Faster, Sooner, and More Simultaneously: How Recent Road and Air Transportation CO_2 Emission Trends in Developing Countries Differ From Historic Trends in the United States

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This article explores historic carbon dioxide (CO_2) emission trends from road and air transportation of the United States and 26 developing and industrializing nations. It is argued that environmental trends in the newest industrializing countries do not follow the more sequential and long-term shifts experienced by the United States. The empirical analysis demonstrates that all rapidly developing countries analyzed exhibit comparable transportation CO_2 emissions per capita levels at lower levels of income per capita, or sooner, than the United States. For some developing countries (the most rapidly growing), these emissions also grow faster over time. Last, there is clear evidence that emissions from road and air sources are occurring more simultaneously compared to the United States. This pattern of changes is in contrast with the common interpretation of environmental Kuznets curves, which suggest that countries follow similar patterns of environmental impacts over time as they develop economically.

Keywords: *transport; carbon dioxide emissions; energy; developing nations; industrializing nations; United States; historical trends; development pattern; Kuznets curve; time-space telescoping*

1.0. Introduction

It is often suggested that the path by which developing countries experience environmental challenges will match those of the developed world. For example, a 1998 *Economist* article on development and the environment started out with a description of the environmental problems in English cities of the mid-1800s written by Friedrich Engels and suggested that conditions in developing cities now are similar to those of Manchester, United Kingdom, in the 19th century (Litvin, 1998). This viewpoint implicitly suggests that developing nations will grow out of their environmental problems, as did many rich nations before them.

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The environmental Kuznets curve (EKC) theory posits a positive correlation between a society's environmental impact and economic growth in the early stages of development and the reverse relationship (i.e., a negative correlation) in later stages. As one EKC scholar has put it, "*ceteris paribus*, in their process of development, individual countries experience income and emission situations lying on one and the same EKC" (Dinda, 2004, p. 434). The simplicity of this relationship, often described as an inverted-U shape, has spawned a large and growing literature. As the number of EKC studies grows, however, the debate continues as to whether the relationship represents a real pattern within growing economies and what drives the outcomes (for reviews, see Dinda, 2004; Ekins, 1997; Panayotou, 2000; Stern, 1998, 2004). It is often assumed that economic growth itself will bring vast improvements to the environment. Although this view is not highly accepted by EKC experts, it still retains influence in both theoretical and policy circles (e.g., see Lomborg, 2001).

This study explores a set of little-studied effects that have come to define the development-environment relationship in rapidly developing countries. Specifically, it examines the impacts of shifting time- and space-related effects on carbon dioxide (CO_2) emissions of developing countries. *Time-space telescoping* theory suggests that the current development context has caused developing countries to experience environmental challenges (in this case, road- and air-transportation CO_2 emissions) at lower levels of income with faster growth and in a more simultaneous fashion than those of a developed country. We compare historic transportation CO_2 emissions in the United States, an example of a developed country with a history of high motor vehicle and air transportation fuel consumption, with those in a set of developing countries from different parts of the world. We argue that if the hypotheses hold true for comparison with the United States, then they will probably hold for other industrialized countries. Our study focuses on fuel consumption by three transportation technologies: passenger vehicles (including automobiles, motorbikes, motorcycles, etc.), heavy-duty trucks, and airplanes.

In the following sections we (a) elaborate on our theory, (b) frame the specific case study that reflects the theory, (c) describe the data collection and analyses, (d) describe our results in the context of our hypotheses, and (e) discuss implications of the findings and suggest directions for future work.

2.0. Theoretical Background: Time-Space Effects

Recent EKC studies conclude both that there is a more diverse set of effects defining the development-environment relationship than originally understood and that these effects change over time. For example, countries that industrialize later in time may leapfrog over more advanced countries by purchasing technologies that are newer and cleaner than those found in nations that industrialized previously (Lindmark, 2004; Stern, 2004). The result of these effects helps to explain the convergence of CO_2 emission intensities between developed and developing countries (Lindmark, 2004). Moreover, these studies suggest that although synchronic cross-sectional comparisons of nations display EKC-type behavior, the processes creating the relationships change over time thus making them contingent upon history and therefore necessitating research into comparative long-term trends (Lekakis, 2000; Lindmark, 2002, 2004).

The context under which national economies expand now is different from that of the past in several ways. The speed of economic development is faster (Crafts, 2000; see also Table 1[1]). The relationship between many sociodemographic drivers and the environment is also different (e.g., see Millennium Ecosystem Assessment, 2003, chapter 4). For example, although population growth has been a significant driving force in environmental change over the past 200 years, many scholars suggest that the end of world population growth is now on the horizon (Lutz, Sanderson, & Scherbov, 2004). Global population growth peaked at 2.1% in the late 1960s, has since fallen to 1.35%, and is expected to continue falling. Moreover, the efficiency and effectiveness of the transmission of goods, services, and knowledge across geographical space has improved, thereby making these items available at lower costs, in greater quantities, and across a larger geographic span than ever before (Drucker, 1986).

This study is underpinned by the perception that current development conditions are significantly different from those of that past and that countries undergoing contemporary development have distinctly different sets of environmental challenges than their predecessors. Such differences can be attributed to time-related and space-related effects. Time-related effects include technological improvements with associated decreases in environmental impacts. Some have suggested that technological improvements drive the downward turn in the inverted-U shape of the EKC: Mature economies slow down in growth thereby allowing technology-driven reductions in environmental intensity to overcome scale effects (Stern, 2004).

Space-related effects include processes that concentrate increasingly diverse phenomena in geographically uneven patterns. This concentration may be of economic activity, people (in cities), or specific types of people (e.g., poor people in slums). Globalization, for example, has

1. Supplemental data may be found online at http://jed.sagepub.com/content/vol14/issue1/.

space-related effects by concentrating certain types of infrastructure (communication, transportation, financial and business services, headquarters of transnational companies) in specific locations around the world (e.g., world cities; Friedmann, 1986; Friedmann & Wolff, 1982; Lo & Yeung, 1998; Sassen, 1991) and through new transportation and communications technologies that have transformed the ability of information, goods, and services to move across space (e.g., see Dicken, 1998).

Previous studies examining a combination of these two effects suggest changes in the constraints placed upon human activities by both time and space and thus how human activities affect the environment. Janelle (1968, 1969), for example, identified the increasing speed at which people move across space and its effects on economic activity and social relations. His term, *time-space convergence*, defined the process of decreasing the friction of distance between places resulting in decreasing average amounts of time needed to travel between them. Processes creating time-space convergence have not only made the world smaller but also have increased our ability to affect a larger number of different environments around the world at a more intense rate. Harvey (1989) focused on what he called *time-space compression* as underpinning the emergence of the postmodern condition. Time-space compression includes processes that revolutionize the objective qualities of space and time and alter, sometimes in quite radical ways, how we represent the world to ourselves. Smith (1990) and Smith and Lee (1993) have identified changing patterns of risk over time, as traditional risks (e.g., those associated with local indoor air pollution) have now combined with more modern risks (e.g., those associated with inhaling pesticides) generating a new genre of mixed risks in low-income countries. These notions demonstrate changes in the speed and location of activities over time, which have thus transformed human behaviors and their resultant environmental impacts.

