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# A Time Series Correlation Analysis Using the Keeling Curve as an Alternative Evaluation Method for Carbon Emission Modeling

Xingyu Lu

**ABSTRACT:** This study uses atmospheric CO<sub>2</sub> concentration data (the Keeling Curve) as an alternative measurement of anthropogenic carbon emissions to test the relationship between environmental pressure and economic development. Using verified detrending procedures, no significant relationship is observed between global population growth and increases in atmospheric carbon concentration. Changes in world GDP, however, have a significant effect on CO<sub>2</sub> concentration in the atmosphere. GDP per capita is also a strong indicator of the Keeling Curve. The use of the affluence level, GDP per capita, correlates to the environmental impact when the environmental pressure is altered to atmospheric CO<sub>2</sub> concentration, even though population does not correlate with the Keeling Curve.

## Introduction

### Malthusian school of thought, The Club of Rome

Since the late 1700's, citizens have expressed concern regarding environmental quality and resource availability due to the explosion of population. In 1798, *An Essay on the Principle of Population* was published anonymously by Thomas Robert Malthus. In this book, Malthus discussed resource depletion: "The power of population is indefinitely greater than the power in the earth to produce subsistence for man." His main concern was that population would increase geometrically, doubling every 25 years, but food production would only grow arithmetically. This difference would result in famine and starvation unless births were controlled. In 1968, a best-selling book *The Population Bomb* earnestly warned of imminent famine due to overpopulation during 1970's and 80's. The author advocated immediate action to limit population growth (Ehrlich, 1968).

*The Limits to Growth* addressed the worries of exponential economic and population growth considering finite resource supplies. The original version presented a model based on five variables: world population, industrialization, pollution, food production, and resource depletion. These variables were considered to grow exponentially, while the ability of technology to increase resource availability was thought to only be linear. These books saw population growth coupled with growing affluence as the primary forces driving adverse environmental impacts (Meadows et al., 1972). An ongoing idea suggests that environmental pressure can be controlled by controlling the population, an idea that is discussed throughout this paper.

### Modern environmental economic studies on pollution

One of the classical and well-studied counterarguments is that technological progress represents a significant positive influence on pollution abatement that is resource conserving, pollution reducing, and growing at a rate large enough to offset the impacts of population growth and rising affluence. This view was in opposition to the Club of Rome approach, in which adverse environmental impact estimates were driven by exponential growth in the use of resources but not technological progress (Kneese and Ridker, 1972).

IPAT is an established theory that uses the I=PAT equation to relate environmental impact (I, typically emissions of a pollutant or natural resource use) to population (P), society affluence (A, often a proxy for per capita income), and a technology index (T) (Arrow, 1995). In a slightly different form, IPAT is known as the Kaya Identity, which is the key theory in the Intergovernmental Panel on Climate Change (IPCC) estimate of future CO<sub>2</sub> emissions. In these estimates, total CO<sub>2</sub> emissions are a product of population, per capita GDP, energy use per capita, and CO<sub>2</sub> emissions per unit of energy consumed.

The Environmental Kuznets Curve (EKC) provides evidence that the relationship between environmental pollution and per capita income follows an inverted U-shaped pattern. It is clear that the IPAT model is simply a restricted version of the EKC. The casual empiricism characterizing much of the early EKC literature established the stylized fact that environmental quality tends to be positive, not negatively, correlated with income in

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wealthier countries. This would suggest that the EKC specification is a distinct improvement over the IPAT model. However, the problem with the EKC lies with the assumption of a causal role of income growth and the inadequacy of reduced-form specifications, which presume that a common income-related process, conditional on fixed effects for political jurisdictions and a few observable covariates, adequately describes the generation of the pollutant of interest. The constant debate throughout this research surrounds data sources and carbon accounting. Here, the Keeling Curve is introduced as a carbon accounting source.

## The Keeling Curve: a continuous measure of atmospheric CO<sub>2</sub> concentration

The worldwide recession of 2007–2009 has been viewed by natural scientists as a cause of the reduction in CO<sub>2</sub> emissions and also a likely reason for the low 2009 increase in atmospheric CO<sub>2</sub> (Friedlingstein et al., 2010). The Keeling Curve is a continuous measurement, since March 1958, of CO<sub>2</sub> concentrations in dry air on the Hawaiian volcano of Mauna Loa (Keeling and Whorf, 2005; Keeling Curve Website). The Keeling Curve represents the longest series of CO<sub>2</sub> levels documenting the changing composition of the atmosphere. This provides another source for evaluating carbon emissions and their relationship with economic development.

The Keeling Curve reveals a rising trend with a regular oscillating seasonal pattern, attributed to differences in the ability of photosynthesis and respiration of the terrestrial biosphere, and other CO<sub>2</sub> sinks, to absorb the gas during the annual seasonal cycle (Conway et al., 1994). Annual mean atmospheric concentrations of CO<sub>2</sub> computed from the Mauna Loa records reveal an almost linear increase of CO<sub>2</sub> atmospheric levels since 1959.

