NORTHERN ARIZONA UNIVERSITY
The W. A. Franke College of Business

Is Global Warming Mainly Due to Anthropogenic GHG Emissions?

Working Paper Series—09-14 | November 2009

Xiaobing Zhao[1]
The W. A. Franke College of Business
Northern Arizona University
20 W. McConnell Drive, Room 311
PO Box 15066
Flagstaff, AZ 86011-5066
E-mail: Xiaobing.Zhao@nau.edu
Phone: (928) 523-7279
Fax: (928) 523-7331

[1] I thank Professor Dean Smith and participants at the 2009 Western Social Science Association Meetings for helpful comments.

Is Global Warming Mainly Due to Anthropogenic GHG Emissions?

1. Introduction

Evidence in support of the notion of global warming is accumulating. In its most comprehensive and up-to-date scientific assessment of climate change, the 2007 Nobel Peace Prize recipient Intergovernmental Panel on Climate Change (IPCC) concludes that “Warming of the climate system is unequivocal” (IPCC, 2007, Working Group I Report Summary for Policymakers, p. 5). The IPCC’s best estimate for global average surface warming at the end of the 21st century ranges from 1.8°C (with 66 percent confidence interval from 1.1°C to 2.9°C) to 4.0°C (with 66 percent confidence interval from 2.4°C to 6.4°C). The most commonly used benchmark is a 3.0 degrees Celsius increase in temperature (e.g. Nordhaus, 2006).

Global warming is important because it may have a significantly adverse impact on economic activities. Researchers have studied the economic impact of global warming with both the structural approach and the reduced-form approach. It is estimated that the adverse economic impact of a 3.0 degrees Celsius increase in temperature can be as much as a three percent permanent decrease in gross domestic product (GDP)! [2]

Given its significantly adverse economic impact, it is therefore critically important to understand the major cause of global warming. It is important to note that there is still a debate regarding the main cause of global warming. Many researchers represented by IPCC (2007) strongly believe that global warming is mainly due to anthropogenic greenhouse gas (GHG) emissions. IPCC (2007) states that “Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations” (Working Group I Report: Summary for Policymakers, p. 10). However, other researchers such as Lindzen (2007) do not agree. Lindzen (2007) argues that the models used by IPCC are oversimplified and overstate the significance of anthropogenic greenhouse gases. Based on a more physically-sound model, Lindzen (2007) estimates a bound on the greenhouse contribution to recent global warming of about 1/3. One key insight of Lindzen (2007) is that the IPCC models omit many important climate factors such as El Niño, the Little Ice Age, the Medieval Warm Period, etc. Many of which are long-time scale phenomena (involving time scales of several years or even centuries), which we do not understand.

The on-going controversy regarding the causes of global warming has significant policy implications. If global warming is mainly due to anthropogenic GHG emissions, GHG mitigation policy may be justified; however, if it is not the case, there is little reason to sacrifice about 0.12% economic

[2] See Mendelsohn et al. (2000), Nordhaus and Boyer (2000), Horowitz (2001), Tol (2002), and Nordhaus (2006).

growth to stabilize CO_2 concentration.[3] Due to its critical importance, we revisit this issue. We propose a reduced-form regression-based test that takes into account the long-time scale climate phenomena. With the U.S. state-level data, we find scant evidence in support of the notion that global warming is mainly due to anthropogenic GHG emissions. Our results therefore call for more research on the causes of recent global warming to more precisely pinpoint its causes and suggest appropriate remedial actions.

The remainder of the paper is organized as follows: Section 2 discusses the debate in more detail. Section 3 presents the data and our empirical methodology. Section 4 reports the empirical results. Section 5 concludes the paper with a brief summary.

2. The Debate

Lindzen (2007) provides an excellent discussion of the debate. We summarize his main points here. The standard global-warming models such as those in IPCC (2007) are based on two ideas: (1) it is primarily thermal radiation that cools the surface of the earth, and (2) greenhouse gases reduce this cooling and serve as a blanket which causes the earth to be warmer than it otherwise would be. Based on the standard models, researchers conclude that recent global warming is mainly due to anthropogenic GHG emissions, because (1) global atmospheric concentrations of GHG have increased dramatically as a result of human activities since 1750 and now far exceed pre-industrial levels, and (2) researchers could not find anything else that could account for recent warming.[4]

However, Lindzen (2007) argues that the standard model is *oversimplified*, because "*the surface of the earth does not cool primarily by thermal radiation*" (p. 939). His argument is that there is so much GHG opacity immediately above the ground that the surface cannot effectively cool by the emission of thermal radiation. Instead, heat is carried away from the surface by fluid motions. These motions carry the heat upward and poleward to levels where it is possible for thermal radiation emitted from these levels to escape to space. This level is referred to as the characteristic emission level by Lindzen (2007).