This article suggests another time-space effect that shapes the contemporary relationship between development and the environment in the developing world. We note a collapsing, compression, and telescoping of previously experienced sequential development patterns so that they occur *sooner*, *faster*, and *more simultaneously* (Marcotullio, 2004a). We call the processes that create these shifts time-space telescoping.

The three effects related to time-space telescoping can be explained as follows. Because of the availability of new technologies, environmental impacts are experienced at lower levels of income in developing countries than in developed countries. This is largely because advanced technology was not available to the developed world at the time. As the price of the technology falls and becomes more accessible, it spreads faster. The concentration of high-income subpopulations within developing cities further facilitates the spread of technology. Increasingly, developing countries face a greater diversity of environmental challenges within concentrated geographic spaces. For example, within almost any city or large urban area of the rapidly developing world, it is not uncommon to have populations without running water, sanitation, and solid waste disposal living close to modern high-rise apartments with all of the latest conveniences.

Recent work has explored the notion of collapsed, compressed, and telescoped transitions within developing countries and their cities (Marcotullio, 2002, 2004b; Marcotullio & Lee, 2003; Marcotullio, Rothenberg, & Nakahari, 2003). Further empirical work, such as the analyses in this article, is necessary to confirm, refine, or refute these concepts.

3.0. Case Study: Comparing Historical U.S. Road and Air Transport CO_2 Emissions With Recent Experience in the Developing/Industrializing World

This study compares per capita CO_2 emissions[2] from road and air transportation technologies (passenger vehicles, trucks, and airplanes) in developing and developed nations (in this case, the United States). We have three hypotheses:

Hypothesis 1: Sooner: Road and air fuel transportation CO_2 emissions in rapidly developing countries appear at lower levels of gross domestic product (GDP) per capita than in the United States. That is, considering all historic values of GDP in a developing country and in the United States (denoted as GDP_{DC} and GDP_{US}, respectively) and all historic values of CO_2 emissions in a developing country and in the United States (E_{DC} and E_{US}, respectively), there exist times when $E_{DC} = E_{US}$ and $GDP_{DC} < GDP_{US}$.

Hypothesis 2: Faster: Road and air transportation CO_2 emissions from rapidly developing countries demonstrate a steeper slope representing growth over time than that of the United States at similar ranges of income. That is, when $GDP_{US,\ Time\ X} = GDP_{DC,\ Time\ M}$ and $GDP_{US,\ Time\ Y} = GDP_{DC,\ Time\ N}$, then during the period from year M to year N for developing countries and during the period year X to year Y for the United States, the rates of emissions growth (as determined by least squares) obey $dE_{DC}/dt > dE_{US}/dt$.

Hypothesis 3: More simultaneously: Road and air CO_2 emissions are shared more evenly among technologies in rapidly developing countries at similar levels of GDP per capita than in the United States. That is, the adoption of various transportation technologies has happened more simulta-

2. The choice of pollutant affects the analysis. CO_2 emissions mirror fuel consumption: Only changes in the number of vehicles, the average distance traveled per vehicle per year, and the average fuel efficiency affect CO_2 emissions. In contrast to other vehicle pollutants, such as nitrogen oxides (NO_x), lead, organic compounds, and particulate matter, there are not extant emission reduction technologies for CO_2. An analysis of a pollutant other than CO_2 might yield results that differ from those presented in this article.

neously in rapidly developing nations than in the United States. Quantitatively, we express this hypothesis via a scalar fuel diversity index, I (defined in detail in § 4.4) that increases from 0 to 1 as the mix of fuel used becomes more varied. The more simultaneously condition holds if $I_{DC} > I_{US}$.

Clearly, other choices of hypotheses are possible to demonstrate these phenomena. For instance, the empirical data could be expanded to include rail transport so as to cover the entire transportation sector. We do not address this technology in the current analysis because (a) this is technically challenging given data availability and the need to characterize time trends in the CO_2 intensity of electricity for 27 nations and (b) it is not necessary to include rail transport for the current purpose of initial demonstration of sooner, faster, and more simultaneously. To whit, considering one sector, air, in addition to road transport is sufficient to establish more simultaneous adoption of transport technologies. Also, it could be more appropriate to frame the hypotheses in terms of the average experience of rich industrialized countries (i.e., include Europe). However, collecting and estimating these historical data is challenging and beyond the scope of the current research and also, in this case, is not required to address our intended point. The United States is clearly an extreme case of historically rapid adoption of road and air transport. If the hypotheses work for the United States, the contrast should be even more extreme if the European experience is considered. Lastly, the rates of change for the faster hypothesis could alternatively be defined via endpoint differences instead of least squares (i.e., $E_{DC,\ Time\ Y} - E_{DC,\ Time\ X}/(\text{Year Y} - \text{Year X}) > E_{US,\ Time\ N} - E_{DC,\ Time\ M}/(\text{Year N} - \text{Year M})$). However, we found that the inequality relationship we are testing is not sensitive to which definition is used and proceed with the least squares version.

The hypotheses are tested by comparing the experiences of 26 developing/industrializing nations to that of the United States. This article evaluates emission trends with respect to the three hypotheses, leaving for future work an exploration of the specific factors inducing the sooner, faster, and more simultaneously conditions.

4.0. Data and Methods

Our analyses incorporate three main types of data: (a) historic (1905-2000) road and air CO_2 emissions in the United States, (b) recent (1960-2000) road and air CO_2 emissions in developing and other countries, and (c) per capita income (Geary-Khamis international dollars) for all countries analyzed. Below, we describe our data sources and analyses methods.

4.1. EMISSIONS IN THE UNITED STATES

CO_2 emissions are estimated based on an emission factor (U.S. Department of Energy & Energy Information Agency, 2004) and the quantity of fuel consumed. This approach provides actual estimates of emissions rather than values that are proxies for emissions. Readily available estimates of disaggregated transportation CO_2 emissions for these fuels begin with year 1949 (U.S. Department of Energy, 2002). For our analysis, we needed pre-1949 emission estimates, because current and recent levels of wealth in the developing world compare to those of the Unites States before 1949. The appendix[3] provides details of how we estimated these pre-1949 CO_2 emissions in the United States. For all three technologies (gasoline-powered passenger vehicles, diesel-powered heavy-duty trucks, and airplanes), our CO_2 emission estimates for the United States begin approximately when the technology ceased to be a novelty and entered the mainstream marketplace. For vehicles, this year was in 1905; for airplanes, the year was 1926. The automobile was invented in the late 1800s. The Ford Model A came out in 1903, and the first Ford Model T sold in 1908. Airplanes were invented in December 1903. Commercial airlines for passenger transportation began in the United States from 1925 to 1930, and in the 1930s, they became a mainstream industry.

