SUSTAINABLE DEVELOPMENT: MODEL AND TEST

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ABSTRACT

Over the last two hundred years, the world's level of economic growth has increased dramatically. While this has led to breath-taking improvements in the standards of living for many, the world has concurrently observed increases in its population, greater competition for its resources, and vast degradation to its environment. In the face of such rapid growth, many economists have begun to contemplate the consequences of an ever-increasing amount of development, with some proposing that global growth be limited. The purpose of this paper is to examine the validity of such proposals. This paper applies time-series data for the United States and China over a three decade period, and empirical results indicate support for the Environmental Kuznets Curve (EKC). The growth of environmental degradation first rises and then falls as an economy moves through the growth process. *JEL Classifications**:** Q01, O13, O33*

INTRODUCTION

"The years have been good for humanity." This statement, made by American economist Julian Simon, can be witnessed in many of man's endeavors. There is perhaps no facet of life where it holds truer, however, than that of the economy. For thousands of years, the rate of economic growth within the world was nearly imperceptible, and people did not expect to see conditions change within their lifetimes. In the age of industrial revolution at the dawn of the nineteenth century, however, increases in wealth began to translate into higher standards of living for many people around the globe. Today, incomes within a majority of the world's nations have doubled within a single generation, and continual gains are viewed as normal.

According to Maddison (2008), the world's gross domestic product in 2003 was $47 trillion, a number that represented an increase of nearly 850 percent from the $5.6 trillion in 1951. Other economic and non-economic indicators have risen during this same time as well. For example, worldwide per capita incomes have grown to $7,275 from $2,197 and world life expectancies have reached nearly 65 years of age, see (Maddison). Other benefits from growth include better health outcomes (e.g. higher inoculation rates and lower infant mortality), more variety, higher leisure rates, and of course educational attainments, etc.

While humans today enjoy an ever-increasing quality of life as a result of a swelling global economy, the growth and the innovation that the world has experienced in recent centuries have come at a cost. Several historical and contemporary writers have argued that economic growth cannot continue forever. The implication is that today's growth will reduce the welfare of future generations of people. For example, in 1972 a widely-read book entitled *The Limits to Growth* came to the following alarming conclusion about economic growth: "If present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity." (Meadows 1972, pp. 23)

Also, since 1960, nearly eight trillion kilowatt hours of electricity have been produced worldwide (World Bank 2005). Because the burning of coal, oil, and various forms of fuel is required to create electricity, electrical production has likely been one of the factors responsible for the increase in greenhouse gasses. Most prevalent among these potentially harmful gasses is carbon dioxide, or CO_2.

This paper examines problems associated with an expanding global economy—problems that have been cause for much debate throughout history. Some economists have voiced concerns that future increases in human wealth may not be able to offset an ever-rising demand for the world's resources. Today, many anxieties regarding overpopulation persist, and discussion continues to center on limits to growth.

A Perspective on Growth

While there is no doubt that sustainable development is of interest to today's economists, it can be dated back to the literature for several hundred years. Thomas Malthus is often credited for having one of the first models of limits of growth. He believed that an increase in labor (resulting from population gains) working a fixed supply of land would cause diminishing returns, and this would eventually cause less food to be supplied to workers. He concluded that because the power of population is greater than the earth's power to produce sustenance, the future of the human race would be stricken by famine and poverty as a result of overpopulation.

More recently, Paul Ehrlich continues to offer warnings about the potential consequences of sustained economic growth. In *The Population Bomb*, Ehrlich (1968) echoed the concerns of Malthus when he stated that by 1970 extreme congestion problems would occur as a result of a growth-driven overpopulation. His book *Population, Resources, Environment: Issues in Human Ecology* (1970) reiterates this discussion, warning specifically that the growing number of people on earth would create an excessive demand for its resources. Ehrlich details the various problems encountered from growth, including: increased air, water, and solid waste pollution.

Today, the United Nations Environmental Programme's 1999 work, *Global Environmental Outlook 2000* and the UN's literature from the 2007 Bali conference suggests "the global ecosystem is threatened by grave imbalances in productivity and in the distribution of goods and services," and it suggests that the solution to the poor nations' low standards of living lies in getting developed nations to cease their "excessive" consumption. Sustainable development and resource management are topics of interest for both the developing and developed world.