---

[3] After evaluating various climate-change mitigation strategies, IPCC (2007) estimates that stabilizing CO_2 concentrations and limiting the long-term temperature rise may result in a 0.12 percent reduction in the annual growth rate of global GDP.

[4] For instance, Alan Thorpe, the head of NERC states "The size of the recently observed global warming, over a few decades, is significantly greater than the natural variations in long simulations with climate models (if carbon dioxide is kept at pre-industrial levels). Only if the human input of greenhouse gases is included does the simulated climate agree with what has been recently observed." (http://www.nerc.ac.uk/about/consult/debate/debate.aspx?did=1&pg=1). The arguments are the same as those presented in Chapter 12 of the IPCC Working Group I Third Assessment Report (2001).

When the earth is in a radioactive balance with space, the net incoming solar radiation is balanced by the outgoing longwave radiation from the characteristic emission level. When greenhouse gases are added to the atmosphere, the characteristic level is raised in altitude, and, because the temperature of the atmosphere decreases with altitude, the new characteristic emission level is colder than the previous level. As a result, the outgoing longwave radiation no longer balances the net incoming solar radiation, and the earth is no longer in thermal balance with space. In order to reestablish balance, the temperature at the new characteristic level must increase to about the temperature that had existed at the initial characteristic level. Therefore, it is the warming at characteristic level that is the fundamental warming associated with the climate greenhouse effect.

How warming at the characteristic level relates to warming at the surface is not straightforward. However, Lindzen (2007) argues that the warming at characteristic level is from more than twice to about three times larger than near the surface regardless of which models researchers use.[5] Since the trend in the troposphere is about 0.1 degree C per decade, this should be associated with a surface trend of between 0.033 and somewhat less than 0.05 degrees per decade, which is a third of the observed trend at the surface. Lindzen (2007) stresses that this is a bound more than an estimate, because warming at characteristic level does not have to be greenhouse warming. Therefore, Lindzen (2007) concludes that global warming is not mainly due to anthropogenic GHG emissions.

In reply to the claim that nothing else could account for recent warming, Lindzen (2007) points out that the standard models omit many important climate factors such as El Niño, the Little Ice Age, the Medieval Warm Period, etc. Many of which are long-time scale phenomena (involving time scales of several years or even centuries).[6] However, it is also clear that we do not have adequate understanding of these effects to fully take them into account in structural models. This observation motivates us to use a reduced-form approach to examine the relationship between recent global warming and anthropogenic GHG emissions. Furthermore, as Campbell and Diebold (2005) point out, although structural atmospheric models may be best for modeling and forecasting for a short horizon, it is not at all obvious that they are best for longer horizons. Successful modeling and forecasting does not necessarily require a structural model, and in the last several decades statisticians and econometricians have made great strides in the nonstructural modeling and forecasting of time series trend, seasonal, cyclical, and noise components.

[5] See also Lee et al. (2007).

[6] See also Tsonis et al. (2007) and Smith et al. (2007).

3. Empirical Methodology and Data

3.1 Empirical Methodology

We follow Campbell and Diebold (2005) and assume a simple linear model for temperature. Let

$$T_{i,t} = a + bGHG_{i,t} + \sum_{j=1}^{k} c_j GC_{i,t}^{j} + e_{i,t} \qquad (1)$$

where $T_{i,t}$ is the temperature at location *i* in year *t*, $GHG_{i,t}$ is the corresponding GHG concentration, *GC*s represent relevant geographic and climate factors such as altitude, latitude, and the effects of long-time scale phenomena such as El Niño, the Little Ice Age, the Medieval Warm Period, etc., and *e* represents a random shock. We assume the values of *GC*s do not change in the short run (over a year) since by nature they represent long-term effects or fixed geographic effects. Then we can simplify our model by focusing on the first difference instead of the level of temperature. That is,

$$\Delta T_{i,t} = b\Delta GHG_{i,t} + \Delta e_{i,t} \qquad (2)$$

where $\Delta GHG_{i,t}$ represents the change in GHG concentration. We assume it is equal to the GHG emission for simplicity. The insight of this simple model is that even if there may be some long-term scale phenomena that we do not understand, as long as their effects are long term and do not change much from one year to another, we can still isolate their effects and estimate the relationship between GHG emissions and temperature changes with such a simple regression model. The coefficient estimate of *b* would be statistically insignificantly different from what we would get with a full-scale model in Equation (1).