4.2. EMISSIONS IN RAPIDLY DEVELOPING AND OTHER NATIONS

The next set of data collected was for rapidly developing and other countries. Here, two questions were raised: (a) What countries should be characterized as rapidly developing? and (b) How could their experience be differentiated from nonrapidly developing nations?

There is a wide literature on high-growth countries (e.g., see World Bank, 1993). In this article, rapid developers are defined as those with GDP growth between 1970 and 2000 of more than 116%, which is twice the world average growth of 58% during this period. Intermediate developers are defined as countries having GDP growth during 1970 and 2000 of between 58% and 116%. Nonrapid developers are defined as countries with GDP growth during the same period of less than 58%. Countries corresponding to these labels[4] are listed in Table 2. These three

3. Supplemental data may be found online at http://jed.sagepub.com/content/vol14/issue1/.

4. Nonrapid developing countries included Albania, Argentina, Czechoslovakia, Hungary, Philippines, Poland, Romania, and Yugoslavia. Note that two of these countries, Argentina and the Philippines, are usually considered rapid developers within their regions—Latin America and Southeast Asia, respectively. Therefore, these two were included with their regional groups but separated later to test for differences in their experiences from the rapidly developing countries.

Table 2
Country Gross Domestic Product (GDP) Per Capita Descriptive Statistics (Over Period 1971-2000, in 1990 Geary-Khamis International $)

	GDP Per Capita				
	Minimum	*Maximum*	*Range*	*Average*	*Percentage Change 1971-2000*
Nonrapid developers					
Albania	1,451	2,660	1,209	2,132	27
Argentina	6,436	9,123	2,688	7,774	13
Czech Republic	7,819	9,047	1,228	8,451	2
Former Yugoslavia	2,437	6,559	4,122	4,541	3
Hungary	3,649	7,138	3,488	5,721	36
Philippines	1,808	2,425	618	2,182	32
Poland	3,215	7,215	4,000	5,176	53
Romania	1,844	4,215	2,371	3,284	–7
Intermediate developers					
Brazil	3,279	5,556	2,277	4,819	69
Chile	4,323	9,841	5,518	6,436	74
Japan	3,986	21,069	17,083	13,342	110
Mexico	4,363	7,218	2,856	5,955	65
Rapid developers					
China	799	3,425	2,627	1,710	329
Egypt	1,283	2,920	1,637	2,187	128
Hong Kong	5,968	21,503	15,535	14,089	260
India	834	1,910	1,076	1,197	123
Indonesia	1,235	3,655	2,419	2,272	159
Ireland	4,282	22,015	17,733	9,388	246
Korea	2,522	14,343	11,821	7,120	461
Malaysia	2,180	7,874	5,694	4,677	353
Portugal	2,956	14,022	11,067	7,962	139
Singapore	4,909	22,207	17,298	12,405	353
Taiwan	3,324	16,642	13,318	8,811	267
Thailand	1,725	6,877	5,152	3,836	401
Tunisia	1,982	4,538	2,556	3,166	129
Vietnam	710	1,790	1,080	1,048	137
United States	4,561	28,129	23,569	12,405	58

Source: Calculated from data provided by Maddison (2001).

groups provide samples to further test the hypotheses that rapid developers are special cases.

Our analysis of transportation CO_2 emissions includes gasoline, diesel, and aviation fuels for use in different vehicles (which we shorthand as passenger vehicles, trucks, and airplanes) in the above set of countries. CO_2 emissions are calculated in the same manner for developing countries as for the United States from emission factors (U.S. Department of Energy & Energy Information Agency, 2004) and the quantity of fuel consumed. Fuel consumption is available for the three transportation uses (on-road gasoline, on-road diesel, and aviation fuel[5]) beginning in 1960 or 1970 for each country (International Energy Agency, 2002a, 2002b).

Consumption of alternative transportation fuels such as bio-fuels, electricity, heavy oils, natural gas, and liquid petroleum gas were excluded from the analysis. For most countries, gasoline, diesel, and aviation fuels describe air and road transport closely. For the United States, only 0.14% of fuels come from other sources. Argentina and Brazil have an average contribution of alternative fuels over the interval of 1970 to 2000 of approximately 1.8% and 2.1%, respectively. This is not enough to change their rates of growth to be faster than those experienced by the United States across comparable income ranges. Korea and Japan, on the other hand, have an average 6.4% and 2.9% contribution from alternative fuels over the interval from 1960 to 2000—mainly liquid petroleum gas used in taxis. For these two countries, our estimation should be thought of as a lower bound. Assertions regarding the sooner, faster, and more simultaneously conditions holding for the lower bound also apply to the full sum; thus, the omission of alternative fuels for these countries also does not affect our main conclusions.

4.3. PER CAPITA INCOME

Our analysis requires converting the CO_2 emissions estimates from time series (i.e., indexed by calendar year) to development-level series (i.e., indexed by constant-dollar per capita GDP). Maddison (2001; see also Maddison, 2004) provides GDP in 1990 Geary-Khamis international dollars.[6] These data were chosen for several reasons. First, data sets typically used for international comparative analyses (e.g., World Bank and Penn World Tables) do not include information before 1950 and therefore are inadequate for our analyses, which use comparative data beginning in 1905. Second, although an alternate purchasing power parity (PPP) method exists (the Eleto-Köves-Szulc method), the U.S. Bureau of Labor Statistics, which has been preparing comparative analysis tables for many years, states that "there appear to be no compelling reasons to select one set of PPPs as preferable to another" (International Labour Office, 2004, ¶ 2). Third, the Maddison (1995, 2001) data have already

5. Aviation fuel includes aviation gasoline, gasoline-type jet fuel, and kerosene-type jet fuel.

6. The Geary-Khamis dollar results from an aggregation method in which international prices (reflecting relative category values) and country purchasing power parity (depicting relative country price levels) are estimated simultaneously from a system of linear equations. It has the properties of base-country invariance, matrix consistency, and transitivity (see United Nations, 2003).

been used in a number of studies including those comparing the development patterns between developing and developed countries (Crafts, 2000) and in EKC studies (e.g., see Lindmark, 2004).

Using the Geary-Khamis data set, the U.S. per capita income was approximately $4,500 from 1905 to 1908, roughly $10,000 in 1950, and about $28,000 in 2000 (all GDP and per capita GDP values presented in this work are in Geary-Khamis 1990 international dollars). The analyses for Hypothesis 2, faster, was restricted to countries with a minimum current income of more than $4,500 because of the necessity of making valid comparisons with the United States' experiences (see Table 2 for the countries and their range of incomes). For some countries (e.g., Japan, Ireland, and Portugal), there are several decades of overlapping incomes. For some countries (e.g., Thailand), income levels reach about $4,500 only during the late 1980s. For these countries, there is little more than a decade of data points for which to perform analyses. Finally, some countries (e.g., China, India, and Vietnam) do not yet have income levels of $4,500. These countries could not be included in the faster analysis.