A Shift in Thinking

In contrast to the grim views provided by Malthus and Ehrlich, several modern day economic theorists have brought optimism to the discussion of sustained growth. Most of this discussion revolves around technological progress, which is the key to sustainability. The common belief that economic growth must necessarily deplete our resources ignores the power of technology, see Van den Berg (2009). This is mentioned by Robert Stavins, who states "A common misunderstanding among noneconomists about the nature of economic growth. They seem to think of it in terms of more and more cars or refrigerators for those who already have them, not more efficient refrigerators, more CD's instead of record players, or more and better vaccines to prevent disease." (Stavins, 1992, pp. 50).

With regards to connecting this idea to theory, we initially look to Solow (1956) and the neoclassical growth model. The Solow model assumes diminishing returns, but can accomidated the key point in this discussion: technology. By including the effects of technology in his model, Solow accounted for the fact that greater output can be generated using similar or lesser amounts of input as a result of technological change and innovation. Therefore, an economy that continued to increase the level of its technology could conceivably avoid the law of diminishing returns among factors of production and raise its per capita growth indefinitely. For a review of more recent growth models and empirics, see also Romer (1994), Weitzman (1998), and Barro and Sala-i-Martin (2004).

One of the most important discoveries to impact growth-congestion literature has been that of Grossman and Krueger (1995). While examining cross sectional data to measure correlation between per capita income and various forms of pollution, they found that the environment does not necessarily deteriorate with economic growth. While growth does initially cause a great deal of degradation to the environment, a point is eventually reached when the state of the environment improves. After testing measures of pollution against the per capita incomes of a cross-section of countries, Grossman and Kreuger (1995) concluded that the "turning point" in a nation's attitude regarding the environment is reached when per capita income nears $8,000. The econometric model that illustrates the relationship between per capita income and environmental deterioration is known as the Environmental Kuznets Curve (EKC).

Economist Indur M. Goklany offered several explanations for this turnaround in his 2007 book *The Improving State of the World.* First, as affluence increases, it becomes possible for a society to improve the quality of its environment both better and more cheaply. Not only does wealth make the purchase and use of new or existing cleaner technologies more affordable, but it also means that more resources are available for researching and developing such technologies. Also, richer countries spend disproportionally more of their GDP on broad-based research and development (R&D) than do poorer countries. This R&D spending is beneficial even if it is not specifically targeted to environmental problems, for advances in one field of science often spread to stimulate innovations in others. In addition, affluence enables a society to use funds for developing and maintaining its human capital. Education (most notably post-secondary education) increases with wealth, and in turn serves as a catalyst for the cycle of progress.

Together, affluence and technological change influence first a period of transition in environmental impact, and then a decline. This, decline, however, is not a foregone conclusion. Empirical tests conducted by Khanna-Florenz (2006) serve as reminders that the EKC relationship is not inevitable, and that voters' demands, along with resulting policy changes, may be vital to the decline in pollution. Consumer preferences can either encourage or retard a reduction in emissions. If, as a society grows richer, consumers fail to exercise environmental effort, then abatement technologies may not prevent an increase in pollution. Still, if abatement is sufficiently effective, consumers need not have very "green" preferences for pollution to ultimately fall with income. In essence, the EKC illustrates that environmental consciousness is a luxury that can be achieved only after a nation achieves a minimum level of per capita income ($8,000).

This paper examines the cyclical relationship of growth, congestion, and technology. In view of recent movements toward sustainability and energy efficiency by governments, enterprises, and individuals alike, this work is undoubtedly timely. This paper is also significant in that it utilizes time series data in its examination of the limits to economic growth. Theories were tested using ordinary least squares regression models, and conclusions were drawn from the resulting data. This paper presents an empirical test of a proposed theory regarding the limits of economic growth for China and the United States.

This paper proceeds as follows: section II develops the econometric model to be tested, section III reports the results from stationarity and cointegration testing of the time-series data, section IV reports the finding from the economic models, and section V concludes with a summary and provides suggestions for future research on the topic.

