predictor of threatened mammals and birds irrespective of spatial models. Among socio-economic factors, human population level and population growth rate significantly influence the number of threatened mammals and birds irrespective of models except case of spatial lag model for mammals. For 1970 per capita income level and the average rate of income growth between 1970 and 2007, the influences on threatened mammals and birds are model specific. Generally, 1970 income has exhibited environmental Kuznets curve relationship with number of threatened mammals and birds in 2007 however, the influence of per capita income growth rate is limited only to mammals when spatial autocorrelation is controlled by lagged dependent variable suggesting that higher per capita income growth rate indicates higher number of threatened mammals in a country.

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