Following Lindzen (2007), we focus on the equilibrium instead of transient relationship between GHG concentrations and temperature. To estimate this equilibrium relationship, we implement a regression approach widely used in the financial economics literature, which is proposed by Fama and MacBeth (1973) and more recently applied by George and Hwang (2004). Specifically, we estimate the cross-sectional model in Equation (2) for each year, and then average the year-by-year estimates of *b*. This average represents the equilibrium not transient relationship between GHG concentrations and temperature, because it is based on cross-sectional regressions not time-series regressions.

The effect of CO_2 emissions on temperature may take time to show up. We therefore also consider two alternative regression models. The first model is

$$\Delta T_{i,t} = b\Delta GHG_{i,t-k} + \varepsilon_{i,t} \qquad (3)$$

where $\varepsilon_{i,t}$ is a random shock. We assume that it takes as many as *k* years for GHG emissions to affect temperature, where *k* = 0, 1, 2, 3, 4, and 5. The second model is

$$\Delta T_{i,t} = b\sum_{k=0}^{K} \Delta GHG_{i,t-k} + \varepsilon_{i,t} \quad (4)$$

where again $\varepsilon_{i,t}$ is a random shock. We basically assume that GHG emissions in the past *k* years all affect temperature, where *k* = 0, 1, 2, 3, 4, and 5.

3.2 Data

We focus on the 48 contiguous states of the U.S. and CO_2 emissions from fossil fuel combustion to carry out our cross-sectional analysis mainly due to data availability. According to Department of Energy,[7] nationally, CO_2 emissions from fossil fuel combustion represented the largest source (80%) of total global warming potential (GWP) weighted emissions from all emission sources in 2006 (EPA, 2008). Similarly, CO_2 emissions from fossil fuel combustion are the largest source of GHG emissions within individual states. While emissions from other sources (i.e. industrial processes, solvents, agriculture, waste, and land-use, land-use change, and forestry) are important and are often significant within a state, they are not available due to a lack of data, higher level of uncertainty in quantification methods, and smaller contribution to total emissions. The annual CO_2 emissions from fossil fuel combustion data are available for the period from 1990 to 2005 for all 50 states.

The monthly temperature data from 1895 to 2009 for the 48 contiguous states of the U.S. are available from the National Climatic Data Center. We calculate the annual temperature as the simple average of the monthly temperatures from January to December. Since our CO_2 emissions data are only available from 1990 to 2005 and our temperature data are only available for the 48 contiguous states, we focus on the relationship between temperature and CO_2 emissions in the 48 contiguous states over 1990 to 2005.

Table 1 presents some summary statistics. As we can see, there are large variations in both temperature and CO_2 emissions across the U.S. The average temperature goes from 40.94 deg F in North Dakota to 66.97 deg F in Louisiana, where the average emission goes from 6.3 million metric tons CO_2 ($MMTCO_2$) in Vermont to 650 $MMTCO_2$ in Texas. The year-to-year changes in average temperatures measured by the standard deviations are also not trivial, from 0.76 in California to 1.75 in North Dakota and South Dakota. Therefore, our sample provides non-trivial variations in both dependent and independent variables for testing the main hypothesis whether global warming is mainly due to anthropogenic GHG emissions.

[7] http://www.epa.gov/climatechange/emissions/state_energyco2inv.html.

Table 1. Summary Statistics (1990-2005)