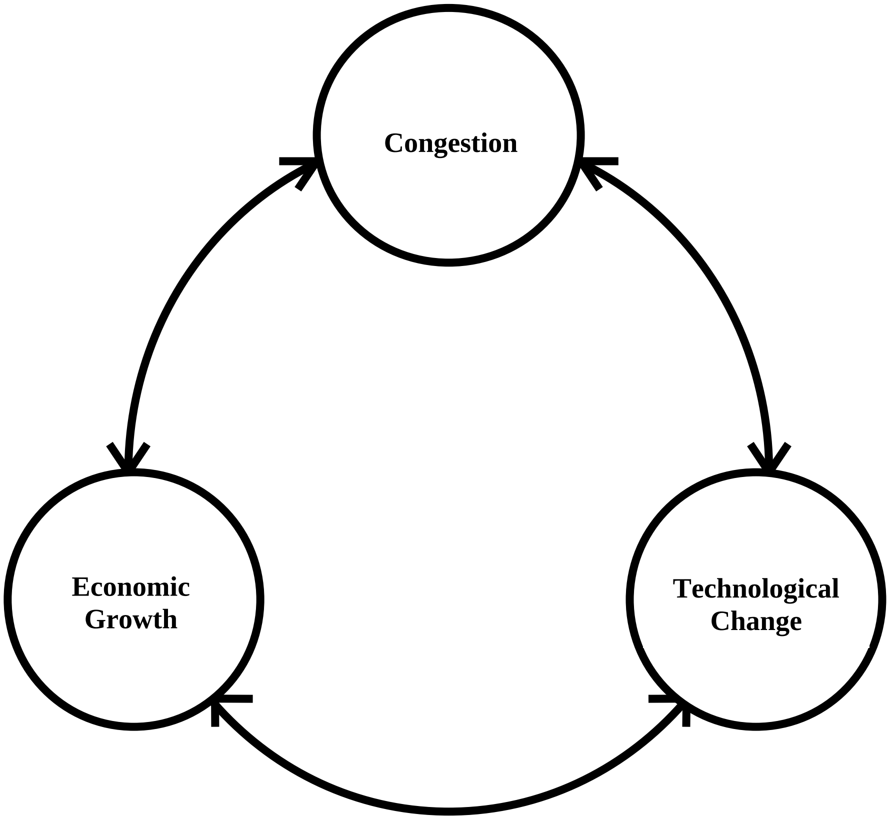
A MODEL OF GROWTH

The methodology of this paper includes both a conceptual model of an economic growth cycle as well as ordinary least squares testing. The conceptual portion, which serves to explain the logic behind the regression equations, will be discussed first. The ordinary least squares model will then be considered as an empirical test of the conceptual theory, and the results will be analyzed.

The Cyclical Nature of Growth

The argument among economists as to the limits of economic growth remains, with disagreement still existing over the causes of growth, the problems that can stem from rapid economic expansion, and what solutions to these problems may be. Regardless of the perspective offered, however, each major growth model contains three basic elements (or some variation thereof): congestion, technological change, and economic growth. These common elements do not exist independently; growth is cyclical by nature, and as a result each variable in the model is directly impacted by the other two. A diagram of this circular relationship is pictured in Figure 1.

FIGURE 1
CONCEPTUAL ECONOMIC GROWTH MODEL



The proposed cyclical connection can move in either the clockwise or counterclockwise direction. The clockwise relationship is perhaps the more intuitive of the two. First, economic growth creates greater populations, which in turn greatly increase the amount of congestion. In order to combat the problems posed by congestion, society creates new technologies. Because nations with high rates of technological change are known to also experience large amounts of economic growth, the cycle then continues. As previously stated, this paper theorizes that a counterclockwise cyclical relationship also exists between the three variables. Nations with faster economic growth also create more technologies, which in turn serve to lessen the burden of congestion. Because this decrease in congestion increases societal well-being, it is viewed as growth.

In order to show a connection between the three variables portrayed in the cyclical model, time series data was collected. This article focuses exclusively upon two nations: the United States and China. The data for both economic superpowers spans over thirty-years, from 1970 to 2004. The two nations were chosen because it is proposed, based on observed per capita incomes, that each lies upon a different portion of the previously referenced Kuznets Curve. The reasoning for the selected time frame rests upon the availability of data. Three variables, (1) economic growth, (2) congestion, and

(3) technological change are presented in three equations in an endogenous manner. A complete list of all endogenous and exogenous variables, along with a brief description of each, can be found in Table 1.

**TABLE 1:
DEFINITION OF VARIABLES**

Endogenous Variables	Description	Source
GRGDP	Growth of Real GDP	World Bank[1]
GRPCY	Growth of Real Per Capita GDP	World Bank[1]
GCO_2	Growth of CO_2 in Kilotons	World Bank[1]
GTECH	Growth of Patents in Force	World Bank[1]

Exogenous Variables	Description	Source
CO_2	CO_2 in Kilotons	World Bank[1]
LGRGDP	Lagged Growth of Real GDP	World Bank[1]
LGRPCY	Lagged Growth of Real Per Capita GDP	World Bank[1]
$LGCO_2$	Lagged Growth of CO_2 in Kilotons	World Bank[1]
LGTECH	Lagged Growth of Patents in Force	World Bank[1]
GLABOR	Growth of Labor Force	World Bank[1]
GKAPITAL	Growth of Capital Formation	World Bank[1]
GTRADE	Growth of Real Trade (Exports + Imports)	World Bank[1]
FREE	Economic Freedom Index	Fraser Institute[2]
HUMAN	School Enrollment, Secondary (% Gross)	World Bank[1]

Notes: [1] World Bank (2007) *World Development Indicators Database*. [2] Gwartney, James, Lawson, Robert (2007) *Economic Freedom of the World 2007 Annual Report*. Vancouver, Canada: Fraser Institute.

