THE ECOLOGICAL IMPLICATIONS OF POPULATION AGING: A CROSS-NATIONAL ANALYSIS OF THE ECOLOGICAL FOOTPRINT

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(Chair)

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Abstract

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Human ecologists have placed importance on demographic processes in explaining environmental degradation. However, population size has received much more attention than other demographic factors, such as age structure. Population aging is a historically unprecedented and global phenomenon. With such a drastic demographic change presently occurring, it is important for environmental sociology to assess what the environmental effects may be. Through a cross-national analysis of the ecological footprint, I examine the effect of population aging on the environment. The analysis reveals that older populations have larger ecological footprints than younger populations. This effect was found to vary between the major subcomponents of the ecological footprint; older populations consume more food, fiber, and timber but not energy.

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INTRODUCTION

Sociologists in the human ecology tradition argue that human social systems are dependent on the natural environment for their functioning (Catton and Dunlap 1980; Catton 1980; Freese 1997). Human societies and natural ecosystems are in constant interaction; not only does the environment affect human societies, but human societies also affect the environment (Freese 1997). Identifying and understanding the underlying social dynamics of environmental degradation is a major concern in this field. Demographic factors have occupied an important place in human ecologists' explanations of these anthropogenic environmental impacts (Catton 1980; York, Rosa, and Dietz 2003a). However, most demographically focused research has focused on population size to the neglect of other demographic characteristics, such as age structure (e.g., Ehrlich and Ehrlich 1990). In the present study I assess the environmental implications of population aging.

Population aging is a historically unprecedented and global phenomenon. Cohen (2003:1173) puts it into perspective when he states, "The 20th century will probably be the last in which younger people outnumber older ones." With such a drastic demographic change presently occurring, it is important for environmental sociology to assess what the environmental effects of population aging may be.

Age structures, as well as population sizes and growth rates, are changing due to the global demographic transition. As Vallin (2002:113) notes, "The transition is not simply the passage from one mortality and fertility regime to another. It is also a transformation of the age pyramid." As evidenced by advanced industrial countries (e.g., Italy, Germany, and Japan), when fertility and mortality are low, populations develop an older age structure.

The drivers of population aging are well-known. Decreasing fertility is the main driver of population aging; decreasing mortality has a more nuanced effect. Decreasing infant mortality tends to increase the number of young people in a population. On the other hand, decreases in mortality due to longer life expectancy at later stages in the life-cycle contribute to population aging (Vallin 2002). In addition, immigration has been found to have a relatively minor effect on population aging (Bermingham 2001; Uhlenberg 2006).

Due to the rapidity with which developing countries are moving through the demographic transition relative to the historical paths of developed countries, population aging will occur much quicker in developing countries. For example, it took France approximately 200 years to go from an average of six births per woman to two. In China, this took only thirty years. The result is that in less than 25 years (by 2025) China's percentage of people over sixty years old will double from ten percent to twenty percent; by comparison, it took France 150 years to go from ten percent to twenty percent (Vallin 2002). China is not a special case; it is projected that many developing countries will double their percentage of population over sixty-five years of age (from seven percent to fourteen percent) in, at most, half the time it took France (Harper 2006). Hence, it is important to recognize that population aging is not a phenomenon restricted to developed countries. In fact, aging is occurring much faster in developing countries than in developed countries. By 2030, it is projected that 71 percent of the global population age 65 and over will live in developing countries (Kinsella and Velkoff 2001).

While the body of macro-comparative sociological research addressing the social structural drivers of environmental impacts has grown in recent years, population aging has not been systematically addressed. One notable exception is York's (2007) study of energy consumption in European Union nations. The present study goes beyond York's by analyzing a more diverse sample of 87 countries and by assessing the effects of population aging (measured as aging index) on three consumption-based measures of anthropogenic environmental pressure: (1) total ecological footprint (2) total food, fiber, and timber footprint and (3) total energy footprint. I perform OLS and robust regression on data for these 87 countries to estimate three STIRPAT elasticity models in order to determine if aging index has a significant effect on each of the aforementioned dependent variables.

This study makes a general contribution to human ecology's understanding of the role of population age structure in societal-environment interactions. More specifically, it provides much-needed empirical analysis of the effects of population aging on the natural environment. Furthermore, the results of this study uncover promising areas for further research.

In the next section, I discuss at more length human ecology's theoretical approach to understanding the social structural drivers of environmental degradation.

THEORY

New Human Ecology

According to Buttel (1987), the "core" of environmental sociology is the new human ecology, the main thrust of which is the rejection of the idea that "the exceptional characteristics of our species (culture, technology, language, elaborate social organization) somehow exempt humans from ecological principles and from environmental influences and constraints" (Dunlap and Catton 1979: 250). In describing this new human ecology it is useful to draw distinctions between it and conventional human ecology. Below are several important ways that new human ecology differs from conventional human ecology.

First, conventional human ecology and new human ecology conceptualize the environment in different ways. Conventional human ecology, while professing to take into consideration the natural environment in explanations of social phenomena (e.g., Park 1936), has typically used the term, environment, to either represent "the friction of space limiting the daily range of human travel" or conceptualized it as "consist[ing] of other human groups competing with other people for resources" (Buttel and Humphrey 2002:37). In essence, as Dunlap and Catton (1979) argue, conventional human ecology ignores the biophysical environment, or at most reduces it to a social or spatial variable. The new human ecology, on the other hand, conceptualizes the environment as the biophysical environment, and therefore, as more than merely the space a community takes up (Catton 1994:82).

One reason why these two theoretical approaches conceptualize the environment differently lies in their uses of ecological concepts. For conventional human ecology,

ecology serves as an analogy or perspective for studying human societies (Beus 1993; Catton 1994). Ecological concepts and terms are only utilized metaphorically, which results in the inability of this field to address ecological problems (Beus 1993). New human ecology, in contrast, takes seriously the science of ecology and what its concepts can offer in the way of understanding society-environment interaction (e.g., Catton 1980, 1987). The second major distinction between conventional and new human ecology is fundamentally rooted in these different employments of ecological concepts.

