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# Is There a Path for Green Growth? Evidence from India

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**Abstract**
This paper uses historical temperature fluctuations in India to identify its effects on economic growth rates. Using a climate-adjusted form of the Solow growth model, I find that one degree Celsius increase in temperature decreases GDP per capita growth by 0.71%. This finding informs debates over the role of climate on economic development and suggests the possibility of a green path for economic growth, a policy agenda that is both sustainable and pro-growth.

**Keywords**
India, economic growth rate, temperature fluctuation, Solow growth model, green growth

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Abstract

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## I. Introduction

Climate change from greenhouse gas emission is infamously known as the "mother" of all negative externality of the market, a problem that requires international corporation to mitigate. While scientists are still debating the severity of this problem, in my opinion it is still very hard to agree with the 45th President of the United States. Climate change is not a hoax created by the Chinese government when 195 countries have already signed the Paris Agreement in March to reduce temperature by 1.5° Celsius by cutting greenhouse gas emissions. The potential repercussions of one country's pulling out from an important agreement like this are the motivation for my paper. Thus, the purpose of this paper is not to provide new insight on the science of climate change, but only to use empirical data from India to establish that temperature change negatively affect economic growth.

Often, when growth is taught in undergraduate neo-classical economics classes, there are only three factors involved: technology, labor and capital represented in the Solow growth model. At steady state, the only catalyst for economic growth according to the Solow growth model is technology. In context of a developing country where agriculture contributes mainly to annual GDP growth - the measure of economic growth in this paper – temperature change plays a role in economic growth. Technology may increase crops productivity to a certain extent, but unusual heat and drought or excessive precipitation and flooding affect the year's agricultural outcomes almost instantly, not to mention other non-economic consequences such as diseases and conflicts (Hsiang, Burke & Miguel, 2013) . These non-economic outcomes have been found to affect human capital and productivity, which is the catalyst for growth in the Solow growth model (Zivin and Neidell, 2012 & 2013). In addition to agriculture, industrial output might suffer when extreme weather affects resource productivity. If the rate of temperature change is as significant as most environmental scientists speculate, long term economic growth for a developing country like India will suffer. Thus, for economists, a relationship between temperature anomaly and economic growth contributes to the growing research on the economic consequences of "one of the biggest market failure the world has seen" (Stern, 2007). The development of a growth model that encompasses systematic changes like climate change will open new path to more creative policies with even more potentials improve people's lives especially in the more vulnerable population of the world.

While there has been significant progress towards growth in the developing world, the challenge of overcoming poverty and inequality will be greatly compounded by climate change and environmental degradation, which disproportionately hurt the poor and most vulnerable. These increasingly interlinked crises threaten development gains and prospects for continued progress. While the Paris agreement is one commitment on paper to do more, the world's collective response has fallen far short of what is needed. Unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality (Burket, Hsiang and Miguel, 2015). Thus, if adequately examined, this research question poses an interesting policy outlook: if there is a relationshop between economic growth and climate change, then any investment in a sustainable economy will in turn have a positive feedback on the economy, open up opportunity for green growth. On top of that, there are great potentials for delivering a "triple bottom line" of job–creating economic growth coupled with environmental protection and social inclusion (World Resources Institute, 2012)**.** Developing countries might benefit greatly from an investment in sustainable growth, both economically and environmentally. The economic benefits of a transition to a green economy is a question that not only policymakers would want answers to, but also every sector of the economy and are relevant to all investors and businesses. For investors, if there is consensus on how climate change negatively affects the economy, investments in "socially responsible" businesses are more attractive as these businesses are contributing more to the economy's growth than regular businesses. The benefits of being a sustainable business may outweigh the costs, which incentivizes businesses to internalize their carbon emission. Decisions made by private sector investors and financial institutions will have a major influence on how society responds to climate change.