State	Temperature		CO_2 Emission		State	Temperature		CO_2 Emission	
	Mean	STDEV[1]	Mean	STDEV		Mean	STDEV	Mean	STDEV
Alabama	63.20	0.92	130.22	9.28	Nebraska	49.36	1.39	39.40	3.71
Arizona	61.34	0.82	77.53	11.60	Nevada	50.62	0.93	39.38	5.54
Arkansas	60.88	1.03	58.79	5.04	New Hampshire	44.27	1.21	16.93	2.41
California	59.89	0.76	368.72	16.61	New Jersey	53.26	1.17	125.21	5.02
Colorado	46.05	1.07	79.76	9.45	New Mexico	54.19	0.88	54.43	3.40
Connecticut	49.55	1.31	41.11	2.09	New York	46.01	1.39	206.14	6.59
Delaware	55.82	1.16	17.58	0.97	North Carolina	59.50	0.97	136.09	13.75
Florida	71.15	0.73	221.71	24.20	North Dakota	40.94	1.75	45.17	2.46
Georgia	63.84	0.93	155.67	15.05	Ohio	51.39	1.34	256.88	7.43
Idaho	45.21	1.06	13.85	1.53	Oklahoma	59.94	0.98	97.45	4.50
Illinois	52.37	1.32	218.63	15.79	Oregon	49.12	0.88	38.68	3.68
Indiana	52.21	1.34	216.95	12.26	Pennsylvania	49.41	1.25	268.51	5.97
Iowa	48.21	1.45	74.16	5.79	Rhode Island	50.63	1.26	12.00	1.31
Kansas	54.77	1.17	72.48	3.24	South Carolina	62.79	0.96	73.34	8.86
Kentucky	56.19	1.15	139.65	10.49	South Dakota	45.63	1.75	12.97	0.73
Louisiana	66.97	0.80	198.60	6.62	Tennessee	58.10	1.02	118.77	8.07
Maine	41.27	1.23	20.83	1.78	Texas	65.42	0.84	650.14	44.84
Maryland	54.79	1.15	74.95	4.80	Utah	49.53	1.09	59.47	4.02
Massachusetts	48.41	1.22	83.01	1.81	Vermont	43.01	1.37	6.30	0.41
Michigan	45.06	1.51	188.75	6.06	Virginia	55.65	1.09	111.39	11.20
Minnesota	41.84	1.73	91.38	7.18	Washington	49.05	0.98	80.93	4.31
Mississippi	63.73	0.88	57.04	6.84	West Virginia	52.26	1.09	108.66	5.72
Missouri	55.01	1.22	121.82	13.69	Wisconsin	43.83	1.59	100.49	8.28
Montana	43.32	1.40	31.33	2.29	Wyoming	42.56	1.10	61.04	2.27

[1] STDEV stands for standard deviation.

CO_2 emissions from fossil fuel combustion are from Department of Energy at http://www.epa.gov/climatechange/emissions/state_energyco2inv.html. The monthly temperature data for the 48 contiguous states of the U.S. are from the National Climatic Data Center. We calculate the annual temperature as the simple average of the monthly temperatures from January to December. Table 1 presents summary statistics.

4. Empirical results

The results based on Equation (2) are presented in Table 2. We report the cross-sectional regression results for each year as well as the average coefficient estimate. Since our dependent variable is the change in temperature, our sample starts in 1991. As we can see, in none of 15 years is there a significant positive relationship between temperature changes and CO_2 emissions across the 48 states. The average coefficient estimate is also not statistically significant.

Table 2. Regression Results (1990-2005)

	Estimate of *b*	t-statistics	Adj-R^2
1991	0.0004	0.57	-0.01
1992	-0.0007	-0.30	-0.02
1993	0.0033	1.71	0.03
1994	-0.0030	-1.57	0.05
1995	0.0005	0.59	-0.01
1996	0.0015	1.73	0.02
1997	-0.0022	-1.91	0.02
1998	0.0009	0.36	-0.02
1999	-0.0016	-1.06	0.02
2000	0.0016	1.55	0.01
2001	-0.0012	-1.22	0.01
2002	0.0005	0.63	-0.01
2003	-0.0010	-0.50	-0.02
2004	0.0011	0.94	0.00
2005	-0.0004	-0.61	-0.02
Average	**0.0000**	**-0.02**	**0.00**

We estimate the following cross-sectional model for each year and then average the year-by-year estimates of *b*.

$$\Delta T_{i,t} = b\Delta GHG_{i,t} + \Delta e_{i,t}$$

where $T_{i,t}$ is the temperature at location *i* in year *t*, and $\Delta GHG_{i,t}$ represents the GHG emission.

If it takes time for CO_2 emissions to affect temperature, Equation (2) is misspecified. We therefore also test the relationship between temperature changes and CO_2 emissions based on Equations (3) and (4). We only report the average coefficient estimates and their associated t-ratios, for k = 0, 1, 2, 3, 4, and 5. As we can see, even if we take into account the lagged effects of CO_2 emissions, there is still no evidence in support of the notion that recent global warming is mainly due to CO_2 emissions. This is the key finding of the paper.

Table 3. Lagged regression

Lag	Average estimate of *b*	t-statistics	Average Adj-R^2
0	-0.00001	-0.02	0.00
1	0.00000	-0.01	0.00
2	0.00005	0.23	0.01
3	-0.00025	-1.16	0.01
4	-0.00002	-0.09	0.00
5	-0.00002	-0.15	0.00

The effect of CO_2 emissions on temperature may take time to show up. We therefore consider the following alternative regression model:

$$\Delta T_{i,t} = b\Delta GHG_{i,t-k} + \varepsilon_{i,t}$$

where $T_{i,t}$ is the temperature at location *i* in year *t*, and $\Delta GHG_{i,t}$ represents the GHG emissions. We assume that it takes as many as *k* years for GHG emissions to affect temperature, where *k* = 0, 1, 2, 3, 4, and 5. To save space, we only report the average coefficient estimates and their associated t-ratios.