Second, while conventional human ecology proposes that human societies tend toward equilibrium with their natural environments, the new human ecology argues that human societies can and do degrade the natural environment (Buttel 1987). The conventional human ecology argument is that the growth of human societies does not face ecological constraints because technology and social organization can always increase the supply of resources necessary for the population (Dunlap, Lutzenheiser, and Rosa 1994). In contrast, new human ecology recognizes that the natural environment has limits and that these limits can be crossed with the result being environmental degradation and the concomitant reduction in the ability of the environment to support humans. Thus, regardless of human ingenuity, societies are constrained by the limits imposed on them by the natural environment (Catton 1987).

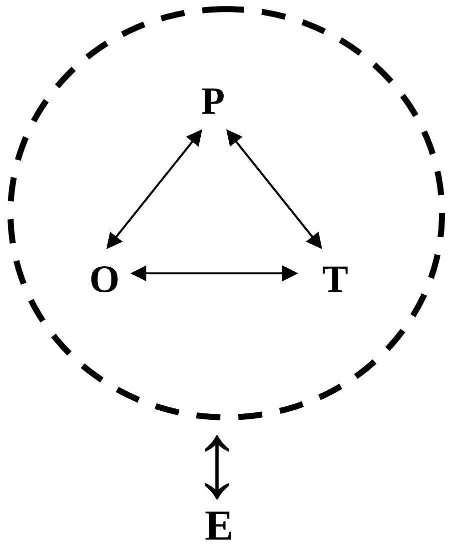
Third, conventional and new human ecology do not share the same central problematic. According to Beus (1993), conventional human ecology has been mainly interested in using ecological metaphors to explain the spatial structure of urban areas, as in the classical human ecology of Park (1936), and later, to explain macro-level social organization, as in the neo-classical human ecology of Hawley (1986). New human ecology, on the other hand, focuses on explaining the social dynamics of environmental degradation (Buttel 2003).

As this brief discussion has shown, new human ecology is much distanced from conventional human ecology. However, despite their differences, new human ecology has found some of the concepts of conventional human ecology useful for the purpose of explaining the social dynamics of environmental degradation. One of these concepts is the POET model, also known as the "ecological complex."

The POET Model

The POET model was developed by Duncan (1959, 1961) as a way of thinking about the complex, reciprocal relationships that exist among population (P), social organization (O), the environment (E), and technology (T). This model builds on Park's (1936) concept of the "social complex", which is composed of three of the elements of the POET model, population (P), social organization (O), and technology (T). When utilized by conventional human ecologists, it was generally with an eye towards explaining social organization, and the *E* term in the POET model was treated as the social environment rather than as the biophysical environment (Dunlap and Catton 1979). For the new human ecology, the focus, however, is on how the social complex (P, O, and T) both influences and is influenced by the biophysical environment (see Figure 1 below; Dunlap and Catton 1979).

Figure 1. The POET Model: The Social Complex and its Environment



Adapted from Catton (1987:414).

The environment in this re-conceptualization of the ecological complex serves three functions for society (Dunlap and Catton 2002). First, the environment provides natural resources, such as timber, oil, and freshwater. Second, the environment serves as a “sink” for all of the wastes produced by societies, such as greenhouse gases and toxic industrial by-products. Third, the environment provides living space for people.

Furthermore, the environment is composed of ecosystems; an ecosystem is a “dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit” (Hassan, Scholes, and Ash 2005: 27). When an ecosystem is tapped to serve one of the three functions, it often impairs that ecosystem’s ability to provide the other two. In addition, ecosystems are limited in their ability to fulfill any of these functions, and when ecosystems are overused the result is ecological disruption and deterioration and the ecosystem may no longer be able to fulfill any function at all (Dunlap and Catton 2002).

The sustainable limits of ecosystems to provide for the demands of societies can be described as ecological carrying capacity. Catton (1987:413) defines carrying capacity as "the maximum load an environment [or ecosystem] can permanently support (i.e., without reduction of its ability to support future generations), load referring not just to the *number* of users of an environment but to the total demands they make upon it." The human load on the environment, as the discussion above emphasized, cannot be understood merely as resource demands, but must also include demands for waste absorption and living space. Environmental degradation is the result of the human load on the environment exceeding carrying capacity for one or all three functions.

While the POET model does not offer a theory for explaining anthropogenic environmental degradation, it is useful in that it suggested that "(1) each of three human-based elements, *P*, *T*, and *O*, can directly impact the environment and (2) they may interact in complex ways in producing such impacts" (Dunlap et al. 1994). Thus, the explanation of variation in the human load on the environment across time and between societies can be focused on three factors: population (O), social organization (O), and technology (T).

According to Catton's (1987) definition, the total load is a function of both human population size and per capita demands. In terms of the POET model, this is a framework that views the human load on the environment as being based on *P*, conceptualized as population size, with social organization (O) and technology (T) primarily affecting per capita demands (e.g., Catton 1980, 1987). As Figure 1 above illustrates, organization (O) and technology (T) modify population size (P) in its relation to the environment. Much attention in environmental sociology has been paid to social organization and technology. Catton's (1980) focus on industrialization, Schnaiberg's (1980) focus on capitalist production, and world-system proponents' focus on international political-economic processes (e.g., Jorgenson 2003; Rice 2005) have all emphasized organization and technology to the neglect of other factors. In the present study, I hypothesize that *O* and *T* are not the only factors that affect per capita environmental demands. Thus, following Dietz and Rosa (1994), I argue against reducing the *P* term in the POET model to merely population size; this approach neglects other demographic characteristics such as population age structure that may be important as well.

Structural Human Ecology

Much of new human ecology, especially in its infancy, has been focused at the meta-theoretical level (Buttel 1987). Scholars in this tradition aimed to overturn the implicitly accepted 'human exemptionalism paradigm' of sociology and replace it with a 'new ecological paradigm' (Catton and Dunlap 1980). Because of this meta-theoretical focus, new human ecology was not readily applied to empirical research (Buttel 1987). Relatively recently, however, scholars have introduced 'structural human ecology' which is based on the tenets of new human ecology but focuses on empirical research. The focus of structural human ecology is on disciplining conceptual models by subjecting them to empirical tests (Dietz and Rosa 1994).

Structural human ecology aims to identify and understand the structural drivers of environmental degradation and their dynamics (Dietz et al. 2008). Among macro-comparative environmental sociology perspectives, structural human ecology is distinguished by its emphasis on demographic factors as drivers of environmental degradation and the inclusion of biophysical factors as control variables, such as biogeography and climate, in analyses (York et al. 2003a). Therefore, structural human ecology is a suitable theoretical basis for the present study which seeks to identify the effects of population aging on the natural environment from a human ecological perspective.