For many developing nations, current climate policies agenda means relying heavily on financial and technical assistance from developed countries. Additionally, many developing nations are not solely concerned about climate change, but also prioritize expanding energy access to their peoples in order to move toward a better standard of living. One country that faces this dichotomy is India, for its economic status, population challenge and energy issues. It is the fourth largest greenhouse gas (GHG) emitter, accounting for 5.8 percent of global emissions. India's emissions increased by 67.1% between 1990 and 2012, and are projected to grow 85% by 2030[2].Yet, India faces a major energy issue: nearly 300 million people that do not have access to even one electric light bulb[3].This is even more challenging because the mean rate of population growth in is 1.9% (Table 2), which is relatively high when compared to developed nations[4]. How India balances expanding electricity access and economic targets while at the same time achieving its climate targets will indeed be paramount to the future of global climate change action. Thus, the answer to my research question is will provide a clear picture to achieve the twofold challenge of green economic growth. Ebinger (2016), in the Brookings policy brief even asserts that, "If India fails, Paris (Agreement) will fail".

In the next section, I will describe what has been done in the literature surrounding the relationship between economic growth and temperature change. In section III, I will develop a regression model to answer my research question based on a climate-Solow growth model. In section IV, I will discuss the data collected to test my hypothesis, and in section V, I will use that data with my theory as evidence for my question. In section VI, I will conclude.

## II. Literature review

There is a large and growing literature that examines the causal effect of temperature change on economic growth. It is not my objective to review all studies; rather, the goal is to review those studies that have some connections to my research question. The literature suggest that impact of climate change on GDP growth are found through two channels: climate direct impact on aggregate output and pollution impact on human capital.

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[2] "India's Climate and Energy Policies." *Center for Climate and Energy Solutions*, October 2015.

[3] Ebinger, Charles K. "India's Energy and Climate Policy: Can India Meet the Challenge of Industrialization and Climate Change?" *The Brookings Institution*, June 2012.

[4] The World Factbook, Center Intelligence Agency.

The first channel is  found in studies that examine the *level* impact of climate change as an equivalent of income gain or loss in percent of GDP. Frankhauser and Tol (2005) justifies their hypothesis by arguing that the prospect of future damages (or benefits) of global warming affects capital accumulation and people's propensity to save, which in turn, affects output. In terms of capital accumulation, with a constant saving rate, if climate change has a negative impact on output, the amount of investment in an economy is reduced which lead to a lower GDP and capital stock. Lower in investment can also slowdown technical progress and/or labor productivity or human capital accumulation. The savings effect is when faced with uncertainty posed by climate change: people change their behavior to save less and consume more today. Both effects are found to be negative, and in an endogenous growth model, there is a different rate of technical progress, thus enhances the savings and capital accumulation effects. The authors examined the statistical approach in Mendelsohn's work (Mendelsohn, Morrison, Schlesinger, and Andronova, 2000; Mendelsohn, Schlesinger, and Williams, 2000). It is based on direct estimates of the welfare impacts, using observed variations (across space within a single country) in prices and expenditures to discern the effect of climate. Mendelsohn assumes that the observed variation of economic activity with climate over space holds over time as well; and uses climate models to estimate the future effect of climate change. Mendelsohn's estimates are done per sector for selected countries, extrapolated to other countries, and then added up, but physical modeling is avoided. Nordhaus (2006) and Maddison (2003) use versions of the statistical approach as well. However, Nordhaus uses empirical estimates of the aggregate climate impact on income across the world (per grid cell), while Maddison (2003) looks at patterns of aggregate household consumption (per country). Like Mendelsohn, Nordhaus and Maddison rely exclusively on observations, assuming that "climate" is reflected in incomes and expenditures—and that the spatial pattern holds over time. Rehdanz and Maddison (2005) also empirically estimate the aggregate impact, using self-reported happiness measures from dozens of countries. The problem with these research is that, even though they are able to establish and justify a clear linkage between climate and change in the level of GDP, they did not employ a clear representation of climate within their research models.