Table 4. Lagged cumulated emission regression

Lag	Average estimate of *b*	t-statistics	Average Adj-R^2
0	-0.00001	-0.02	0.00
1	0.00000	-0.01	0.00
2	0.00002	0.23	0.01
3	-0.00006	-1.16	0.01
4	-0.00000	-0.09	0.00
5	-0.00000	-0.15	0.00

The effect of CO_2 emissions on temperature may take time to show up. We therefore consider the following alternative regression model:

$$\Delta T_{i,t} = b\sum_{k=0}^{K} \Delta GHG_{i,t-k} + \varepsilon_{i,t}$$

where $T_{i,t}$ is the temperature at location *i* in year *t*, and $\Delta GHG_{i,t}$ represents the GHG emissions. We assume that GHG emissions in the past *k* years all affect temperature, where *k* = 0, 1, 2, 3, 4, and 5. To save space, we only report the average coefficient estimates and their associated t-ratios.

5. Conclusion

Although there is little controversy about global warming, there is still a debate regarding whether global warming is mainly due to anthropogenic GHG emissions. Many researchers represented by IPCC (2007) strongly believe that global warming is mainly due to anthropogenic GHG emissions. However, other scientists such as Lindzen (2007) argue that the standard models are oversimplified by omitting many important climate factors and therefore overstate the importance of CO_2 emissions. Due to the critical importance of this debate, we revisit the issue. We propose a reduced-form regression-based test, which does not force us to select an equilibrium structural atmospheric model and therefore may avoid model specification error. With the temperature and CO_2 emissions data from the U.S., we find little evidence in support of the notion that recent global warming is mainly due to CO_2 emissions. Our results may not be precise since we do not model short-time scale climate factors that may affect temperature over a year and our sample period is very short and limited to the U.S. However, the point of the paper is that the effect of CO_2 emissions on temperature changes may not be as significant as many researchers believe, and therefore, more research should be devoted to understanding this issue before society decides to sacrifice about 0.12% economic growth to stabilize CO_2 concentration (see IPCC, 2007).

References

Campbell, S. D, Diebold, F. X. 2005. Weather Forecasting for Weather Derivatives. *Journal of the American Statistical Association* vol. 100:6-16.

EPA. 2008. Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2006. U.S. Environmental Protection Agency, Washington, D.C., April 15, 2008. EPA 430-R-08-005

Fama, E. F., and MacBeth, J. 1973. Risk, Return and Equilibrium: Empirical Tests. *Journal of Political Economy* 81:607-636.

George, T. J., and Hwang, C. 2004. The 52-Week High and Momentum Investing. *Journal of Finance* 59:2145-2176.

Horowitz, J. 2001. The Income–Temperature Relationship in a Cross-Section of Countries and Its Implications for Global Warming. Working paper, University of Maryland, Maryland.

IPCC. 2001. Climate Change 2001, the Scientific Basis. Cambridge, UK: Cambridge University Press.

IPCC. 2007. Summary for Policymakers, Fourth Assessment Report, Working Group I.

Lee, M. I., Suarez, M.J., Kang, I.S., Held, I. M., and Kim, D. 2008. A Moist Benchmark Calculation for the Atmospheric General Circulation Models. *Journal of Climate* 21:4934–4954.

Lindzen, R.S. 2007. Taking Greenhouse Warming Seriously. *Energy & Environment* 18: 937-950.

Mendelsohn, R., Morrison, W., Schlesinger, M., and Andronova, N. 2000. Country-Specific Market Impacts of Climate Change. *Climatic Change* 45:553-569.

Nordhaus, W. 2000. Geography and Macroeconomics: New Data and Findings. *Proceedings of the National Academy of Science* 103:3510-3517.

Nordhaus, W., and Boyer, J. 2000. Warming the World: the Economics of the Greenhouse Effect. Cambridge, MA: MIT Press.

Smith, D. M., Cusack, S., Colman, A. W., Folland, C. K., Harris, G. R., and Murphy, J. M. 2007. Improved Surface Temperature Prediction for the Coming Decade from a Global Climate Model. *Science* 317:796-799.

Tol, R. 2002. Estimates of the Damage Costs of Climate Change–Part II: Ddynamic Estimates. *Environmental and Resource Economics* 21:135-160.

Tsonis, A. A., Swanson, K., and Kravtsov, S. 2007. A New Dynamical Mechanism for Major Climate Shifts. *Geophysical Research Letters* 34: L13705.