Structural human ecology has made progress in developing an adequate statistical method for the testing of human ecological theory, STIRPAT, which is logically compatible with POET, but more suitable for statistical modeling. POET is difficult to operationalize because the factors *P*, *O*, *E*, and *T* are all reciprocally linked and therefore the model is underidentified (Dietz and Rosa 1994). The POET model, however, is recognized as remaining a useful heuristic device for thinking about the social dynamics of environmental degradation.

The STIRPAT model and its precursor, IPAT, are discussed in more depth in the methods and data section. In the next section, the existing literature on the effects of population age structure and population aging on the environment is reviewed.

LITERATURE REVIEW AND HYPOTHESES

Population aging is a simple term for a complex process. The main driver of population aging is decreasing fertility (Vallin 2002). It is for this reason that as the proportion of elderly increases, the proportion of young decreases (Grigsby and Olshansky 1989). An aging population, as the term indicates, is first and foremost characterized by a high proportion of elderly (i.e., age 65 and up). However, an aging population also exhibits a low proportion of children (i.e., age 0 to 14) and, conversely, a high proportion of adults (i.e., age 15 and up). The main point here is that multiple components of population age structure are affected by the process of population aging. For this reason the following literature review begins with those cross-national studies that have considered age structure in general as a driver of environmental load.

In a cross-national study, York et al. (2003a) found that the nondependent (i.e., age 15 to 64) proportion of the population has a positive, statistically significant effect on total ecological footprint.[1] This finding was based on circa 1996 data for 142 countries and was consistent across several differently specified models. In addition, Shi's (2003) analysis of pooled data on 93 countries from 1975 to 1996 indicated that the nondependent proportion of population has a positive, statistically significant effect on carbon dioxide emissions. These two studies indicate that age structure is an important factor affecting environmental impacts at the national level. However, the findings of these studies may lead one to conclude that population aging negatively affects environmental impacts since it contributes to increases in the dependent proportion of the population. That is, if the proportion of the population age 15 to 64 decreases because

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[1] The ecological footprint is a measure of environmental load; it is described in depth in the methods and data section below.

the proportion of those age 65 and over increases, it would follow that the reduction of the non-dependent share of the population would result in a lowering of total environmental load. This conclusion may not be appropriate, however, because the dependent proportion of the population is composed of both those under age 15 and those over age 64. It is not at all apparent that changes in the proportions of these two groups affect environmental load in the same way. However, by directly analyzing the effect of population aging on environmental outcomes, the relationship between changes in the youth share of the population and environmental impacts is also assessed, because these two demographic characteristics are highly negatively correlated.

The only cross-national study that has directly assessed population aging's effect on an environmental impact indicator is York's (2007) article on energy consumption. York analyzed cross-sectional time-series data spanning 1960 to 2000 for fourteen European Union member countries. His findings indicate that population aging, measured as the percentage of the population age 65 and up, has a positive, significant effect on total commercial energy consumption. He concludes that older populations consume more energy than younger ones, controlling for other factors.

The main limitation of York's study is that it focuses solely on European Union nations. The relationship between population and energy consumption revealed in this study could possibly be due to socio-cultural factors specific to this regional bloc; therefore it may not be generalizable. Furthermore, it leaves open the question of whether population aging has similar effects on the consumption levels of other natural resources. These two issues are addressed in the present study in which I analyze data from 87 countries to assess the relationship between population aging and three consumption-based measures of environmental load, including an energy consumption measure.

Additional research has uncovered links between age structure and a specific type of energy consumption- transportation. Liddle's (2004) analysis of OECD (Organization for Economic Cooperation and Development) member countries indicates that countries with younger age structures have higher per capita road energy use. In contrast, York (2003) found that countries with a higher proportion of people age 15 and up (i.e., older populations) have larger passenger car fleets.[2] These two findings indicate that population aging might lead to lower intensity of energy consumption for transportation, but at the same time more extensive use of automobiles (i.e., more cars being driven less). Changes in patterns and levels of transportation energy consumption is, therefore, one way in which population aging may affect country-level environmental loads. Below, several other pertinent links between population aging and the environment are discussed.

As the POET model (described in the last section) indicates, demographic changes may have direct as well as indirect effects on the environment. These indirect effects could operate through changes in social organization, other demographic characteristics, or technology. The present study addresses population aging as a structural factor, thus, analyzing each proximate factor connecting population aging to environmental outcomes is beyond the scope of this paper. Therefore, while I review some of these factors below, in order to illustrate some of the possible linkages between aging and the environment, the subsequent analysis does not include these factors.

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[2] As discussed on p.11, older populations are also characterized by a high proportion of adults (age 15 and up).

The most direct relationship between population aging and environmental impacts concerns food consumption. Adults require a higher caloric intake than children (Hassan et al. 2005:224). This is because adults are typically bigger than children. Since in aging populations adults outnumber children, an older population will, *ceteris paribus*, require more food energy than a younger population. Freese (1997b:197) observes that larger populations require more resources than smaller populations because a "population is so much biomass." Similarly, an older population of a given size is more biomass than a younger population of the same size, because there are more large people (i.e., adults) in the older population. This may increase demand on food-producing ecosystems. There are also several proximate factors that indirectly link population aging to country-level environmental loads.

First, older populations tend to have smaller average household sizes (MacKellar et al. 1995). There are several reasons for this: decreasing family size; increased longevity; the mortality gap between men and women; and the ability of the elderly to live alone. First, since population aging is driven by low fertility, older populations have smaller families and therefore, smaller households (Bongaarts 2001). Next, offspring live for longer periods of time outside of their parents' home due to increased longevity. Furthermore, the mortality gap between men and women results in a high number of widows who live alone (Keilman 2003). Finally, the elderly are more likely than other age groups to live alone, especially, of course, children (O'Neill and Chen 2002).

Research has shown that households exhibit economies of scale in per capita food, transportation, and energy consumption as well as other areas (Nelson 1988; Moll et al. 2005; O'Neill and Chen 2002). As Keilman (2003) notes, this occurs because, among other things, members of a household share space, furniture, appliances, transportation, and energy. Therefore, smaller households result in higher per capita consumption of resources. For instance, U.S. data show that in 1993-1994 two-person households consumed 17% less energy per capita than single occupant households (Keilman 2003). In addition, Liu et al. (2003) note that as average household size decreases, the number of housing units required for a given population size increases, thereby raising the consumption levels of land and materials (e.g., wood, concrete, and steel) for housing construction.