A description of the models used in this article can be found in following section.

The Ordinary Least Squares Model

Two sets of three OLS equations depict the growth-congestion-technology relationship. Their purpose was to explore possible causation effects of the growth of real gross domestic product (GRGDP) and/or the growth of real per capita GDP (GRPCY), the growth of carbon dioxide emissions (GCO_2), and the growth of patents in force (GTECH), given other independent variables. The ordinary least squares equations below are variations of Mankiw, Romer and

Weil (1992) and Kaiser's (2006) and cross-sectional models. The first model grouping emphasizes the GDP-congestion-technology relationship, while the second model grouping focuses on the per capita GDP-congestion-technology relationship.

The GDP growth-congestion-technology model:

$$GRGDP = \alpha_0 + \alpha_1 GRGDP(-1) + \alpha_2 GCO_2(-1) + \alpha_3 GTECH(-1) + \alpha_4 GLABOR + \alpha_5 GKAPITAL + \alpha_6 GTRADE + \alpha_7 \log(FREE) + u$$

$$GCO_2 = \beta_0 + \beta_1 GRGDP(-1) + \beta_2 GCO_2(-1) + \beta_3 GTECH(-1) + \beta_4 GLABOR + \beta_5 GKAPITAL + \beta_6 GTRADE + \beta_7 \log(FREE) + u$$

$$GTECH = \gamma_0 + \gamma_1 GRGDP(-1) + \gamma_2 GCO_2(-1) + \gamma_1 GTECH(-1) + \gamma_4 GLABOR + \gamma_5 GKAPITAL + \gamma_6 GTRADE) + \gamma_7 \log(FREE) + \gamma_8 \log(HUMAN) + u.$$

The per capita GDP growth-congestion-technology model:

$$GRPCY = \alpha_0 + \alpha_1 GRPCY(-1) + \alpha_2 GCO_2(-1) + \alpha_3 GTECH(-1) + \alpha_4 GLABOR + \alpha_5 GKAPITAL + \alpha_6 GTRADE + \alpha_7 \log(FREE) + u$$

$$GCO_2 = \beta_0 + \beta_1 GRPCY(-1) + \beta_2 GCO_2(-1) + \beta_3 GTECH(-1) + \beta_4 GLABOR + \beta_5 GKAPITAL + \beta_6 GTRADE + \beta_7 \log(FREE) + u$$