The current paper uses carbon emission data from the EIA (Energy Information Agency), the IEA (International Energy Administration), and the IPCC (United Nation

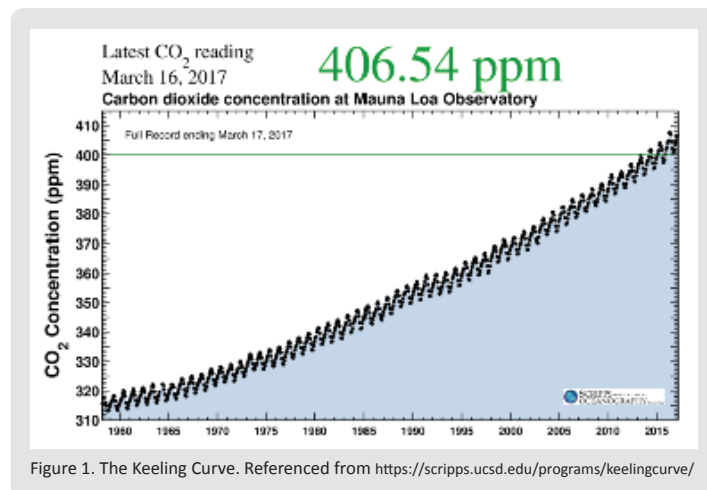
Intergovernmental Panel on Climate Change). The common characteristic of these data sources is that carbon emissions are based on estimates of energy consumption reported by industrial sectors. It can be beneficial to use an alternative carbon accounting methodology to eliminate human errors if the Keeling curve is properly adjusted in a few geological factor.

Two possible geological variables affecting the Keeling Curve are volcanic activity and the El Niño–Southern Oscillation (ENSO). Volcanic activity emits CO<sub>2</sub> and ENSO is an irregular periodical variation in winds and sea surface temperatures over the tropical Eastern Pacific Ocean.

## Overview

Traditionally, the theories of EKC and IPAT are used to test the pollution output and economic growth for individual countries. In this study, these theories are assessed using comprehensive data for the entire human population GDP and population measures use global data. Carbon emissions (representing environmental pressure) are represented by the Keeling Curve. A correction of the Keeling Curve due to anthropogenic activity is introduced as a variable term (ENSO activity). In this study, the possibility of using the Keeling Curve for the measurement of environmental impact, as an alternative to estimated emissions, is discussed. The viability of this alternative method is tested using correlation tests and a verified detrending method.

The remainder of this article is organized into six main sections. Section II provides background information that connects this study with previous literature on the Keeling Curve and pollution modeling. Section III presents the methodology. The empirical results are reported in section IV, along with a discussion of the results. Conclusions are reported in Section V.



## Literature Review

### Carbon emission modeling and forecasting

Although this study is not, at present, concerned with evaluating emission models, it is helpful to review the existing literature on pollution modeling. Here, the known variables in pollution models are reviewed and their relationships with atmospheric carbon concentration are tested. In this review, we focused on IPAT and EKC models. For other models and perspectives one can refer Zhang and Cheng, 2009; Holdren, 2000

Specifically, the Kaya identity is a form of IPAT that assesses the level of human impact on climate, including emissions of CO<sub>2</sub>. The Kaya identity equates the level of CO<sub>2</sub> emissions to the product of population, GDP per capita, energy intensity, and carbon intensity (Kaya, 1990). In the Kaya identity, the impact is carbon emissions, while technology is split into energy use per unit of GDP and carbon emissions per unit of energy consumed. Most emission forecasts, including those from the Intergovernmental Panel on Climate Change, are based on the Kaya identity (IPCC, 2000; EIA, 2011):

$$F = (P)\left(\frac{G}{P}\right)\left(\frac{E}{G}\right)\left(\frac{F}{E}\right)$$

where:

F = global CO<sub>2</sub> emissions from human sources

P = global population

G = world GDP

E = global energy consumption

The first body of literature discussed here is related to the nexus of energy consumption and output. It suggests that economic growth and energy consumption are closely related, as a higher level of economic development requires greater energy consumption. The common empirical implication underlying all IPAT models is that pollution should monotonically increase with P and A and monotonically decrease for improvements in T. Yang and Schneider (1998) provide a decomposition analysis across countries with this assumption. Many relevant studies can be found in the IPCC special report on emission scenarios (SRES) (see IPCC 2000). The literature regarding empirical results from causality tests between energy consumption and economic growth is mixed regarding the Granger causality (which is a statistical hypothesis test for determining whether one time series is useful in forecasting another).

These studies are based on the IPAT/Kaya identity and use econometric tools to estimate reduced form models. The advantage of these econometric forecasting models is that they require fewer structural assumptions and data points. The drawback of these models is that the reduced form specification does not separate the income effect from other factors driving emissions (Arrow 1995).