This has become a significant concern in the population-environment literature due to current demographic trends. The global average for household size has been decreasing over the years. From 1970 to 2000, the average household size in less developed countries decreased from 5.1 to 4.4 and from 3.2 to 2.5 for more developed countries (Keilman 2003).

The household has been demonstrated to be an important subject for research on the link between demographic factors, consumption patterns, and environmental impacts (Bin and Dowlatabadi 2003; Keilman 2003; Liu et al. 2003). When taking into account indirect household energy consumption (i.e., energy used in production and distribution of goods and services for households and in disposal of consumer waste) as well as direct energy consumption (i.e., utilities, transportation), 70-80% of a nation's energy consumption and greenhouse gas emissions is related to household consumption (Moll et al. 2005). For example, in the U.S., household consumption accounts for 85% of total U.S. energy consumption (Bin and Dowlatabadi 2003). Furthermore, Spangenberg and Lorek (2002) identified housing, transportation and mobility, and food and nutrition as the three most significant household consumption clusters; approximately 70% of an economy's energy consumption and material extraction can be attributed to these three clusters.

Therefore, by decreasing average household sizes, population aging may indirectly result in higher per capita consumption levels, leading to larger environmental impacts at the national level. Indeed, previous research has linked average household size to a number of different environmental outcomes. Liddle (2004) found that countries with smaller average households exhibit higher per capita road energy use. Furthermore, higher average household size is associated with lower carbon dioxide emissions (Cole and Neumayer 2004).

In addition, population aging has macroeconomic effects as well as social structural effects. These effects on the economy (including changes in the ratio of capital to labor and the composition of consumption demand), transportation infrastructure, and the provision of social services likely affect the environmental load of a country (York 2007; Börsch-Supan 2006). These structural changes due to population aging may affect the environmental load, but as of yet, the research remains scant on these topics.

In conclusion, the research findings reviewed in this section mainly point to population aging having a positive effect on the environmental load. However, only one study has directly tested this relationship and that study focused on energy consumption (York 2007). In the present study, I test three hypotheses on three different consumption-based measures of environmental load, one to determine if population aging affects total environmental load, and the other two to determine if this effect differs among loads resulting from different categories of resource consumption:

Hypothesis 1: Older populations have higher total environmental loads.

Hypothesis 2: Older populations have higher environmental loads resulting from food, fiber, and timber consumption.

Hypothesis 3: Older populations have higher environmental loads resulting from energy consumption.

METHODS AND DATA

STIRPAT

To test the three hypotheses, I use the STIRPAT statistical model developed by Dietz and Rosa (1994) and further elaborated by York, Rosa, and Dietz (2003b). This model has been shown to be a useful tool for testing hypotheses derived from environmental sociological theory (York et al. 2003a).

STIRPAT stands for Stochastic Impacts by Regression on Population, Affluence, and Technology. It is a reformulation of the IPAT environmental accounting equation that resulted from the debate in the 1970s on the drivers of human-caused environmental impacts between Erlich and Holdren on one side and Commoner on the other (York et al. 2003b).

In the IPAT equation (I=P·A·T), environmental impacts (I) are the product of population size (P), per capita consumption, or affluence (A), and impact per quantity of consumption, or technology (T). The POET model and the IPAT equation are logically compatible (Dunlap et al. 1994). However, IPAT reduces the social organization (O) element of POET to simply affluence (A). Dunlap et al. (1994) argue that this oversimplifies the social organization element of the POET model. In addition, the IPAT equation shares the POET model's inability to be used for hypothesis testing; both remain useful only as heuristic devices for thinking about the drivers of environmental impacts.

In its functional form as a mathematical identity, IPAT can not be used to test hypotheses because the effects of each driver are assumed to be proportional (York et al. 2003c). The stochastic reformulation, STIRPAT, improves upon this model by allowing for the testing of hypotheses concerning specific variables by estimating the parameters for each variable, rather than assuming proportional effects (Rosa et al. 2004). This approach "link[s] the venerable but analytically limited IPAT model of environmental impact to contemporary social science theory and methods" (Dietz et al. 2001:5).

The STIRPAT model has the following basic specification:

$$I_i=aP_i^bA_i^cT_i^de_i$$

In this model, the multiplicative logic of IPAT is retained, but the exponents of *P*, *A*, and *T* (b, c, and d, respectively) are estimated rather than assumed. Since there is no widely accepted single measure for *T*, it is typically included in the error term (York et al. 2003c). Furthermore, York et al. (2003b) suggest log-transforming each variable so that the coefficients provided by the STIRPAT model can be interpreted in terms of ecological elasticity (i.e., the coefficients will indicate the percentage increase in *I* for a 1% increase in that specific driver while holding all others constant). As defined by York et al. (2003b:354), ecological elasticity is "the responsiveness or sensitivity of environmental impacts to a change in any one of the driving forces."

After taking logarithms and including *T* in the error term, the STIRPAT model takes the following form (York et al. 2003b):

$$\ln I_i = a + b(\ln P_i) + c(\ln A_i) + e$$

The subscript, *i*, indicates that the values of *I*, *P*, and *A* vary across observations, which in this study are countries; *a* is the constant and *e* is the error term.

While this is the basic form of the STIRPAT model, Dietz and Rosa (1994:287) note that "it is possible to substitute a vector of cultural, political and social structural variables for T and examine the net effect of each on I." STIRPAT thus corrects the IPAT equation's reduction of the POET model's emphasis on social organization (O) to merely affluence (A). In addition, demographic characteristics other than population size may also be included in the model as drivers (Dietz and Rosa 1994). The STIRPAT model is quite flexible in allowing any theoretically appropriate variables to be included and tested in the model (e.g., York et al. 2003a). In the next section, the variables that are included in the analysis for the present study are described.

I use both ordinary least-squares (OLS) and robust regression to estimate the STIRPAT models using cross-sectional data for 87 countries. A number of researchers have suggested that robust regression should be used in conjunction with OLS when analyzing cross-national data because robust regression is less susceptible to influential cases and to violations of the assumption of normality in the error term (Dietz, Frey, and Kalof 1987; Jorgenson 2006). Robust regression downweights observations that have larger residuals and thus provides more conservative estimates. I perform robust regression (iteratively reweighted least squares) with Huber and biweight functions tuned for 95% Gaussian efficiency (Hamilton 2003).