4.4. TESTING THE HYPOTHESES

Figure 1 illustrates how results confirming the hypotheses would appear in graphical form. As shown in the first graph, sooner means that a country exhibits transportation CO_2 emissions to the left of (i.e., at lower levels of GDP per capita than) the United States's curve, at least in early stages of development. In the second graph, faster is illustrated by the regression line for the developing country's hypothetical history of CO_2 emissions having a steeper slope than the slope for the comparable regression line for the United States comparing similar GDP per capita ranges.[7] The third graph illustrates the more simultaneously condition when the Marshall Fuel Diversity Index is higher for the developing country than for the United States (see below for the definition of this index). Our analyses include tests for individual countries and country groupings based upon similar development characteristics.[8] These groups facilitated the presentation of material in figures. Tables include all nations used in the analyses.

7. The residuals for time-series data tend to be highly correlated, and therefore, the coefficients may be biased. However, as mentioned in Section 3, less sophisticated analyses (e.g., simple rates of change over the respective periods of time and between highest and lowest values over the time period) demonstrate similar results.

8. Groupings consisted of four members of the Association of Southeast Nations (ASEAN: Indonesia, Malaysia, the Philippines, and Thailand), the four Asian Tigers (Hong Kong, Singapore, South Korea, and Taiwan–Chinese Taipei), Latin American nations (Argentina, Brazil, Chile, and Mexico), North African nations (Egypt and Tunisia), European peripheral rapid developers (Ireland and Portugal), and Central and Eastern European countries (Albania, Czech Republic, the former Yugoslavia, Hungary, Poland, and Romania).

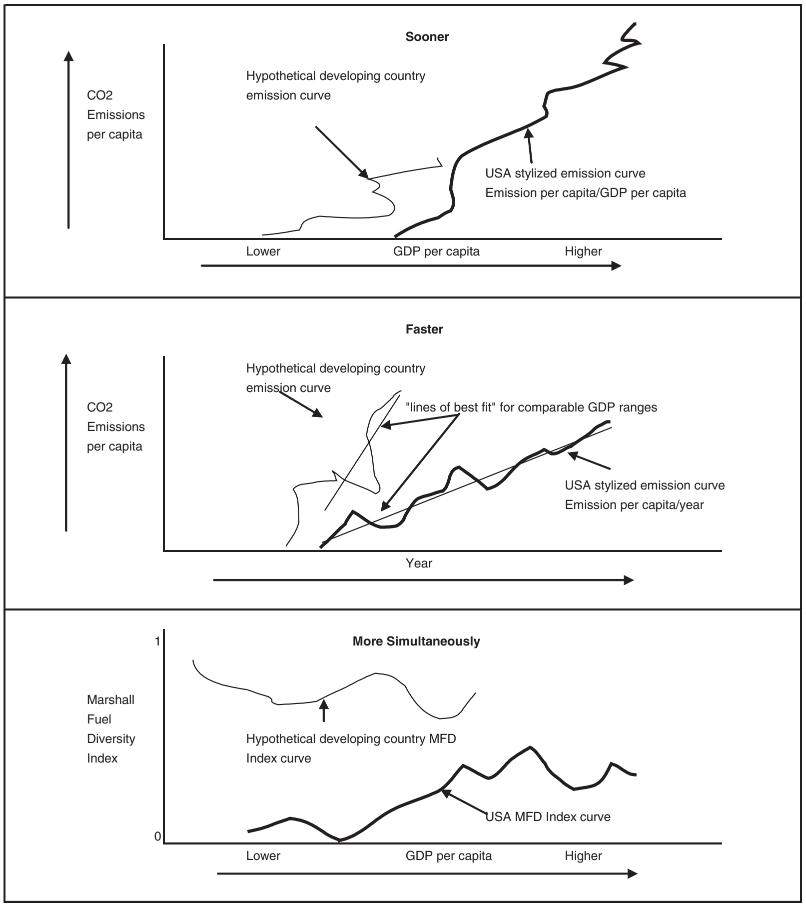

Figure 1: Graphical Illustration of Sooner, Faster, and More Simultaneously Hypotheses

We test the sooner hypothesis by identifying whether the nations in our database experienced CO_2 emissions at lower development levels than those of the United States. We used a binary test by recording whether there were CO_2 emissions at income levels less than those of the United States when its transportation systems began to consume quantities of petroleum-based fuels.

To test the second hypothesis, we compare rates of change (over time) in transportation CO_2 emissions. We make these comparisons at similar income ranges between individual countries and the United States to adequately compare histories.

To test the third hypothesis, we developed an index that combines CO_2 emissions data for the three fuels in a way that indicates the extent to which one or two fuels dominate the overall source of emissions. The Marshall Fuel Diversity Index, which is adapted from the Herfindhal measure of market concentration, is defined as:

$$\text{Marshall Fuel Diversity } I = \frac{1}{2}\left(\frac{(x+y+z)^2}{x^2+y^2+z^2} - 1\right).$$

Here, x, y, and z are the CO_2 emissions from the three transportation technologies, respectively. The Marshall Fuel Diversity Index takes on values between 0 and 1. If only one fuel is being used ($x > 0; y = z = 0$), the value of the index is 0. If two fuels have the same CO_2 emissions and the third fuel is not being used ($x = y; z = 0$), the index value is 0.5. If CO_2 emissions from all three fuels are equal ($x = y = z$), the index value is 1. The indices are averaged over the course of the sample years and compared. Standard t tests demonstrate whether the differences between the samples of each country are significantly different from those of the United States.

5.0. Comparison of Rapidly Developing Countries With the United States

In this section, we test the three hypotheses outlined in Section 3. We find strong support for the first and third hypotheses (sooner and more simultaneously). Results for the second hypothesis (faster) are mixed.

5.1. SOONER

The evidence considered in this study supports the sooner hypothesis. Figure 2 presents the levels of total CO_2 emissions of the country groupings and that of Japan compared with those of the United States. The figure illustrates the emergence of transportation CO_2 emissions at lower GDP per capita levels in developing countries than in the United States. Similar to Figure 2, the separate trends of each of the three transportation technologies (passenger vehicles, trucks, and aviation technologies) also support the hypothesis (for country-level statistics, see Table 3[9]). Figure 2 and Table 3 demonstrate higher levels of CO_2 emissions from almost all countries in almost all fuels at similar or lower levels of GDP than that of the United States.