A broader version of the IPAT model is the EKC

hypothesis, which focuses on the nexus of environmental pollution and economic growth. It was initially proposed by Grossman and Krueger (1991, 1995) and Selden and Song (1995). They suggest that levels of degradation and pollution increase at early stages of economic growth. After a certain level of income per capita, however, the trend reverses, such that a high level of income leads to environmental improvement. Overall, the EKC hypothesis indicates that pollution rises with income up to a point and then falls after some threshold level, forming an inverted U-shape relationship. In the EKC hypothesis, the logarithm of the indicator is modeled as a quadratic function of the logarithm income. The standard EKC regression model is as follows:

$$\ln(E)_t = \alpha + \beta_1 \ln(GDP/P)_t + \beta_2 [\ln(\frac{GDP}{P})_t]^2 + \varepsilon_t \quad (1)$$

where:

E = emissions

P = population

GDP = gross domestic product

ln = the natural logarithm.

The turning point or threshold level for maximum emissions is given by:

$$\tau = \exp\left(-\frac{\beta_1}{2\beta_2}\right)$$

(Grossman, 1995; Stern, 2004; Holtz-Eakin and Selden, 1995).

The empirical evidence on whether a turning point for CO<sub>2</sub> exists is mixed. Since CO<sub>2</sub> emissions stem largely from energy use, any downturn in per capita emissions could be due to changes in agent preferences or policies regarding energy consumption and production, rather than GDP per capita (Lieb, 2004).

It is also worth noting that, according to this EKC-hypothesis, environmental pressure tends to rise faster than income growth in the early stages of economic development, then slows down, reaches a turning point, and declines with further income growth. This last stage has been referred to as the 'de-linking of environmental pressure from economic growth' (Simonis, 1989).

### Factors in the Keeling Curve

**Geological factors:** ENSO activity refers to a pattern of climate changes (with associated floods and droughts) across the tropical Pacific Ocean, which recurs at intervals of 3 to 7 years. Negative values correspond to cold years ("La Niña"), and positive values to warm years ("El Niño"). ENSO activity is thought to strengthen CO<sub>2</sub> capture by the oceans during warm years (Krakauer and Randerson, 2003). Research by Ciais et al. (2005) points out that ENSO affects atmospheric CO<sub>2</sub> levels because warmer years increase the capture of CO<sub>2</sub> by increasing the growth rate of trees. ENSO affects CO<sub>2</sub> concentration by changing the net productivity, land use, etc. The direct link between CO<sub>2</sub>

concentration and ENSO is unclear; however, it is common to use a linear model to represent the relationship (Le Quere 2007).

There are also studies on the effect of volcanic activity on carbon concentration in the atmosphere (Kasting and Walker, 1992; Trenberth and Dai, 2007; Krakauer and Randerson, 2003; Ammann et al 2003). Reviews and analysis of volcanic activity and its relationship with atmospheric carbon concentration are beyond the scope of this study. The main reason is conflicting results and difficulties in quantification (because the index rating is non-formulated). This topic is more suited to separate event studies rather than a modeling study.

**Human Factors:** The dependence of CO<sub>2</sub> concentration on natural phenomena explains why, for instance, the observed CO<sub>2</sub> increase in the atmosphere averaged over several years accounts for only approximately 56% of the fossil fuel input, and this despite the fact that deforestation is ongoing (Hansen, 2010). The relationship between fossil fuels and carbon concentration is considered to be positively correlated. Research into this subject has mainly been performed by Le Quere and collaborators (2007; 2009; 2013) and Peters et al. (2011).

### **Current debate on carbon modeling based on economic development: problems with estimated emissions**

There are many investigations into how natural factors affect the short-run fluctuations in CO<sub>2</sub> concentrations. But as yet, there have been few known attempts to connect the evolution of CO<sub>2</sub> concentration with changes in the global economy. The link between estimated emissions and atmospheric concentration is unclear. However, the measurement of atmospheric CO<sub>2</sub> levels is much more accurate and reliable than the estimation of emissions (from statistics on fuel consumption, exports, imports, etc.), which is subject to considerable margins of error (Nordhaus, 1994, p. 27; Nisbet and Weiss, 2010).

The existing literature measures environmental pressure using estimated emissions (greenhouse gases including CO<sub>2</sub>, CH<sub>4</sub> etc., as well as the widely studied SO<sub>2</sub>). It is proposed that, if natural factors are accurately considered, focusing on atmospheric CO<sub>2</sub> levels is a better methodological choice than estimating anthropogenic carbon emissions. Such estimates only involve energy consumption and cement production (see methodology part), which can cause major errors.

The long-term goal of this study is to replace environmental pressure (estimated emission) in pollution models with the Keeling Curve, with the addition of some geological variables. Throughout the existing literature, the affluence level, determined from the GDP per capita, is considered the cause of environmental pressure. By using the same factors and alternative data, this

study aims to investigate the link between atmospheric carbon concentration and affluence level (determined by economics and population growth).