Ecological Footprint

The indicator for environmental load used in this study is the ecological footprint. The ecological footprint is an appropriate measure because it is firmly grounded in human ecology theory. For one, it is based on Catton's (1987) concept of the human load on the environment (Rees 1996; Wackernagel and Rees 1996). Furthermore, it takes into account all three of the functions of ecosystems for humans: resource supply, waste absorption, and living space (Wackernagel et al. 2002). Though the ecological footprint has its critics, it remains a useful indicator of country-level environmental loads.[3] Indeed, it has become a widely used measure of anthropogenic environmental pressure in sociological research (e.g., Jorgenson 2003; Rice 2007; York et al. 2003a).

The ecological footprint is defined by Rees (2002:6) as "the area of land and water ecosystems required on a continuous basis to produce the resources that the population consumes, and to assimilate (some of) the wastes that the population produces, wherever on Earth the relevant land/water may be located." The EF is a consumption-based measure, which means that only the resources consumed within a country are attributed to its footprint; a country's exports are attributed to the footprints of the countries which import them (i.e., consumption = production + imports – exports). This is particularly useful because, due to international trade, the environmental consequences of consumption often occur far from the site of consumption (Jorgenson and Rice 2005).

One major analytical advantage of the EF is that it combines the consumption of many different types of resources, the use of land for living space, and the production of wastes into a single common metric: global hectares. A global hectare is a hectare of biologically productive land or water adjusted to the world average productivity (Rees 2006).[4] This makes it possible to analyze the overall environmental load of a country using a single indicator (York et al. 2003a)

The EF can be broken down into three subcomponents: the food, fiber, and timber footprint; the energy footprint; and the built-up land footprint (Global Footprint Network

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[3] For a review of criticisms of the ecological footprint and answers to them, see Rees (2006).

[4] A hectare is equal to approximately 2.471 acres.

2005).[5] The *food, fiber, and timber footprint* is the total land and water area, in global hectares, required for cropland to grow the food, livestock feed, fiber, rubber, and oils; grazing land to produce the meat, hides, wool, and dairy products; forest land to harvest the wood fiber and timber; and fishing grounds for the freshwater and marine fish and other seafood that a country consumes. The *energy footprint* is the total land area, in global hectares, required for forest land to provide the fuelwood and the land area needed for the sequestration of the carbon dioxide emissions, primarily from burning fossil fuels, for a country's energy consumption.[6] The energy footprint also includes the energy required to produce (i.e., embodied energy) the energy-intensive non-organic products consumed in a country (Rees 2006). The *built-up land footprint* is the total land area required to accommodate infrastructure for transportation, housing, hydro-electric dams, and industrial production in a country (Wackernagel et al. 2002:9266).

The EF is not a fully comprehensive measure of environmental load. It does not include all wastes in its calculations; only carbon dioxide emissions and organic nutrients such as nitrates and phosphates are included (Rees 2006). Furthermore, not all resources are accounted for in the EF due to insufficient data (Wackernagel et al. 2002). Thus the EF likely underestimates the human load on the environment (Rees 2006). Despite these limitations, the EF remains a valid indicator and is widely used.

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[5] On average, for the 87 countries analyzed here, each subcomponent contributes to the ecological footprint as follows: food, fiber, and timber footprint, 46.27%; energy footprint, 50.12%; built-up land footprint, 3.61%.

[6] Nuclear energy is treated as fossil fuel energy in EF calculations because of inconclusive data about its long-term ecological effects. Hydro-electric power is included in the built-up land footprint.

Dependent Variables

As Jorgenson, Rice and Crowe (2005) observe, very few studies concerning the ecological footprint have examined whether the structural causes vary for different subcomponents of the footprint (for an exception, see Rosa et al. 2004). In this study, I analyze the total ecological footprint and two of the subcomponents, the total energy footprint and the total food, fiber, and timber footprint, in order to determine whether population aging has similar effects on all three variables.[7] Data from 2003 are used because it is the most recent publicly available data for the ecological footprint. All ecological footprint data are from Global Footprint Network (2006).

Total ecological footprint, *2003* is the dependent variable in Model 1. This variable measures the overall environmental load of a country. Total ecological footprint was obtained by multiplying the per capita footprints provided by Global Footprint Network (2006) by total population for the year 2003, which was gathered from World Bank (2007). This variable is log-transformed.[8]

Total food, fiber, and timber footprint, *2003* is the dependent variable in Model 2. This variable measures the environmental load resulting from a country's consumption of food, fiber, and timber.[9] Total food, fiber, and timber footprint is calculated from the per capita footprint in the same manner as total ecological footprint. This variable is log-transformed.

Total energy footprint, *2003* is the dependent variable in Model 3. This variable measures the environmental load resulting from a country's energy consumption

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[7] I do not separately analyze the built-up land footprint; it is a relatively minor subcomponent which, as previously noted, only makes up 3.61% of the total ecological footprint on average for this sample.

[8] All log transformations are natural logarithms (i.e., with a base of *e*).

[9] Wood used for fuel is not included here because it is part of the energy footprint.

(including fossil fuels, nuclear energy, and embodied energy in goods). The energy footprint differs from York's (2007) energy consumption measure in that the energy footprint includes the embodied energy of traded goods; therefore, it is possible that the findings for this variable may differ. Total energy footprint is calculated from energy footprint per capita in the same manner as total ecological footprint. This variable is log-transformed.

Independent Variables

Aging Index, 2003 is the indicator of population aging used in this study.[10] The aging index is the ratio of the population age 65 and up to the population under age 15 (Gavrilov and Heuveline 2003). Previous research has used the percentage of population age 65 and up (York 2007). Aging index is used in this study because demographers have described it as the best measure of population aging because it takes into account the two population groups most altered by this demographic process (Grigsby and Olshanksy 1989; Shyrock and Siegel 1980). This variable was calculated, using demographic data from World Bank (2007), by dividing the percentage of population age 65 and up by the percentage of population under age 15. This variable is log-transformed.