9. Supplemental data may be found online at http://jed.sagepub.com/content/vol14/issue1/.

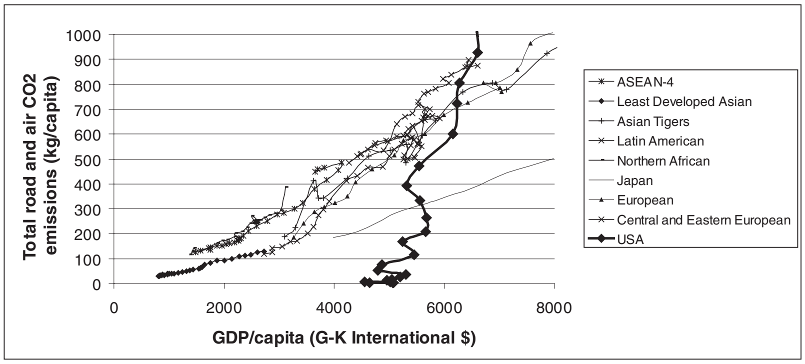

Figure 2: Sooner—Total Road and Air Transportation Carbon Dioxide (CO_2) Emissions (kg/capita) Per Gross Domestic Product (GDP) Per Capita

Note: ASEAN-4 = Association of Southeast Nations, including Indonesia, Malaysia, the Philippines, and Thailand; G-K = Geary-Khamis.

5.2 FASTER

Table 4 presents the rate of change in CO_2 emissions over time, testing the faster hypothesis. Rates of change were calculated by finding the least squares slopes of emission increases over time intervals in the test country and for the United States with the starting point and endpoint of the same GDP per capita. Results are mixed in that only four of the eight rapid developers demonstrated faster growth of total road and air transportation CO_2 emissions (Hong Kong, Malaysia, Singapore, and South Korea). Two rapid developers came close to but remained below U.S. rates of change (Taiwan and Thailand), and two experienced between 50% and 60% of U.S. speed in road and air transportation CO_2 emission growth (Ireland and Portugal). It is worth noting that only the most rapid developers (all of which are Asian nations) demonstrated the faster trend for total transportation CO_2 emissions growth compared to that of the United States. All other countries either from the intermediate or nonrapid development group did not. For diesel and aviation fuel, many of the developing countries demonstrate faster growth trends than those of the United States. Gasoline consumption in the United States, however, overwhelmed similar consumption in all other countries.

Figure 3 demonstrates graphically the comparisons of total road and air transportation CO_2 emissions over time for those countries that exhibited faster total growth rates: Hong Kong, Malaysia, Singapore, and South Korea. These figures demonstrate some important findings. First, the developing countries' curves are always shorter than those of the United States because they grew more rapidly and hence needed less

Table 4

Comparison of Increases Over Time in Carbon Dioxide (kg/Capita/Year) Between Selected Countries and the United States

						United States				
Country	*Time Interval*	*Aviation*	*Diesel*	*Gasoline*	*Total*	*Time Interval*	*Aviation*	*Diesel*	*Gasoline*	*Total*
Rapid developers										
Hong Kong	1971-2000	42.92	49.23	3.25	95.40	1905-1986	11.60	12.09	58.98	82.69
Ireland	1968-2000	4.86	24.95	14.92	44.73	1905-1987	11.71	12.27	58.58	82.60
Malaysia	1989-2000	13.32	18.99	45.99	78.30	1905-1940	0.27	4.00	53.68	57.95
Portugal	1968-2000	1.61	25.39	16.83	43.81	1905-1965	7.31	7.34	55.55	70.20
Singapore	1971-2000	60.59	21.11	7.51	89.21	1905-1987	11.71	12.27	58.58	82.56
South Korea	1983-2000	6.71	34.70	34.75	76.20	1905-1938	0.23	21.11	51.34	55.22
Taiwan	1976-2000	9.14	12.33	40.88	62.35	1905-1975	10.70	9.17	59.77	79.64
Thailand	1990-2000	3.30	24.91	12.97	41.18	1905-1939	0.24	3.89	53.00	57.13
Intermediate developers										
Brazil	1977-2000	0.40	6.77	0.06	7.23	1905-1935	0.20	3.19	46.59	49.98
Chile	1971-2000	2.93	13.74	4.56	21.22	1905-1950	1.30	4.68	52.80	58.79
Japan	1962-2000	6.36	19.61	21.81	47.77	1905-1985	11.52	11.90	59.41	82.84
Mexico	1972-2000	1.57	13.98	11.78	27.32	1905-1940	0.27	4.00	53.68	57.95
Nonrapid developers										
Argentina	1971-2000	2.43	7.08	–6.28	3.24	1905-1949	1.08	4.54	54.43	59.03
Hungary	1974-1991	1.61	6.47	9.30	17.41	1905-1938	0.22	3.82	53.21	57.26
Poland	1966-2000	0.48	1.74	6.64	8.85	1905-1940	0.27	4.00	53.68	57.95

Note: Total is slope of sum, not sum of slopes, and thus does not add. Intervals indicate periods of similar gross domestic product per capita levels.

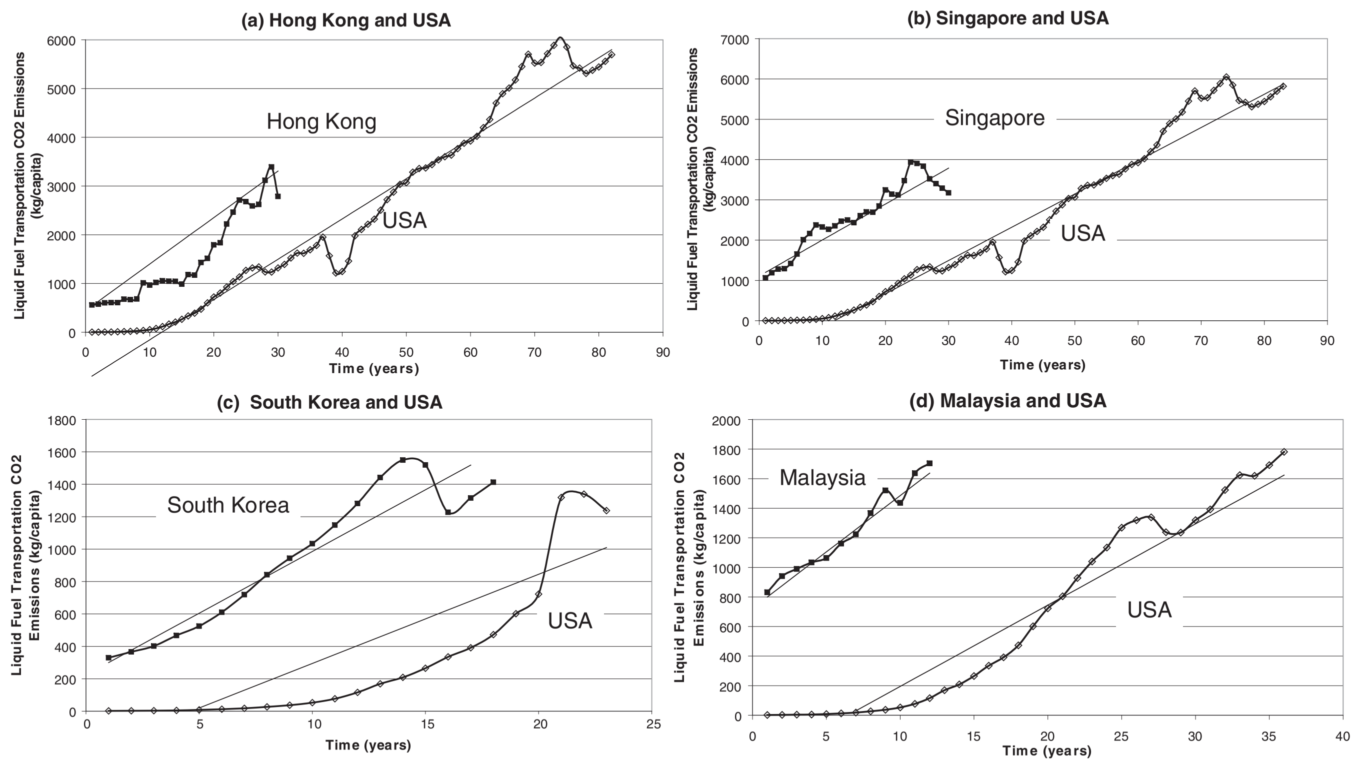

Figure 3: Faster—Comparisons for the Four Most Rapid Developers
Note: Solid line reflects least squares slope.