### **Methodology**

#### **Data: alternative carbon accounting**

The source of carbon accounting has been a major difficulty in this type of research. In older publications, the standard data set on carbon/sulfur emissions was the World Health Organization Global Environmental Monitor System (WHO GEMS/AIR, further abbreviated to GEMS). However, this program was terminated in the late 1990's due to funding issues. Since then, various carbon accounting methods have been used. This includes the United Nation Intergovernmental Panel on Climate Change Report (IPCC), the International Energy Agency report, government census department or statistic department reports, and industrial estimates of energy consumption and carbon emission, among others. In this research, the Keeling Curve is used as a substitute for the estimated carbon emission method (that measures energy consumption and cement production) to test whether existing literature conclusions/results (using estimated emissions) still apply when an alternative carbon accounting method is employed. A potential problem with this approach is that geophysical activities (especially ENSO) have strong effects on the Keeling Curve over a short time scale.

#### **Data Sourcing**

All data used in this analysis are from open access sources. Mean annual concentrations of atmospheric CO<sub>2</sub> (in parts per million by volume) are taken from the Scripps CO<sub>2</sub> Program ([http://scrippsco2.ucsd.edu/data/atmospheric\\_co2](http://scrippsco2.ucsd.edu/data/atmospheric_co2)). In particular, the average of raw "monthly CO<sub>2</sub> reported average" data is used as the annual average. World GDP (WGDP, in trillions of 2000 constant U.S. dollars) is from the World Development Indicators database ([data.worldbank.org/data-catalog/world-development-indicators](http://data.worldbank.org/data-catalog/world-development-indicators)) of the World Bank. The same source as the world population (in millions, taken from the United Nations Population Division). According to NY.GDP.PCAP.KD metadata, the GDP per capita is a simple division of constant U.S. dollar GDP (NY.GDP.MKTP.KD) over total population (SP.POP.TOTL).

A few variations in trade indicators are included (total trade, merchandise trade, % and \$ of GDP) to determine the potential cost and benefit to the environment of trading, as presented by Grossman and Krueger 1993. These data are from World Development Indicators. Bimonthly figures for ENSO activity were taken from NOAA sources (Wolter, 2016). The annual index of ENSO activity (AIEA) was computed as follows:  $AIEA = [DECJAN + JANFEB + FEBMAR + MARAPR + APRMAY + MAYJUN + JUNJUL + JULAUG + AUGSEP + SEPOCT + lag(OCTNOV) + lag(NOVDEC)]$ , where DECJAN is the value for December–January, JANFEB is the value for January–February, etc., and lag(OCTNOV) is the value for October–November of the previous year.

**Time series analysis using detrending**

From the literature review, there may be several potential or known factors that correlate with the Keeling Curve carbon concentration. Since the relevant correlations are known to display lags, we examined these correlations at several different lags. Because the annual increase of CO<sub>2</sub> concentration has been growing over time, detrending the series of CO<sub>2</sub> concentrations by either taking first differences or subtracting with a linear trend—the two standard methods of detrending—are not appropriate. Most common methods used in similar studies use non-linear detrending by subtracting trends computed both with the Hodrick–Prescott (HP) filter and with centered moving means (cMM). Here, the HP filter was applied with smoothing parameters of  $\lambda = 100$  and  $\lambda = 6.25$ , which are the extremes of the range of values recommended by various authors to detrend annual data series (Ravn and Uhlig, 2002; Maravall and del Rio, 2007). The moving means were computed with windows of five, seven, and nine. From the literature, it seems that HP6.25 and cMM7 are the preferred methods. For lags, lag +1 indicates that a certain factor occurs one period (in this paper, one year) after all other factors.

**Results**

**Correlation Analysis**

Figures 3 through 5 gives a good visual aspect of the improvement by applying time series detrending.



Figures 4a, 4b, 4c.

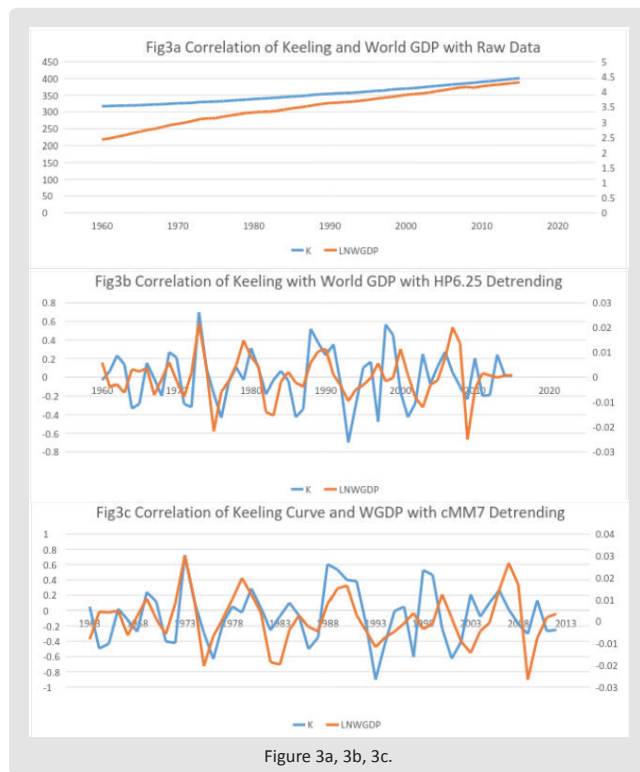


Figure 3a, 3b, 3c.