Total population, 2003 controls for the size of the population. Research has indicated that population size is a significant driver of total ecological footprint (York et al. 2003a; Rosa et al. 2004). Data for this variable are from World Bank (2007). This variable is log-transformed.

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[10] The aging index is also commonly referred to as the elder-child ratio or the aged-to-youth ratio.

Gross national income per capita (in US$), 2003 controls for affluence (or per capita wealth).[11] This variable is from United Nations Statistics Division (2008a) and is log-transformed. This variable was divided by total population to obtain the per capita measurement. Gross national income (GNI) is equal to "[Gross domestic product] less net taxes on production and imports, less compensation of employees and property income payable to the rest of the world plus the corresponding items receivable from the rest of the world" (United Nations Statistics Division 2008b). In other words, GNI takes into account only the income that is kept within a country while GDP takes into account all of the economic activity within a country no matter where the income generated goes. It is debatable which of the two is the best measure of affluence, but as a control variable for affluence, GNI works as well as GDP; for instance, Shandra (2007) uses GNI to control for economic development in his cross-national analysis of deforestation.

Percent urban, 2003 controls for the percentage of a country's population living in urban areas. Percent urban is included as a control variable because it has been found to have a positive, significant impact on total ecological footprint (York et al 2003a). Data are from World Bank (2007). This variable is log-transformed.

Land area per capita (in hectares), 2003 controls for the basic biogeographical characteristic of countries. Structural human ecologists argue that biogeographical features, such as land area per capita, condition countries' use of resources (Dietz et al. 2007). Previous research has found that land area per capita has a positive, significant effect on total ecological footprint (York et al. 2003a; Dietz et al. 2007). These data are from World Resources Institute (2005) and this variable is log-transformed.

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[11] Gross national income is identical to gross national product.

Latitude controls for climate. Structural human ecologists argue that climate influences countries' use of natural resources, especially energy consumption; countries in colder climates (i.e., higher latitudes) are expected to use more natural resources and previous research has provided evidence of this (Dietz et al. 2007; York et al. 2003a). Latitude is measured as a dummy variable with three categories: tropical (latitude less than 30˚); arctic (greater than 55˚); and temperate (30˚ to 55˚). This is the same criteria used by York et al. (2003a). Tropical is the omitted category in all models. These data are from Central Intelligence Agency (2008).

Table 1. Descriptive Statistics of Variables Included in Analyses

Variable	Mean	Standard Deviation
Total Ecological Footprint (ln)	17.331	1.558
Total Food Fiber and Timber Footprint (ln)	16.504	1.485
Total Energy Footprint (ln)	16.564	1.761
Population (ln)	16.315	1.411
Gross National Income p.c., US$(ln)	8.568	1.203
Percent Urban (ln)	4.141	.352
Land p.c. (ln)	-6.328	1.298
Latitude		
Arctic	.103	.306
Temperate	.506	.503
Tropical	.391	.491
Aging Index (ln)	3.512	.950

Note: All variables are from the year 2003; N=87

Sample

The sample for this study consists of all middle and high income countries for which the necessary data are available.[12] Low income countries are excluded from the sample for three reasons. First, the vast majority of these countries have only relatively recently entered the fertility transition and thus have not begun to experience substantial population aging. This clustering of young populations in the low income countries resulted in excessive multicollinearity in models (not reported here) which included them. Second, there is the issue of aging index reflecting not just age structure, but also a country's development level if low income countries are included in the sample, thus obscuring the effect of population age structure. Third, many of the described mechanisms linking population aging to environmental impacts may not be operative in the lowest income countries due to economic constraints. These problems are mitigated by including only middle and high income countries in the sample.

The data are for the year 2003, which is the most recent publicly available data for the ecological footprint. The size of the sample is somewhat restricted by the number of countries for which the ecological footprint (EF) is calculated; countries with populations under one million are excluded and sufficient data to calculate the EF were lacking for three other countries: Bhutan, Oman, and Singapore (Global Footprint Network 2006). Thus, the EF is available for 147 countries, 88 of which are middle and high income. However, in the EF data, Belgium and Luxembourg are treated as one country and therefore have one ecological footprint. In order to keep both in the analysis, all other data for Belgium and Luxembourg are aggregated (i.e., these two countries are treated as

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[12] I used the criterion set forth in World Bank (2003) to identify low income countries: 2002 GNI per capita (World Bank Atlas method) below $736.

one country in the analysis). Furthermore, due to the lack of GNI data for Serbia and Montenegro, it is excluded from the analysis. This gives a total sample of 87 observations. A list of all countries included in the analysis is provided in Appendix A. Table 1 provides descriptive statistics for all variables included in the analyses.

RESULTS AND DISCUSSION

Bivariate correlations of all variables included in the analyses are presented in Table 2. Results of the analyses are presented in Table 3, Table 4, and Table 5. All three models provide a good fit: the lowest R^2 of the OLS models is .8778. According to the correlation matrix in Table 2, multicollinearity does not appear to be a problem. Furthermore, the highest VIF in all models is 2.83, with a mean of 1.82, which is well within accepted guidelines (Chatterjee, Hadi, and Price 2000; York et al. 2003a). A Breusch-Pagan/Cook-Weisberg test for heteroskedasticity was employed, and the results for all three models indicated the presence of heteroskedasticity. As a result, robust standard errors are reported for the OLS coefficients of all models.

As discussed in the methods section, a number of researchers have suggested that robust regression should be used alongside OLS when analyzing cross-national data because it is less susceptible to influential cases (Dietz et al. 1987; Jorgenson 2006). Robust regression downweights cases that have larger residuals and thus provides more conservative estimates; this method is more efficient than outlier deletion (Dietz et al. 1987). I report both OLS and robust regression results for each model. The findings differ between OLS and robust regression in all models, indicating the presence of influential observations. Since the robust regression results are less biased in the face of outliers, I focus on them in this section. To simplify the discussion of the results I identify only the robust regression models with the number associated with the hypothesis each tests (e.g., Model 1 refers to the robust regression model testing Hypothesis 1).

Table 2. Correlations for all Variables Included in the Analyses.