time to achieve similar levels of GDP as the United States. Second, they appear above the U.S. curve as a result of the sooner pattern (i.e., they experienced higher levels of CO_2 emissions at lower levels of income). Third, the slopes of the curves for the rapidly developing countries are slightly steeper than those of the United States.

The direct reasons for these differences vary between countries. Malaysia and South Korea had increases in both aviation and road emissions. Malaysia had strong increases in its gasoline consumption, whereas South Korea had lower rates of increases in gasoline but had equal rates of increases in diesel consumption. Hong Kong and Singapore had extremely high rates of increases in their aviation-related fuel consumption, and Hong Kong also experienced high growth in diesel fuel consumption. Right behind these countries were Taiwan and Thailand, both of which had fast rates of increases but not faster than the United States. Taiwan's growth was due in large part to increases in gasoline consumption, whereas Thailand had higher rates of diesel consumption than gasoline. These last countries also underwent rapid development (particularly over the last few decades) and have seen their motorized transportation systems increase.

The rates of change for CO_2 emissions over time for other countries are significantly lower than those of the United States, as was expected by the theory (only rapid developers are expected to experience time-space telescoping). The fact that some rapidly developing countries have faster growth of CO_2 emissions is notable considering that the United States may have shown the fastest growth in transport emissions among developed countries. The faster trend may be even more pronounced if these countries were compared to an average of developed countries' emissions levels.

Last, note that our definition of *faster* is based on comparing growth over time periods with fixed GDP per capita endpoints. One could also argue that the time allowed to respond to a problem can be as important as wealth. This suggests that setting the intervals to a fixed number, for example, 30 years, is a reasonable alternative definition of faster. It is clear from the graphs in Figure 3 that the typical slope for the United States is lower for the first 30 years as opposed to longer intervals; thus, growth of emissions from developing countries is even faster (relatively) under this alternative definition.

In addition to measuring rates of change over time according to the faster hypothesis, we also estimate rates of change over development level (i.e., the change in CO_2 emissions per change in per capita GDP). Table 5 presents the results for individual countries. All developing countries studied demonstrated lower growth of CO_2 emissions per GDP increase than that of the United States. We speculate that this result is heavily influenced by our choice of the United States as the basis of comparison. The historic rise of the internal combustion engine in the

Table 5

Comparison of Increases Over Gross Domestic Product (GDP) in Carbon Dioxide (kg/Capita/$1000 GDP/Capita) Between Selected Countries and the United States

						United States				
Country	*Time Interval*	*Aviation*	*Diesel*	*Gasoline*	*Total*	*Time Interval*	*Aviation*	*Diesel*	*Gasoline*	*Total*
Rapid developers										
Hong Kong	1971-2000	71.98	76.38	5.37	154.00	1905-1986	58.11	61.07	270.00	390.00
Ireland	1968-2000	14.14	72.44	39.01	126.00	1905-1987	57.68	61.07	264.00	383.00
Malaysia	1989-2000	44.30	60.67	146.00	251.00	1905-1940	2.29	42.98	561.00	606.00
Portugal	1968-2000	5.62	96.72	65.08	167.00	1905-1965	48.10	45.41	318.00	412.00
Singapore	1971-2000	98.18	32.83	12.09	143.00	1905-1987	57.68	61.07	264.00	383.00
South Korea	1983-2000	12.51	64.78	63.59	140.88	1905-1938	1.69	41.48	556.00	599.00
Taiwan	1976-2000	19.43	24.73	83.00	127.00	1905-1975	64.32	52.42	317.00	434.00
Thailand	1990-2000	16.87	140.00	58.89	216.00	1905-1939	1.62	41.86	554.00	597.00
Intermediate developers										
Brazil	1977-2000	13.47	147.00	23.29	184.00	1905-1935	0.17	18.32	231.00	250.00
Chile	1971-2000	16.77	67.82	39.65	124.00	1905-1950	13.38	37.61	387.00	438.00
Japan	1962-2000	49.15	14.19	44.26	108.00	1905-1985	58.62	61.03	277.00	397.00
Mexico	1972-2000	21.34	115.00	161.00	296.00	1905-1940	2.29	42.98	561.00	606.00
Nonrapid developers										
Argentina	1971-2000	24.80	83.39	–19.50	88.73	1905-1949	13.98	42.33	453.00	509.00
Hungary	1974-1991	19.11	103.00	124.00	247.00	1905-1938	1.07	37.21	510.68	548.95
Poland	1966-2000	4.23	29.48	74.12	108.00	1905-1940	2.29	42.98	561.18	606.45

Note: Total is slope of sum, not sum of slopes, and thus does not add. Intervals indicate periods of similar GDP per capita levels.

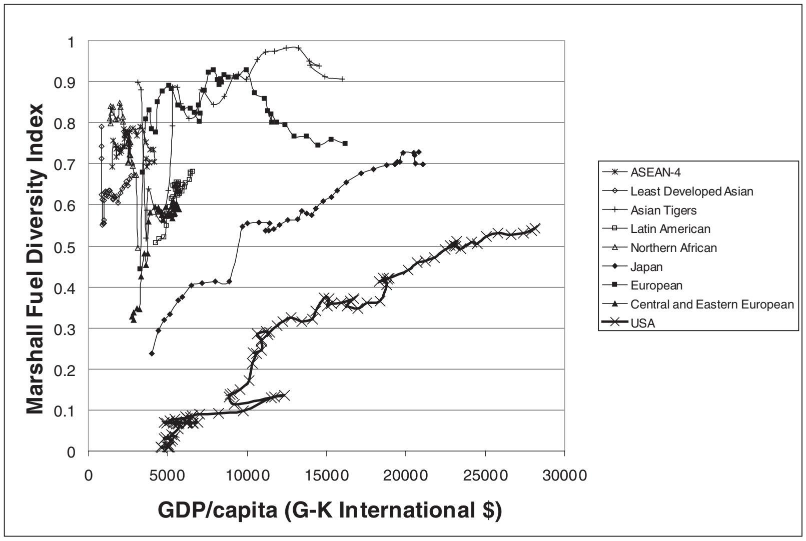

Figure 4: More Simultaneously—Comparison of Fuel Diversity Consumption by Gross Domestic Product (GDP)/Capita

Note: ASEAN-4 = Association of Southeast Nations, including Indonesia, Malaysia, the Philippines, and Thailand; G-K = Geary-Khamis.