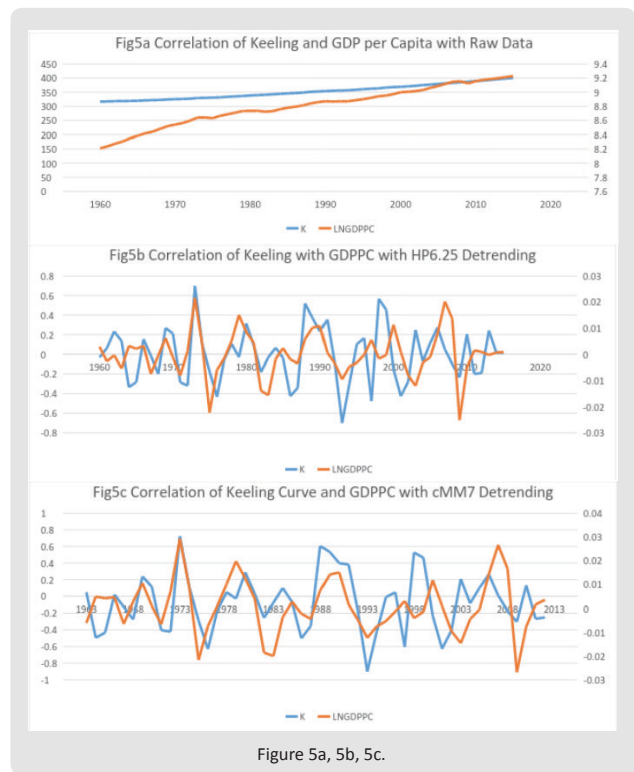


Figure 5a, 5b, 5c.

If one examines Figure 3a, 4a, and 5a, all factors seems correlated. But because these factors naturally increase over time, these figure does not provide information on their correlations. Figures 3-5 b and c are two sample figures that after the data has been detrand (getting rid of the time series effect). For detailed data please see tables.

It is clear from Table 1 that correlations of CO<sub>2</sub> concentrations with WGDP are positive and statistically significant (P < 0.05) for all detrending methods, and strongly significant (P < 0.01) for four out of five methods. Correlations of CO<sub>2</sub> with world population are statistically indistinguishable for all five methods of detrending. Similarly, the GDPPC (GDP per capita), which is essentially GDP/WP (or Ln(GDPPC)=Ln(GDP)-Ln(WP)), shows a statistically significant (P < 0.05) correlation with atmospheric carbon concentration for all detrending methods and a strongly significant (P < 0.01) correlation for four out of five methods. This result indicates that GDP and GDP per capita are good estimators of atmospheric carbon concentration. In conclusion, WGDP is strongly significant with Keeling Curve data while the world population (WP) is not, and GDPPC (GDP per capita) is a consistent indicator of CO<sub>2</sub> concentration. This result may seem counter intuitive; however, counter-neo-Malthusian theories are common (Reed, 2008). They generally argue that population control is unnecessary and anti-human. This study does not attempt to fully examine the neo-Malthusian theory, but the results of this paper suggest that an increase in population is not directly related to an increase in atmospheric carbon concentration.

It should be noted that, when CO<sub>2</sub> is represented by estimated emissions from industrial sectors, all the established EKC models, all KAYA/IPAT models, and most GEMS use GDP per capita, not world GDP (because the EKC require the independent variable to be per capita

income, as with IPAT models, which define emissions using affluence level). If human activities are the cause of changes in the Keeling Curve, the existing models should have no difficulty changing the dependent variable from estimated CO<sub>2</sub> emissions to Keeling Curve data. In other words, using an alternative carbon accounting method should be consistent with the current state of pollution economics research, and use GDP per capita. From the correlation test of this paper, GDP and GDPPC behave similar when testing their correlation with Keeling Curve.

Time series analysis methods, especially detrending methodology, will improve substantially in the near future. Thus, a benchmark correlation measure of the detrending method is included in Table 2. Using the existing method (which has been used since 1970) suggests that, for all five methods, ENSO at lag+1 is very strongly significantly correlated (P<0.001) with ENSO at lag -1. For four of the methods, world GDP is not statistically significantly correlated with world population. If using HP100, they show a statistically significant correlation of 0.27 (P=0.04). If the detrending methods cross-section is compared, it is clear that the center moving mean (cMM) correlation increases when the window increases. There is no directional correlation change from HP Lambda 6.25 to 100.