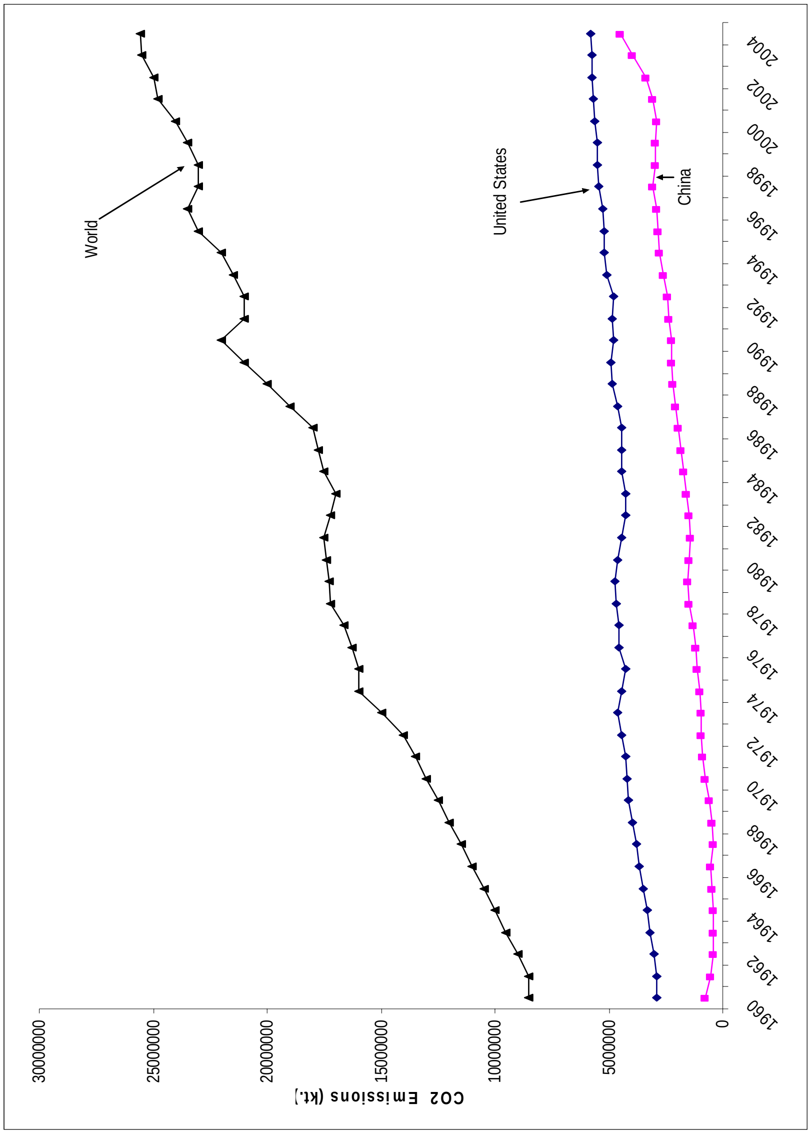
$$GTECH = \gamma_0 + \gamma_1 GRPCY(-1) + \gamma_2 GCO_2(-1) + \gamma_1 GTECH(-1) + \gamma_4 GLABOR + \gamma_5 GKAPITAL + \gamma_6 GTRADE) + \gamma_7 \log(FREE) + \gamma_8 \log(HUMAN) + u.$$

In the model, real Gross Domestic Product (RGDP) and real per capita GDP are used as measures for economic growth, and is measured in millions of real American dollars. Carbon dioxide (CO_2) is the established measure for congestion, and Patents in Force is the designated gauge for technological change. It is worth noting that some of the variables in the regression equations are estimated using logged values. The actual numbers of these variables differ greatly between the United States and China, and logging them accounts for differences in volumes.

Economic Growth

The variables under consideration for assessing the limits to growth are patents in force and levels of CO_2. For the purpose of the OLS regression equation, one-year lagged values of patents in force and levels of CO_2 were used in the estimation process. The reasoning behind this is simple: in the case of patents in force, it is assumed that yesterday's technological innovations are fostering today's growth. Also, a decrease in yesterday's emissions creates a higher societal well-being today. Finally, because it is assumed that yesterday's growth directly contributes to today's growth, the value of the RGDP and GRPCY are also lagged one year in the regression.

FIGURE 2
TOTAL CO_2 EMISSIONS (1960-2004)



Congestion

As a variable, congestion encompasses a diverse set of problems, including air pollution, water contamination, topsoil erosion, nuclear waste, and many more. For the purpose of this paper, air pollution is examined. Pollution in the air can take many forms, such as (but not limited to) chlorofluorocarbons, hydrocarbons, chlorine, ammonia, and CO_2. Because CO_2 is considered to be the most prevalent greenhouse gas, it is used in this paper as the primary variable in determining world congestion. Figure 3 portrays the rising levels of CO_2 in kilotons emitted by the United States, China, and the world as a whole from 1960 to 2004.

As can be observed in Figure 2, the past forty-four years represent a disturbing trend in air pollution, and one that has caused some academics to advocate limiting worldwide economic growth to maintain sustainable development. Because it is assumed that yesterday's growth is creating an increasing number of problems today, a one-year lagged value of RGDP and GRPCY are used in the regression equation. Moreover, a one year lag for patents in force is considered to determine if yesterday's technologies are lowering current levels of congestion. Also, because air pollution is a cumulative problem, a one-year lagged value of CO_2 is used to estimate current congestion.

Technological Change

The primary reason that Thomas Malthus's grim predictions regarding the human race never became a reality is that the economist failed to take technological innovation into account. Contrary to Malthus's theory, increased congestion over the years has not led to a worldwide food shortage. This is because as the earth's population continues to grow, humans continue to find new ways to expand their food supply through innovation. Adhering to this logic, it would seem that the rising levels of CO_2 in the United States and China would motivate the citizens of both countries to fight the growing pollution crisis. The value of CO_2 is lagged one year to determine if yesterday's problems are causing changes today. Also, a one-year lagged value of GRGDP and GRPCY are used in the regression to determine whether or not high growth levels lead to a greater amount of technological change. Finally, because it is possible that yesterday's technologies are influencing today's innovative activities, a one-year lagged value of patents in force is included in the equation.