United States was extremely rapid. Because gasoline accounts for the majority of total emissions, total emissions do increase at a greater rate of GDP per capita in developing countries than in the United States. If we were to use an industrialized country other than the United States as our basis of comparison, we may have less difference in the changes of CO_2 emissions per GDP increase between developed and developing countries. Interpretation and possible implications of these results are discussed further in Section 6.

One interesting aside is that among the sample, many of the most rapid developers had faster growth of CO_2 emissions than Japan, and all of the most recent developers have CO_2 emission curves lying above that of Japan for any given similar GDP per capita level. These observations further support the hypothesis that a comparison with an average for the developed world may demonstrate different findings than those presented in this article.

5.3. MORE SIMULTANEOUSLY

Investigation of the more simultaneously condition yielded results supporting the hypothesis for all countries. The results of calculating the Marshall Fuel Diversity Index for all countries, presented in Figure 4, illustrate that developing countries had a more diverse consumption of fuels as compared to the United States (see also Table 6[10]). In all cases, the United States had a lower diversity index (i.e., consumption was more dominated by one or two fuels) than the other countries. Standard *t* tests indicate that these differences are statistically significant. Similar to the differences demonstrated by the sooner analyses, whether the country is rapidly developing does not make a difference in the outcome.

6.0. Implications of the Findings

The implications of the research have both theoretical and practical importance. Although the theoretical perspective is rooted in geography and theories on technology growth and diffusion, the results have implications for the economics-rooted EKC approach. In its most basic form, the identification of processes related to time-space telescoping provides a counterpoint perspective to effects typically discussed in the EKC literature. In its simplest form, the EKC model suggests that all countries will grow out of their environmental problems with increasing wealth when technology effects overcome both income and scale effects. The time-space telescoping perspective suggests that, in contrast, the different development milieu under which countries are now growing can potentially exacerbate the scale and complexity of environmental challenges.

Consistency among countries in support of the sooner and more simultaneously hypotheses suggests that our findings likely extend beyond the countries we analyzed. Our results imply that relative to the U.S. experience, developing countries face greater environmental challenges at a time when there are fewer economic resources available to address them. We expect this tension to be particularly problematic for countries that are not growing economically. Waiting to respond to environmental issues may be disadvantageous, because challenges can become more complex over time (see below). One issue of concern is a *lock-in* to specific path dependent development trajectories. For example, Barter (2004) suggested that Kuala Lumpur, Malaysia, is already entrenching higher uses of the motor vehicle through its urban structure designs.

In this regard, important lessons can be learned from the United States, if not all industrialized countries. As it developed and embraced the automobile, production of the technology, development of infrastructure, and planning laws enhanced its growth. It is now difficult for the country to get off the automobile-dependent development pathway, as changes would need to be made in not only automobile consumption but in a variety of different ways in which the society is organized. Some

10. Supplemental data may be found online at http://jed.sagepub.com/content/vol14/issue1/.

suggest that carbon lock-in or fossil-fuel-based path-dependent development defines contemporary industrial economies (Unruh, 2000).

This study further implies that in the case of all rapidly developing countries and their cities, there is not only less breathing room for decision makers to change direction once a specific pathway is taken but also greater complexity of conditions to address. This translates into a greater potential threat for locking into development pathways that may not respond quickly to changes in governmental regulation later. That is, the situation can become even more complex when the more simultaneously results apply.

The results of the faster analyses were mixed. The study does show that rapid developers experienced slightly faster increases in transportation CO_2 emissions in terms of changes over time than the United States. The results for Hong Kong and Singapore reflect high consumption of aviation fuel, as these cities are transportation hubs and therefore highly dependent on connections to other countries for local economic growth. Malaysia and South Korea are interesting cases, as both have active automobile production programs and have developed excellent road and highway systems. Given their extraordinary economic growth and commitment to these technologies, it is not surprising that change is occurring more rapidly than experienced by the United States.

This study focused on transportation CO_2 emissions, but the sooner, faster, and more simultaneously conditions may also be occurring for other challenges. The complexity of management challenges increases if brown agenda challenges, such as access to water supplies and provisions of sanitation, emerge along with the gray agenda challenges of traffic congestion, mobile point source pollution, and industrial pollution and green agenda challenges, such as water scarcity and acid rain-related, ozone-depleting and greenhouse gas emissions, and all sets environmental burdens occur at lower levels of income and rise rapidly (e.g., see Marcotullio, 2004a). The management implications of this potential result shed doubt on the application of previously successful policies used in industrialized countries. For example, the United States attacked one environmental problem at a time as they appeared or applied the first-things-first approach (Warner, 1955). This approach may be less effective in rapidly developing contexts. Instead, developing countries may be better off seeking to develop policies that enhance synergistic solutions to a series of environmental challenges simultaneously and in a quicker fashion. As currently industrialized countries' experiences are different from those of rapidly developing countries, policies should reflect this reality.

The results of the analysis are also relevant for modeling and scenario efforts forecasting long-term greenhouse gas emissions. Given the wide variety of approaches used for forecasting future transportation demand and CO_2 intensity, we only make general observations. First, the pattern of transport emissions growth for developing nations is qualitatively distinct from that of the United States. Forecasting methods must thus avoid putting other countries on the same EKC as the United States.

Table 3, which indicates a wide variation in transport emissions between countries but at the same income level, illustrates that GDP alone does not sufficiently explain variations in transport emissions per capita over time. Developing countries demonstrated lower emissions growth than the United States when measured in terms of GDP per capita gains. The extent to which this trend can be viewed with optimism requires further analysis. There are a number of potential competing explanations. Although the higher efficiency of modern vehicles is likely a factor, greater reliance on rail transport is no doubt important for many nations. Also, very rapid economic development could also outstrip a country's ability to provide necessary transport infrastructure (i.e., lack of roads on which to drive). Considering the unprecedented rates of increase in GDP in some developing countries, the United States had a much longer period of time to develop highways and roads for the use of the automobile. Thus, within the developing world, there could be latent demand that could lead to a more sustained growth in transport demand as the infrastructure becomes available.

7.0. Conclusions

This study explored the appearance of what we call time-space telescoping, a process in which environmental conditions in rapidly developing countries tend to collapse, compress, and telescope. We compared historic road and air transportation CO_2 emission trends in the United States with recent trends in developing countries for three technologies: passenger vehicles, heavy-duty trucks, and airplanes. Our three hypotheses were that emissions in developing countries, relative to those in the United States, would occur sooner in the development timeline, increase faster, and develop more simultaneously for the three technologies. We found strong support for the faster and more simultaneously hypotheses and less support for the faster hypothesis. We expect that our finding for the faster hypothesis is attributable in part to having chosen the United States as our representative developed country. The rise of the automobile in the United States was especially rapid.