Furthermore, identical tests were performed for several trade indicators (total trade and merchandise trade in dollars and in % GDP), and none of these indicators show strongly significant relationships (see Table 3). According to (Cole 2004), the manufacture share of GDP is not related to carbon emissions. The idea proposed by Cole (2004), that demographic analysis using a portion (%) of the economy is not a good indicator of environment impact, is examined by analyzing total trade and merchandise trade in dollars and in % GDP. Results show that using a portion of the

Table1: Correlation Analysis of the Carbon Concentration in Atmosphere (Keeling Curve)

Detrending Method	ENSO	ENSOP Lag+1	ENSON Lag-1	WGDP	WP	GDPPC	Sample Size N
A. (HP6.25)	-0.0377 (0.7827)	-0.5596 (0.0000)***	0.482 (0.0002)***	0.3505 (0.0081)**	-0.0379 (0.7813)	0.358 (0.0069)**	56
B. (HP100)	-0.0739 (0.5881)	-0.4288 (0.0011)***	0.3027 (0.0234)*	0.4544 (0.0004)***	0.1318 (0.333)	0.4517 (0.0005)***	56
C. (cMM5)	-0.0095 (0.9468)	-0.6507 (0.0000)***	0.5677 (0.0000)****	0.2793 (0.045)*	-0.0564 (0.6912)	0.2859 (0.0399)*	52
D. (cMM7)	-0.0614 (0.672)	-0.5434 (0.0000)***	0.4469 (0.0011)**	0.4054 (0.0035)**	0.1123 (0.4375)	0.4028 (0.0037)**	50
E. (cMM9)	-0.0707 (0.6328)	-0.4405 (0.0017)**	0.3245 (0.0244)*	0.4837 (0.0005)***	0.2165 (0.1394)	0.474 (0.0007)***	48

Notation on P value of the correlation P<0.05\*; P<0.01\*\*; P<0.001\*\*\*

Notes: A. (HP6.25) Subtraction of a HP trend computed with lambda = 6.25; B. (HP100) Subtraction of a HP trend computed with lambda = 100; C. (cMM5) Subtraction of a moving mean with window size w = 5; D. (cMM7) Subtraction of a moving mean with window size w = 7; E. (cMM9) Subtraction of a moving mean with window size w = 9

Table 1. Correlation Analysis of the Carbon Concentration in Atmosphere (Keeling Curve)

Table2: Bench Mark Measure of the Detrending Method (Correlation)

Detrending Method	(ENSON, ENSOP)	(WGDP, WP)	Sample Size N
A. (HP6.25)	-0.5802 (0.0000)***	0.0964 (0.4797)	56
B. (HP100)	-0.43 (0.0009)***	0.2709 (0.0434)*	56
C. (cMM5)	-0.6763 (0.0000)***	0.022 (0.8768)	52
D. (cMM7)	-0.6175 (0.0000)***	0.0707 (0.6256)	50
E. (cMM9)	-0.5188 (0.0002)***	0.0796 (0.5909)	48

Notation on P value of the correlation P<0.05\*; P<0.01\*\*; P<0.001\*\*\*

Table 2.

Table3: Correlation Analysis of the Carbon Concentration in Atmosphere (Keeling Curve)

Detrending Method	TT	WTGDP	TGDPPC	MT	MTGDP	MTGDPPC	Sample Size N
A. (HP6.25)	0.1377 (0.3206)	0.2454 (0.0737)^	0.2472 (0.0715)^	0.1703 (0.2183)	0.2519 (0.0662)^	0.2534 (0.0645)^	56
B. (HP100)	0.1162 (0.3938)	0.2591 (0.0538)^	0.2563 (0.0565)^	0.1296 (0.3411)	0.2337 (0.0829)^	0.2316 (0.0858)	56
C. (cMM5)	0.0911 (0.5209)	0.1989 (0.1575)	0.2007 (0.1538)	0.0971 (0.4933)	0.1864 (0.1859)	0.1878 (0.1825)	52
D. (cMM7)	0.0911 (0.5209)	0.1989 (0.1575)	0.2007 (0.1538)	0.0971 (0.4933)	0.1864 (0.1859)	0.1878 (0.1825)	50
E. (cMM9)	0.1869 (0.2034)	0.3173 (0.0280)*	0.3145 (0.0295)*	0.2496 (0.0871)	0.3381 (0.0188)*	0.336 (0.0196)*	48

Notation on P value of the correlation P<0.1^; P<0.05\*; P<0.01\*\*; P<0.001\*\*\*

Notes: A. (HP6.25) Subtraction of a HP trend computed with lambda = 6.25; B. (HP100) Subtraction of a HP trend computed with lambda = 100; C. (cMM5) Subtraction of a moving mean with window size w = 5; D. (cMM7) Subtraction of a moving mean with window size w = 7; E. (cMM9) Subtraction of a moving mean with window size w = 9

TT: total trade % of GDP; WTGDP: total trade GDP; TGDPPC: total trade GDP per capita; MT: Merchandise Trade % of GDP; MTGDP: Merchandise Trade GDP; MTGDPPC: Merchandise Trade GDP per capita

Table 3. Correlation Analysis of the Carbon Concentration in Atmosphere (Keeling Curve)

economic indicator is much weaker than using whole economics as indicators (trade GDP vs. GDP; merchandise GDP per capita vs. GDP per capita etc.). This study shows that this characteristic is still true when an alternative carbon accounting method is employed.