Other groups of researchers try to incorporate a clearer link between climate and output into their analysis. Hsiang and Jina (2013) are the first to provide the first global estimates of the effect of large-scale environmental disaster on long-run growth. Through an extensive examination 6,700 tropical cyclones on the planet found that national incomes decline, relative to their pre-disaster trend, and do not recover within twenty years. Income losses arise from a small but persistent suppression of annual growth rates spread across the fifteen years following disaster, generating large and significant cumulative effects: a 90th percentile event reduces per capita incomes by 7.4% two decades later, effectively undoing 3.7 years of average development. This finding substantially alters the costs global climate change, especially on developing countries. However, these are only projections, based on a theoretical derivation under the assumption that the frequencies of cyclones are certain. Similarly, Dell et al. (2012) examine temperature shock and economic growth from panel data from 125 countries from 1950 to 2005. The authors aggregate weather data to a country-year level from a gridded monthly mean temperature and precipitation dataset at 0.5x0.5 degree resolution. Economic data is the value-added agriculture and industrial as percentage of GDP from the World Bank, World Development Indicators. Using various regression models with lags, interaction between dummy variables such as poor and hot countries and political stability, Dell et al. (2012) find three main results. Poor countries, but not wealthier ones,  suffer from reduction in economics growth and growth rates because of higher temperature. More specifically, a 1° Celsius increase in average temperature over a given year will decrease economic growth by 1.3%. In addition, agricultural and industrial output along with political stability decrease with increase in temperature. These findings suggest that poorer countries are the ones suffer more from the negative externality that is climate change. Hsiang (2010), using surface temperatures from National Centers for Environmental Prediction and value added aggregate income by industry data from the United Nations, shows similar findings using annual variation in a sample of 28 Caribbean-basin countries over the 1970–2006 period. National output falls 2.5 percent per 1°C temperature increase. This study further examines output effects by time of year and shows that positive temperature shocks have negative effects on income only when they occur during the hottest season. Low-income countries tend to be in tropical zones closer to the equator. They are already hotter, and their output already suffers to some extent from their higher temperatures in sectors like agriculture. Moreover, low-income countries are typically less able to adapt to climate change both because of a lack of resources and less capable institutions (Adger, 2006; Alberini, Chiabai, and and Meuhlenbachs 2006; Smit and Wandel, 2006; Tol, 2008; Tol and Yohe, 2007b; Yohe and Tol, 2002).  In the papers by Dell et al (2012) and Hsiang (2010), the economic impact of climate change is assessed and valued separately – by industry output as percentage of GDP. However, this method has potential issue: it may ignore interlinkages between the sectors which could possibly affect overall growth data.

One criticism to the cross-sectional studies of temperature effect is that they are driven by country specific characteristics – meaning that the models employed have omitted variables bias. However, Dell, Jones and Olken (2009) also examine the short run effects using sub-national data from 12 countries in the Americas, and provide new evidence that the negative cross-country relationship between temperature and income also exists within countries and even within states. The fact that the cross-sectional relationship holds within countries, as well as between countries, suggests that omitted country characteristics are not wholly driving the cross-sectional relationship between temperature and income. Nonetheless, a deficiency in the 2009 paper is the lack of empirical estimates of long term GDP growth in relation to climate change. They only attempt to reconcile the long run effect through two theoretical mechanisms: convergence and adaptation. The theoretical model suggests that half of the negative short-term effects of temperature may be offset in the long run through adaptation. Thus, it is crucial to look at the empirical evidence from one country over time, to account for the interlinkages cross sectors, and to find meaningful causal effect between temperature and economic growth.

A second channel that climate and pollution can affect growth is through human capital, measured by labor supply, productivity, and cognition. Zivin and Neidell (2011 & 2013) working papers published by the National Bureau of Economic Research find both theoretical and empirical evidences of this channel. Zivin & Neidell (2013) provide a theoretically linkage through the contemporaneous and latent effects of the environment on human capital by doing a meta-analysis of multiple studies. Their justification is that pollution may lead to direct brain development which affects cognitive ability. Alternatively, decrements in lung functioning may affect one's ability to focus and thus perform a wide range of tasks. They categorize the impacts of pollution into contemporaneous latent effects. The indicators of contemporaneous effect are schooling outcomes and labor market outcomes. Currie et al. (2009) use administrative data from the 39 largest school districts in Texas to estimate schooling outcomes. When carbon monoxide (CO) levels rise, absences also rise, 10 unit increase in $CO_2$ decreases test scores by 2.4% of a standard deviation. As for labor market outcomes, Hanna and Oliva (2011) focus on the labor supply of workers in Mexico City and find that a 1 percent increase in sulfur dioxide levels decreases hours worked by 0.72 percent. In addition, Clay et al. (2010) found that workers with higher levels of lead exposure, while lead is still believed to be safe in the 20th century to make pipes, had substantially lower wages, value added per worker and value of capital per worker.