TESTING FOR STATIONARITY AND COINTEGRATION

Because the purpose of this paper is to determine the limits of growth relationships for the United States and China over a thirty-three year period, a time-series framework is utilized. Regression equations with independent and nonstationary variables tend to have "spurious" results, and OLS testing results will be biased toward finding a significant relationship among the variables when one does not exist, see Granger and Newbold (1974) for an extensive study on the spurious regression problem. This paper implements the Augmented Dickey-Fuller (ADF) test modified to permit structural breaks, see Enders (1995). The ADF test statistics for all variables used can be found in Table 2.

Nonstationary variables are differenced until they become stationary. Consistent estimates can then be obtained only if the differences are stationary, and the nonstationary variables are not cointegrated. However, when nonstationary variables are cointegrated, running the series in levels produces consistent long-run relationship estimates. Therefore, the next step in this paper is to test for the presence of cointegration between the nonstationary variables in the equations.

TABLE 2
UNIT ROOT TEST RESULTS

	USA	China
GRGDP	-4.497*	-2.911*
GRPCY	-4.577*	-3.855*
GCO_2	-4.661*	-4.960*
GTECH	-3.834*	-2.638*
LGRGDP	-4.632*	-2.822*
LGRPCY	-4.496*	-3.569*
$LGCO_2$	-4.759*	-4.921*
LGTECH	-2.693*	-2.610*
GLABOR	-3.848*	-1.677
GKAPITAL	-5.120*	-4.696*
GTRADE	-4.835*	-4.252*
FREE	-1.392(a)	-3.499(a)*
HUMAN	-1.713(a)	-1.623(a)

Notes: The Augmented Dickey-Fuller (1979) t_{Φ} unit root test with constant and no trend is reported unless otherwise noted. A lag from 0 to 3 was selected using the Schwartz Information Criterion (AIC).
* indicates significance at the 90% level. (a) ADF t_{9} unit root test with constant and trend.

Cointegration occurs when a linear combination of two or more I(1) variables are stationary, I(0). The number of cointegration vectors in a system is detected with the Johansen-Juselius (1990) vector auto regressive estimation technique. If the presence of cointegration is detected, the variables have a stable long-run linear relationship, and can be tested in levels. Cointegration testing is applied to all equations in this article. These results are reported in Table 3 below.

TABLE 3
COINTEGRATION RESULTS

Country	I(1) Variables	Trace Statistics
United States	FREE	14.897*
	HUMAN	4.164*
China	GLABOR	15.759*
	HUMAN	0.413

Notes: * denotes significance at the 10% level. The 10% critical values for the Trace test are 13.31 and 2.71 for r = 1 and r = 0 respectively. The number of lags in the VAR model is determined by the Schwarz Information Criterion (SC) and the Chi-Squared test for normality.

EMPIRICAL RESULTS

The ordinary least squares equations were designed to test the lagged values of real Gross Domestic Product, real per capita Gross Domestic Product, patents in force, and carbon dioxide emissions on one another given a set of exogenous variables. The regressions presented in the previous chapter were estimated and the results are recorded in this section. It is important to note that none of the independent variables have a correlation of above 0.5, implying that excessive multicollinearity is not a problem.

For the GDP growth equations, table 4 shows the results of the OLS regression equation for the United States, and Table 5 shows the same information for China. The equations are looked at in terms of output, with special emphasis placed on the three variables under consideration. Results are examined at 95 percent confidence levels. The leftmost column lists the various independent variables, and the top row lists the explanatory variables. The coefficients of the independent variables are cross-listed to the dependent variables of each equation, and *t* statistics are listed below these values.

A cyclical relationship exists between economic growth, congestion, and technological change. As the conceptual diagram suggested, bidirectional correlation can be found between some of the variables. For example, the lagged value of the growth of real GDP has a negative, significant effect on the lagged value of CO_2. Also, as can be observed in Table 4, this relationship is bidirectional in the United States, with lagged carbon dioxide emissions having a negative, significant impact on the lag of the growth of real GDP. A similar relationship seems to exist between the two lagged variables in China, though the effect of the lag of the growth of real GDP on CO_2 is insignificant. In both the United States and China, lagged values of growth of real GDP, patents in force, and CO_2 influence the current levels of these variables.