	1	2	3	4	5	6	7	8	9	10
1. Total Ecological Footprint(ln)	1.000									
2. Food, Fiber and Timber Footprint (ln)	-	1.000								
3. Energy Footprint (ln)	-	-	1.000							
4. Population (ln)	.919	.947	.845	1.000						
5. Gross National Income p.c., PPP (ln)	.336	.251	.395	-.006	1.000					
6. Percent Urban (ln)	.315	.294	.292	.162	.388	1.000				
7. Land p.c. (ln)	-.067	-.035	-.118	-.084	-.125	.179	1.000			
8. Arctic	.034	.049	.031	-.125	.286	.151	.257	1.000		
9. Temperate	.246	.205	.293	.167	.185	.179	-.326	-.344	1.000	
10. Aging Index (ln)	.304	.286	.339	.097	.549	.187	-.242	.335	.497	1.000

Note: Correlations of variables not included in the same model are omitted; N=87.

Table 3. OLS and Robust Regression Coefficients Predicting Total Ecological Footprint (Ln), 2003.

	Model I	
	OLS[a]	Robust
Population (ln)	1.010 (.021)***	1.027 (.022)***
GNI, p.c. in US$(ln)	0.380 (.054)***	0.310 (.032)***
Percent Urban (ln)	0.085 (.120)	0.081 (.099)
Land p.c. (ln)	0.059 (.033)*	0.073 (.026)***
Latitude[b]		
Arctic	0.389 (.155)**	0.340 (.139)**
Temperate	0.246 (.112)**	0.207 (.089)**
Aging Index (ln)	-0.003 (.091)	0.111 (.052)**
Intercept	-2.940 (.550)***	-3.027 (.479)***
N	87	
R^2	.9628	
Mean/High VIF	1.82/2.83	

[a] Robust standard errors are reported in parentheses for OLS estimates.
[b] Tropical is the excluded category.
* $p \leq .10$; ** $p \leq .05$; *** $p \leq .01$ (two-tailed tests).

Table 3 examines the effect of aging index on total ecological footprint. As discussed above, the OLS and robust regression results differ substantially. This indicates the presence of unduly influential observations.[13] The robust regression results show that aging index has a positive effect on total ecological footprint, significant at the .05 level. This finding supports Hypothesis 1. The coefficient for aging index is .111, which means that a 1% increase in aging index is associated with a .111% increase in total ecological footprint, controlling for all other variables. The control variables in this model are all significant and in the direction suggested by previous research, except for percent urban.

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[13] Using Cook's Distance diagnostic statistics, United Arab Emirates, Trinidad and Tobago, and Kuwait were identified as the unduly influential observations.

Table 4. OLS and Robust Regression Coefficients Predicting Total Food, Fiber, and Timber Footprint (Ln), 2003.

		Model II
	OLS[a]	Robust
Population (ln)	0.995 (.019)***	1.003 (.019)***
GNI, p.c. in US$(ln)	0.217 (.038)***	0.185 (.028)***
Percent Urban (ln)	0.135 (.073)*	0.120 (.085)
Land p.c. (ln)	0.073 (.027)***	0.065 (.022)***
Latitude[b]		
Arctic	0.389 (.105)***	0.419 (.119)***
Temperate	0.068 (.069)	0.049 (.076)
Aging Index (ln)	0.109 (.060)*	0.149 (.045)***
Intercept	-2.640 (.379)***	-2.599 (.410)***
N R^2 Mean/High VIF	87 .9746 1.82/2.83	

[a] Robust standard errors are reported in parentheses for OLS estimates.
[b] Tropical is the excluded category.
* p≤.10; ** p≤.05; *** p≤.01 (two-tailed tests).

Table 4 examines the effect of aging index on total food, fiber, and timber footprint. The OLS and robust regression results differ somewhat here. Mainly, the p-value is lower and the magnitude of the coefficient is higher for aging index; but also percent urban loses significance in the robust regression model. All other coefficients and p-values are substantively the same. These differences indicate that outliers are present, but are not heavily affecting the results.[14] The robust regression results support Hypothesis 2: aging index has a positive effect, significant at the .01 level, on total food, fiber, and timber footprint. The coefficient of aging index is .149, which means that a 1%

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[14] Cook's Distance diagnostic statistics identified United Arab Emirates, Kuwait, and New Zealand as overly influential cases.

increase in aging index is associated with a .149% increase in total food, fiber, and timber footprint, controlling for all other variables. Of the control variables, the only two that are not significant are percent urban and temperate; all others are significant and in the direction suggested by previous research.

Table 5. OLS and Robust Regression Coefficients Predicting Total Energy Footprint (Ln), 2003.

	Model III	
	OLS[a]	Robust
Population (ln)	1.047 (.046)***	1.045 (.042)***
GNI, p.c. in US$(ln)	0.543 (.091)***	0.403 (.063)***
Percent Urban (ln)	-0.119 (.221)	0.044 (.192)
Land p.c. (ln)	0.023 (.063)	0.077 (.051)
Latitude[b]		
Arctic	0.535 (.330)	0.393 (.270)
Temperate	0.515 (.217)	0.400 (.174)**
Aging Index (ln)	-0.078 (.149)	0.109 (.101)
Intercept	-4.733 (.986)***	-4.760 (.933)***
N	87	
R^2	.8778	
Mean/High VIF	1.82/2.83	

[a] Robust standard errors are reported in parentheses for OLS estimates.
[b] Tropical is the excluded category.
* $p \leq .10$; ** $p \leq .05$; *** $p \leq .01$ (two-tailed tests).

Table 5 examines the effect of aging index on total energy footprint. The OLS and robust regression coefficients differ mainly with regards to the coefficient and p-value for temperate, indicating the presence of overly influential observations.[15] The robust regression results show aging index as having no significant effect on total energy footprint. Hypothesis 3, therefore, is not supported. This finding contradicts York's

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[15] Cook's Distance diagnostic statistics identified United Arab Emirates, Kuwait, and Peru as unduly influential cases.

(2007) finding of a positive, significant relationship between population aging and energy consumption. Of the control variables, only three are significant: population, GNI per capita, and temperate; the rest are not significant

Overall, I find support for two of the three hypotheses. These findings indicate that the effect of population aging on the ecological footprint does vary across the two major subcomponents analyzed here. In general, population aging increases the environmental load of countries, controlling for other factors. However, it appears that most of this effect is the result of aging index increasing food, fiber, and timber footprint.

Total population size is clearly a major driver of environmental load. In all three models, population is significant at the .01 level and has the largest coefficient. The coefficient is approximately 1.0 in all models, which means that for a 1% increase in population, total environmental load increases by 1%. In other words, the ecological elasticity of population is unit elastic. If population doubles, the environmental load doubles. These findings support previous research (York et al. 2003a).