Furthermore, identical tests were performed for several trade indicators (total trade and merchandise trade in dollars and in % GDP), and none of these indicators show strongly significant relationships (see Table 3). According to (Cole 2004), the manufacture share of GDP is not related to carbon emissions. The idea proposed by Cole (2004), that demographic analysis using a portion (%) of the economy is not a good indicator of environment impact, is examined by analyzing total trade and merchandise trade in dollars and in % GDP. Results show that using a portion of the economic indicator is much weaker than using whole economics as indicators (trade GDP vs. GDP; merchandise GDP per capita vs. GDP per capita etc.). This study shows

that this characteristic is still true when an alternative carbon accounting method is employed.

Finally, the ENSO index reveals significant correlations with CO<sub>2</sub> at lags -1 and 1, but not at lag 0 (see Table 1). This is not a new discovery, but confirms the result of Grandiose (2008), which used more years of data (eight data points or 15% more for all detrending methods). As the correlations are negative at lag -1 and positive at lag 1, the pattern confirms the effect of ENSO activity on natural sinks of CO<sub>2</sub>. In the year preceding high ENSO activity, there was high sequestration of CO<sub>2</sub> and concentrations increased below the average rate, while in the year following high ENSO activity, the opposite occurred, and CO<sub>2</sub> concentrations increased by more than the average trend.

### Sample Multivariable Regression to Confirm Key Findings (Table 6)

In this section, I use multivariable regression to see



Table6 Multivariable Regressions Keeling: ENSOP, World GDP, World Population or GDP per Capita													
	ENSOP			WGDP			WP			P-Value	RMSE	R-sq	F
	$\beta$	SE	P-Value	$\beta$	SE	P-Value	$\beta$	SE					
HP6.25	0.02023	0.005097	0***	0.172627	0.089053	0.058	-0.00324	0.016252	0.843	0.25182	0.2865	6.692275	
HP100	0.015845	0.006004	0.011 *	0.295386	0.086626	0.001***,0094508	0.007921	0.238	0.33414	0.2941	7.21999		
cMM5	0.02235	0.004837	0***	0.101105	0.093844	0.287	-0.0033	0.02176	0.880	0.268709	0.3345	7.708063	
cMM7	0.019989	0.00549	0.001***	0.214965	0.088531	0.019*	0.019593	0.019134	0.311	0.307663	0.3118	6.643625	
cMM9	0.018032	0.006339	0.007**	0.275874	0.085163	0.002**	0.026393	0.014832	0.082^	0.334892	0.3212	6.939207	
HP6.25	0.020192	0.005045	0***	0.171934	0.088143	0.057				0.249438	0.2859	10.2108	
HP100	0.015536	0.006023	0.013*	0.313322	0.085652	0.001***				0.335472	0.2747	10.03799	
cMM5	0.022378	0.004783	0***	0.101388	0.092845	0.28				0.265901	0.3342	11.79581	
cMM7	0.019724	0.005487	0.001***	0.216073	0.088572	0.019 *				0.307829	0.2954	9.431026	
cMM9	0.016466	0.006427	0.014 *	0.280103	0.087155	0.002**				0.342858	0.2723	8.420232	
HP6.25	0.020576	0.005229	0***				-0.00201	0.016673	0.905	0.258539	0.2329	7.740982	
HP100	0.016041	0.006579	0.018 *				0.014138	0.008547	0.104	0.36611	0.1362	4.178448	
cMM5	0.022581	0.00484	0***				-0.00376	0.021793	0.864	0.269168	0.3177	10.94431	
cMM7	0.019989	0.005781	0.001***				0.020161	0.020147	0.322	0.323968	0.2195	6.328945	
cMM9	0.018048	0.006976	0.013 *				0.027734	0.016315	0.096	0.368528	0.1593	4.262791	
				GDPPC									
				$\beta$	SE	P-Value				RMSE	R-sq	F	
HP6.25	0.01975	0.004969	0***	0.001226	0.000515	0.021				0.245306	0.3094	11.42402	
HP100	0.015427	0.00594	0.012*	0.001924	0.000493	0***				0.330839	0.2946	11.0685	
cMM5	0.022022	0.00473	0.000***	0.000862	0.000546	0.121				0.262378	0.3517	12.75003	
cMM7	0.01922	0.005368	0.001***	0.001465	0.000509	0.006**				0.301019	0.3262	10.89207	
cMM9	0.01597	0.006283	0.015*	0.001789	0.000498	0.001***				0.335099	0.3049	9.868672	

Table 6. Multivariable Regressions Keeling: ENSOP, World GDP, World Population or GDP per Capita

two key points that was discovered in section IV-1: First, both GDP and GDPPC are good indicators of Keeling Curve while population is not. Second, GDP and GDPPC behave very similar in Keeling Curve-Economic Modeling. This result confirm these two findings. The absent of population did not affect (or even improve) the regression result. From the second and the fourth columns, regression coefficient and R-sq does not change much at all. Which indicate that GDPPC and WGDP are similar factors in this model.