In addition to showing a degree of bidirectional correlation between growth, congestion, and technological change, the results of the experiment support the theory of the EKC. The lag of the growth of real GDP is a negative and significant factor determinant of CO_2 emission for the US, but not China. This would support the idea that the United States and China are currently on different sides of the curve's inverted U-shape. While continued economic growth in America actually causes harmful emissions to decline, this trend is absent in China.

Tables 6 and 7 report the OLS regression equations for the United States and China for the PCY growth equations. Notice that there is a high degree of similarity between the GDP and PCY growth tables. A negative bidirectional correlation can be found between the growth of real per capita GDP and CO_2 for the United States. This relationship does not seem to hold for China. Nonetheless, both sets of regression results show some support for the EKC model.

TABLE 4
UNITED STATES GDP GROWTH RESULTS (1970-2004)

	GRGDP	GCO_2	GTECH
C	5.833	12.098	-4.291
	(1.34)	(5.35)**	(-2.03)**
LGRGDP	0.402	-0.535	-0.083
	(3.70)**	(-4.83)**	(-0.46)
$LGCO_2$	-0.190	0.545	-0.203
	(-3.35)**	(5.34)**	(-1.77)*
LGTECH	0.101	0.129	0.813
	(2.36)**	(1.53)	(7.01)**
GLABOR	0.305		0.645
	(2.53)**		(2.53)**
GKAPITAL	0.098		
	(3.53)**		
GTRADE	0.174	0.319	0.073
	(4.16)**	(5.58)**	(1.46)
FREE	***0.073***	***0.035***	-0.089
	(2.69)**	(0.62)	(-2.21)**
HUMAN			-0.009
			(-4.31)**
R^2	0.999	0.964	0.981
Durbin-Watson	1.765	1.623	2.234
N	33	33	33

Notes: Figures in parentheses are *t*-statistics. **Significant at the 95% level. *Significant at 90% level. Bold and italicized coefficients are first-differenced.

TABLE 5
CHINA GDP GROWTH RESULTS (1970-2004)

	GRGDP	GCO_2	GTECH
CO_2	6.693	97.273	-111.99
	(4.73)**	(1.06)	(-4.89)**
LGRGDP	0.322	-2.701	0.198
	(3.30)**	(-0.66)	(5.84)**
$LGCO_2$	-0.011	0.801	0.047
	(-5.83)**	(6.71)**	(1.14)
LGTECH	0.032	0.625	0.198
	(3.39)**	(1.09)	(1.48)
GLABOR	***-0.110***		3.120
	(-1.08)		(1.49)
GKAPITAL	0.445		
	(8.61)**		
GTRADE	-0.019	-1.436	-0.530
	(-0.73)	(-1.09)	(-1.25)
FREE	0.085	1.956	-2.173
	(2.86)**	(0.99)	(-4.83)**
HUMAN			-0.020
			(-1.29)
R^2	0.999	0.846	0.994
Durbin-Watson	2.262	2.082	1.938
N	33	33	33

Notes: Figures in parentheses are *t*-statistics. **Significant at the 95% level. *Significant at 90% level. Bold and italicized coefficients are first-differenced.

TABLE 6
UNITED STATES INCOME GROWTH RESULTS
(1970-2004)

	GRPCY	GCO_2	GTECH
	2.898	3.810	-4.231
	(2.72)**	(1.94)*	(-2.00)**
LGRPCY	0.441	-0.355	-0.098
	(3.45)**	(-1.23)	(-0.52)
$LGCO_2$	-0.238	0.760	-0.197
	(-3.11)**	(5.10)**	(-1.68)*
LGTECH	0.054	0.027	0.815
	(1.18)	(0.24)	(7.12)**
GLABOR			0.557
			(3.06)**
GKAPITAL	0.116		
	(3.77)**		
GTRADE	0.110	0.120	0.075
	(2.68)**	(2.07)**	(1.44)
FREE	***0.063***	***0.003***	-0.087
	(2.06)**	(0.35)	(-2.19)**
HUMAN	-0.002		-0.009
	(-2.61)**		(-4.35)**
R^2	0.996	0.937	0.971
Durbin-Watson	1.385	1.345	2.238
N	33	33	33

Notes: Figures in parentheses are *t*-statistics. **Significant at the 95% level. *Significant at 90% level. Bold and italicized coefficients are first-differenced.