Gross national income per capita is also a major driver in all three models. This variable is significant at the .01 level in all models. The coefficient of GNI is largest for total energy footprint (Model 3) and smallest for total food, fiber, and timber footprint (Model 2).

Percent urban is not significant in any of the three robust regression models at any level. This finding contradicts most previous research (York et al. 2003a; York 2007; Jorgenson 2003). However, at least one other study has found percent urban to be nonsignificant when predicting ecological footprint (Dietz et al. 2007). In that study, age structure and land area per capita were controlled for as they are in the present study. It is possible that the effect of percent urban is conditioned by these variables. Another likely possibility is that the effect of percent urban is being captured by GNI per capita. Further research should address these findings.

Land area per capita is significant at the .01 level in Models 1 and 2, but is non-significant in Model 3. This suggests that land area per capita has a positive significant impact on total ecological footprint mainly because of its positive impact on total food, fiber, and timber footprint. Countries with more land per capita consume more food, fiber, and timber, but not more energy, all else equal.

The effects of latitude differ among the three models. The analysis of total ecological footprint (Model 1) indicates that, controlling for all other variables, arctic and temperate countries have a larger footprint than tropical countries. Arctic countries have a 40.5% larger footprint than tropical countries while temperate countries have a 23% larger footprint than tropical countries.[16] Findings for Model 2 indicate that arctic countries have a 52% larger total food, fiber, and timber footprint than tropical countries, while temperate countries are not statistically different from tropical ones. Findings for Model 3 show that temperate countries have 49.2% higher total energy footprint than tropical countries while arctic countries are not statistically different from tropical countries. The non-significance of temperate in Model 2 and arctic in Model 3 may be due to collinearity with aging index (for temperate) and GNI per capita (for arctic). Overall, however, these findings support structural human ecology's argument that climate significantly affects countries' consumption of natural resources, net of other factors.

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[16] I calculate these figures by taking the anti-log (e^x) of the coefficients for arctic and temperate; see York et al. (2003b:357) for more details on interpreting dummy variables in STIRPAT elasticity models.

In conclusion, the findings support Hypothesis 1 and 2, while Hypothesis 3 received no support. Population aging has a significant, positive effect on the environmental load of countries. This effect appears to be mainly the result of aging index's effect on the load resulting from food, fiber, and timber consumption rather than the load resulting from energy consumption, on which it has no significant effect. Additional findings support structural human ecology arguments that biogeography and climate are important factors conditioning the environmental load of countries.

CONCLUSION

The purpose of this study was to determine what the effect of population aging is on the environmental loads of countries, measured as ecological footprints. Two of my three hypotheses were supported. The findings indicate that older populations have larger ecological footprints, controlling for other factors. This effect was found to vary between the major subcomponents of the ecological footprint; older populations consume more food, fiber, and timber but not energy.

Demographic characteristics other than population size have not received much attention in research on the social dynamics of environmental impacts. The findings of this study increase knowledge of the role of population age structure in shaping the environmental loads of countries. Specific contributions of this study include finding evidence that: (1) population aging increases the environmental loads of countries and (2) this effect differs for the load resulting from energy consumption and the load resulting from food, fiber, and timber consumption. These findings are important because population aging is a global and unprecedented phenomenon and knowing what the environmental implications of this demographic revolution are is essential for understanding contemporary population-environment issues.

Additional findings support structural human ecologists’ argument that biogeography and climate are important factors in shaping countries’ environmental loads. It was found that arctic and temperate countries have larger total ecological footprints than tropical countries. Additionally, arctic countries have larger total food, fiber, and timber footprints than tropical countries, while temperate countries have larger total energy footprints than tropical countries, net of other factors. Furthermore, land area per capita was found to have a significant positive effect on the total ecological footprint and total food, fiber, and timber footprint, but not on the total energy footprint. Overall, these findings indicate that the effects of climate and biogeography vary for different types of resources; this should be taken into account in future research.

The finding that aging index has no effect on total energy footprint contradicts York's (2007) finding that older populations consume more energy. It is important to consider why the present study does not reveal such a relationship. I put forth two speculative reasons for this anomaly. First, whereas York used panel data on European Union countries, I used cross-sectional data on all middle and high income countries for which I had data. My results therefore, may reflect that the mechanisms linking population aging and energy consumption are not existent in all countries. Second, my energy consumption measure, total energy footprint, includes embodied energy in traded goods, whereas York's does not. Thus, the energy consumption measure used by York, commercial energy use, does not assign energy consumption to the importing country, but rather to the exporting country. The role of embodied energy should be considered in future research.

The findings of this study open up some questions for future research. First, the proximate factors or mechanisms linking population aging to the environmental load are not well known. I reviewed here several, but our understanding of each are far from complete. Future research should work to identify these mechanisms and determine how they operate. Second, this study contradicted York's (2007) findings that older populations consume more energy. However, it remains unclear why this is so. It would be useful to conduct further research to clarify how, and under what conditions, population aging affects energy consumption. One useful route might be to analyze separately whether population aging affects transportation energy consumption and residential energy consumption. By disaggregating energy consumption, we could gain more understanding of the relationship between population aging and energy consumption, and the mechanisms that link them.

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APPENDIX A: LIST OF COUNTRIES INCLUDED IN SAMPLE

Albania
Algeria
Argentina
Armenia
Australia
Austria
Belarus
Belgium and Luxembourg
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Bulgaria
Canada
Chile
China
Colombia
Costa Rica
Croatia
Cuba
Czech Republic
Denmark
Dominican Republic
Ecuador
Egypt, Arab Rep.
El Salvador
Estonia
Finland
France
Gabon
Germany
Greece
Guatemala
Honduras
Hungary
Iran
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Korea, Rep.
Kuwait
Latvia
Lebanon
Libya
Lithuania
Macedonia, FYR
Malaysia
Mauritius
Mexico
Morocco
Namibia
Netherlands
New Zealand
Norway
Panama
Paraguay
Peru
Philippines
Poland
Portugal
Romania
Russian Federation
Saudi Arabia
Slovak Republic
Slovenia
South Africa
Spain
Sri Lanka
Swaziland
Sweden
Switzerland
Syrian Arab Republic
Thailand
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Venezuela