The coefficient parameter estimates for the effect of WGDP on CO<sub>2</sub> concentrations (use column two average correlation of GDP is 0.2 ) indicate that for each trillion dollar that WGDP deviates from trend, CO<sub>2</sub> atmospheric levels deviate from trend, in the same direction about 0.2 of a part per million ( $\pm 0.1$ ). If one focus on the fourth column. One can see that per one thousand dollar GDP per capita deviates from trend for all humankind, CO<sub>2</sub> atmospheric levels deviate from trend, in the same direction about 1.4 of a part per million ( $\pm 0.5$ ).

## Conclusion

The goal of this research was to examine an alternative carbon accounting methodology. It was shown that GDP is a strong indicator of the Keeling Curve, while population is not. Based on an assumption that affluence level are correlated with income level, affluence level (GDP per capita) is a consistent indicator of the Keeling Curve, which is a surprising result given the poor correlation between the Keeling Curve and population. Trade indicators (total trade and merchandise trade) are relatively weak indicators of atmospheric carbon concentration. The result that affluence level is a good indicator of the Keeling Curve is important because it allows atmospheric carbon concentration to be used in existing reduced form models, such as EKC models and CGE models, by substituting emission data

with Keeling Curve data. GDP and GDPPC behave similar in their correlation with Keeling Curve. This may imply that these two factors can substitute each other to some degree. Economic activity and affluent level can be interchanged in carbon concentration modeling according to this result. This paper, among a few others, counter the claim in Lieb, 2004 which both mentioned early in this paper.

From a broader aspect, the conclusion from this paper is not consistent with the Malthusian school of thought (on population as a cause for environment depredation), but one should read about Lambda affecting the detrending result. In comparison to existing research, this methodology has both advantages and disadvantages. The advantage is that human carbon emissions can be measured using atmospheric concentration, which may be more accurate than estimation methods. Geological factors that affect this atmospheric measurement can also easily be taken into consideration (e.g. ENSO). The disadvantage is that the Keeling Curve is an aggregate factor. There is currently no effective way to link this data to a precise demographic/national model (e.g. Nordhaus's DICE 2008). This therefore constitutes a topic for research in the near future. Further improvement could be made regarding the effect of volcanic eruptions on atmospheric carbon concentration.

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## Xingyu Lu

Economics

Xingyu “Lux” Lu recently graduated from UCSD with degrees in Economics and Biology. He is continuing his graduate study at UCSD for master in public policy where he plans to focus policies on energy and environment. He plans to pursue Ph.D. in agriculture and resource economics after his master program.

Lux is an early member of the largest environmental NGO in China (Friend of Nature). He participated in movement regarding the construction of Three Gorges Dam, citing unclear evaluation of environmental impact. Lux likes to learn and play all kinds of strategy games during his spare time. He enjoys playing chess, bridge, and poker.

Mr. Lu suffers from type II bipolar disorder; he did all his research related projects during his hypomanic episode. He wrote this paper in four weeks.

### What motivated you to get into research?

I have been influenced greatly by Neo-Malthusian thought. In particular, some early books, including *The Population Bomb* by Paul R. Ehrlich and *Limit to Growth* by Dennis Meadows, Donella Meadows, Jørgen Randers, William W. Behrens II. In college, I have been heavily influenced by “A Review of the Stern Review on the Economic of Climate Change” by William Nordhaus.

### What do you enjoy about research?

For me, raw passion is what motivated me. I care about sustainable development. Of course, sometimes the research, when you’re doing it, is not enjoyable, is not fun. It’s a lot of text and technical work. Still, research- it’s not a religion or a belief, but if my work makes a better world, I will do it.

### What does research mean to you?

I always say research is reading after thoughts- after reading papers and chapters, and generating your own belief. You think, so you’re alive. The research is a transcript of how you think, what you think. Obviously there’s other work, like writing or reading that takes most of the time, but thinking is the most important part. Reading other people’s thoughts and generating your own. The personal opinion that was put into some of the research is not decisive, but is important.

### What has been your greatest challenge in research?

For me, it’s more the technical stuff- some of it is not so easy. A lot of the methodology is divided by series and as an undergraduate, if you look at it and want to use it right away it’s almost impossible. For example, Professor X at UCSD, has the latest data; however, there is a technical challenge for undergrads because the lack of cross discipline technicalities. Professors think it’s easy to grasp- they give you an abbreviation and expect the student to be able to understand or perform all the stuff on the computer, but as a student you see a lot of technical stuff. At the end, it’s more like learning by doing.

### What advice would you give to your first-year self?”

Take as many math and CS classes as possible. And figure out what you want to do for your life. For me, I strongly oppose getting the highest earning job and worrying about your life later. Finding your passion should come before any job.

### How do you keep your life in balance?

Ahh, I don’t. My life is kind of tweaked. I suggest to other people: don’t do it that way. It’s true. For me, it’s this project, next project- it never ends so you have to have a lot of passion. You want to do something and your life is tweaked and you just keep doing it. You don’t try to balance it. It’s the truth.