Areas of future refinement for this research include testing the three hypotheses using a representative sample of developed countries including rail-related CO_2 emissions in a comparative study of a smaller number of countries and identifying the (time- and space-related) drivers of change underpinning the processes. It is also important to work toward understanding the practical implications of the results for policy supporting sustainable development. We believe the effects of the sooner and more simultaneously conditions, for example, have broad and significant implications for policy in developing nations.

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References

Barter, P. (2004). Transport, urban structure and “lock-in” in the Kuala Lumpur metropolitan area. *International Development Planning Review*, *26*, 1-24.

Crafts, N. (2000). Globalization and growth in the twentieth century. In International Monetary Fund (Ed.), *World economic outlook, supporting studies* (pp. 1-51). Washington, DC: International Monetary Fund.

Dicken, P. (1998). *Global shift: Transforming the world economy*. London: Paul Chapman.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics*, *49*(1), 431-455.

Drucker, P. (1986). The changed world economy. *Foreign Affairs*, *64*, 768-791.

Ekins, P. (1997). The Kuznets curve for the environment and economic growth: Examining the evidence. *Environment and Planning A*, *29*, 805-830.

Friedmann, J. (1986). The world city hypothesis. *Development and Change*, *17*, 69-83.

Friedmann, J., & Wolff, G. (1982). World city formation: An agenda for research and action. *International Journal of Urban and Regional Research*, *6*, 309-343.

Harvey, D. (1989). *The urban experience*. Baltimore: Johns Hopkins University Press.

International Energy Agency. (2002a). *Basic energy statistics—non-OECD member countries*. Paris: Organization for Economic Cooperation & Development & IEA World Energy Statistics & Balances.

International Energy Agency. (2002b). *Basic energy statistics—OECD member countries*. Paris: Organization for Economic Cooperation & Development & IEA World Energy Statistics & Balances.

International Labour Office, Bureau for Workers’ Activities. (2004). *United States Bureau of Labor Statistics, comparative levels of GDP per capita and per employed person*. Retrieved

April 15, 2004, from http://www.itcilo.it/actrav/actrav-english/telearn/global/ilo/seura/usgdp.htm
Janelle, D. G. (1968). Central place development in a time-space framework. *Professional Geographer*, *20*, 5-10.
Janelle, D. G. (1969). Spatial reorganization: A model and concept. *Annals of the Association of American Geographers*, *59*, 348-364.
Lekakis, J. N. (2000). Environment and development in a Southern European country: Which environmental Kuznets curves? *Journal of Environmental Planning and Management*, *43*, 139-153.
Lindmark, M. (2002). An EKC-pattern in historical perspective: Carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997. *Ecological Economics*, *42*, 333-347.
Lindmark, M. (2004). Patterns of historical CO_2 intensity transitions among high and low-income countries. *Explorations in Economic History*, *41*(4), 426-447.
Litvin, D. (1998). Dirt poor: A survey of development and the environment. *The Economist*, *346*(8060), 3-16.
Lo, F.-C., & Yeung, Y.-M. (Eds.). (1998). *Globalization and the world of large cities*. Tokyo: United Nations University.
Lomborg B. (2001). The truth about the environment. *The Economist*, *360*(8233), 63-65.
Lutz, W., Sanderson, W. C., & Scherbov, S. (Eds.). (2004). *The end of world population growth in the 21st century, new challenges for human capital formation & sustainable development*. London: Earthscan.
Maddison, A. (1995). *Monitoring the world economy 1892-1992*. Paris: OECD Development Centre.
Maddison, A. (2001). *The world economy, a millennial perspective*. Paris: OECD.
Maddison, A. (2004). *Faculty of Economics, University of Groningen*. Retrieved December 10, 2003, from www.eco.rug.nl/~Maddison/
Marcotullio, P. J. (2002). Why are urban environmental problems different in Third World cities? A comparison of Western and Asia Pacific experiences (in Japanese). *Comprehensive Urban Studies*, *77*, 55-97.
Marcotullio, P. J. (2004a). *Time-space telescoping and Asian urbanization.* Yokohama, Japan: United Nations University Institute of Advanced Studies.
Marcotullio, P. J. (2004b). Why the Asian urbanization experience should make us think differently about planning approaches. In A. Sorenson, P. J. Marcotullio, & J. Grant (Eds.), *Towards sustainable cities: East Asian, North American and European perspectives on managing urban regions* (pp. 38-58). Aldershot, UK: Ashgate.
Marcotullio, P. J., & Lee, Y.-S. F. (2003). Urban environmental transitions and urban transportation systems: A comparison of North American and Asian experiences. *International Development Planning Review*, *25*, 325-354.
Marcotullio, P. J., Rothenberg, S., & Nakahari, M. (2003). Globalization and urban environmental transitions: Comparison of New York's and Tokyo's experiences. *Annals of Regional Science*, *37*, 369-390.
Millennium Ecosystem Assessment. (2003). *Ecosystems and human well-being*. Washington, DC: Island Press.
Panayotou, T. (2000). *Economic growth and the environment* (Center for International Development at Harvard University Working Paper No. 56). Cambridge, MA: Harvard University.
Sassen, S. (1991). *The global city: New York, London, Tokyo*. Princeton, NJ: Princeton University Press.
Smith, K. (1990). The risk transition. *International Environmental Affairs*, *2*, 227-251.
Smith, K. R., & Lee, Y.-S. F. (1993). Urbanization and the environmental risk transition. In J. D. Kasarda & A. M. Parnell (Eds.), *Third World cities: Problems, policies, and prospects* (pp. 161-179). Newbury Park, CA: Sage.

Stern, D. I. (1998). Progress on the environmental Kuznets curve? *Environment and Development Economics*, *3*, 173-196.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development*, *32*, 1419-1439.

United Nations. (2003). *Glossary for world comparison real gross domestic product and purchasing power, Statistics Division, Department of Economic and Social Affairs, United Nations*. Retrieved April 15, 2004, from http://unstats.un.org/unsd/methods/icp/gdp/gdp06_htm.htm

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, *28*, 817-830.

U.S. Department of Energy. (2002). *Annual energy review 2002. Table 5.12c: Petroleum consumption: Transportation sector and end-use total, 1949-2002*. Retrieved May 10, 2004, from www.eia.doe.gov/emeu/aer/petro.html

U.S. Department of Energy & Energy Information Agency. (2004). *Fuel and energy source codes and emission coefficients*. Retrieved June 15, 2004, from www.eia.doe.gov/oiaf/1605/factors.html

Warner, S. B. (1955). Public health reform and the depression of 1873-1878. *Bulletin of the History of Medicine*, *29*, 503-516.

World Bank. (1993). *The East Asian miracle, economic growth and public policy*. New York: World Bank & Oxford University Press.

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