TABLE 7
CHINA INCOME GROWTH RESULTS
(1970-2004)

	GRPCY	GCO_2	GTECH
CO_2	-4.164	39.233	-180.02
	(-5.21)**	(1.22)	(-4.95)**
LGRPCY	0.385	0.074	0.534
	(4.59)**	(0.18)	(5.87)**
$LGCO_2$	0.00004	0.824	0.051
	(0.01)	(7.08)**	(1.22)
LGTECH	0.026	0.253	0.207
	(3.23)**	(0.48)	(1.57)
GLABOR			8.662
			(4.22)**
GKAPITAL	0.346		
	(7.11)**		
GTRADE	-0.056	-1.709	-0.513
	(-1.21)	(-1.34)	(-1.21)
FREE	0.112	0.913	-2.231
	(3.57)**	(0.43)	(-4.82)**
HUMAN	-0.0002		-0.018
	(-0.23)		(-.17)
R^2	0.999	0.843	0.994
Durbin-Watson	1.594	2.104	1.971
N	33	33	33

Notes: Figures in parentheses are *t*-statistics. **Significant at the 95% level. *Significant at 90% level. Bold and italicized coefficients are first-differenced.

CONCLUSION

The purpose of this paper was to examine possible cyclical relationships between economic growth, the world's congestion problems, and technological change in an attempt to assess the global limits to growth. The empirical results suggest that bidirectional correlation existed between growth of real GDP, CO_2 emissions, and technological progress (e.g. measured as patents in force). Also, time series data for the United States and China supports the EKC theory. Future research on the EKC is needed, and further efforts should focus on testing different countries, variables (including various forms of congestion), and time periods.

REFERENCES

Barro, Robert J. and Xavier Sala-i-Martin. 2004. *Economic Growth*, 2nd Ed, Cambridge, MA: MIT Press.

Ehrlich, Paul A. 1968. *The Population Bomb* New York, NY: Sierra Club-Ballantine.

Ehrlich, Paul A. and A. H. Ehrlich. 1970. *Population, Resources, Environment: Issues in Human Ecology* San Francisco, CA: W.H. Freeman.

Enders, W. 1995. *Applied Econometric Time Series* New York: John Wiley and Sons.

Goklany, Indur M. 2007. *The Improving State of the World* Washington, D.C.: Cato Institute.

Granger, C.W.J. and Newbold, P. 1974. "Spurious Regressions in Econometrics." *Journal of Econometrics* 2 (2): 419-35.

Grossman, Gene M. and Alan B. Krueger. 1995. "Economic Growth and the Environment." *The Quarterly Journal of Economics* 110 (2): 353-77.

Johansen, S. and Juselius, K. 1990. "Maximum Likelihood Estimation and Inference on Cointegration with Application to the Demand for Money." *Oxford Bulletin of Economics and Statistics* 52 (2): 169-210.

Kaiser, David. 2006. *Estimating the Limits to Economic Growth: An Empirical Test Among Selected OECD Nations* Graduate Master's Thesis, University of Nebraska-Lincoln.

Khanna, Neha and Plassman, Florenz. 2006. "Preferences, Technology, and the Environment: Understanding the Environmental Kuznets Curve Hypothesis." *American Journal of Agricultural Economics* 88 (3): 632-643.

Maddison, Angus. 2008. "Statistics on World Population, GDP and Per Capita GDP, 1-2006 AD." taken from (http://www.ggdc.net/maddison/).

Meadows, Donella H. 1972. *The Limits to Growth* New York: NY, Universe Books.

Romer, Paul M. 1994. "The Origins of Endogenous Growth." *Journal of Economic Perspectives* 8 (1): 3-22.

Solow, Robert. 1956. "A Contribution to the Theory of Economic Growth." *Quarterly Journal of Economic* 70 (1): 65-94.

Stavins, Robert. 1992. "Comments and Discussion." to William D. Nordhaus 1992. "Lethal Model 2: The Limits to Growth Revisited." *Brookings Papers on Economic Activity* 2.

United Nations. 1999. *Global Environmental Outlook 2000* New York, NY: United Nations.

Van den Berg, Hendrik. 2009. *Economic Growth and Development* forthcoming manuscript.

Weitzman, Martin L. 1998. "Recombinant Growth." *Quarterly Journal of Economics* 113 (2): 331-360.

World Bank. 2005. *World Development Report* Washington D.C.: The World Bank.

Acknowledgements

The authors would like to thank Frank G. Landram and the Economic Issues I session participants at the 2009 Southwestern Society of Economists annual conference for their most helpful comments on this paper. All remaining errors are those of the authors.