The latent effects stem from the hypothesis that negative shocks early in life may lead to a wide range of lasting effects, which may arise even without noticeable impacts at the time of exposure (Almond and Currie, 2011). In 2011, Zivin and Neidell look at the impacts of pollution on labor market outcomes. Labor market productivity of agricultural workers is measured to examine the impact of ozone pollution on productivity. Their data on daily worker productivity is derived from an electronic payroll system used by a large farm in the Central Valley of California who pays their employees through piece rate contracts (in which the employee is paid for each unit of production at a fixed rate). Piece rates reduce shirking and increase productivity over hourly wages and relative incentive schemes, particularly in agricultural settings. To quantify for pollution, Zivin and Neidell used measures of environmental conditions come from data on ozone levels from the system of monitoring networks maintained by the California Air Resources Board. Ozone is not directly emitted but forms from complex interactions between nitrogen oxides (NOx) and volatile organic chemicals

(VOCs). They found that 10 parts per billion decrease in ozone concentrations increases worker productivity by 4.2 percent.

Considering the theoretical and empirical evidences of the two channels that link climate change and economic growth, this paper proposes to capture this dynamic effect by using a different model to assess empirical data. I want to combine effect of temperature and the effect of pollution on long run economic development, which has not been done before. I use carbon emission as an indicator of pollution as informed by Burke et al. (2015). They found that under business as usual emissions throughout the 21st century will decrease per capita GDP by 23% below what it would otherwise be. Using data from India, I am able to capture the long run effects of temperature and carbon emissions on one country's GDP growth.

## III. Modeling

To answer my research question: "Is there a negative effect of climate on economic growth?" I use the simplified Solow-like growth model derived by Tsigaris and Wood (2016) as a theoretical basis. To account for the effect of climate through the direct and human capital channels discussed in section II, I consider environmental conditions as an important factor of production into my model. First, consider a simple economy:

$$Y_t = A_t L_t^{\alpha} \quad (1)$$

where $Y$ is aggregate output, $L$ measures population, $A$ measures total factor productivity. A damage function $D_t = e^{\theta_1 T_t E_t}$, where $T_t$ is temperature anomaly in year *t* from year *t-1*, $E_t$ is the growth of carbon emission in year *t* from year *t-1*, and $\theta_1$ is a constant less than 0. The damage function is added to the output per worker Cobb-Douglas production function $y_t = A_t L_t^{\alpha}$. The climate-Solow growth model is:

$$Y_t = D_t A_t L_t^{\alpha} \quad (2.1)$$

*Ceteris paribus,* output per worker is reduced with increased temperatures. Along the balanced growth path, output per worker grows at a rate dependent on growth rates of temperature and carbon emission, the growth rate of total factor productivity, $g_{At}$ and the growth rate of the capital labor ratio weighted by the income share of capital, α. In addition to Tsigaris and Wood (2016)'s climate-Solow model, I followed Dell et al.'s (2008) idea to incorporate climate growth's effect on productivity growth:

$$g_{At} = g_{it} + \theta_1 T_t E_t \quad (2.2)$$

Equation (2.1) captures the *level* effect of climate on production. For example, the effect of current temperature on output per capita. Equation (2.2) captures the *growth* effect of climate; e.g. the effect of climate on features such as institutions that influence productivity growth. The growth equation in (2.2) accounts for weather shocks while allowing separate identification of level effects and growth effects. In particular, both effects influence the growth rate in the initial period of a temperature. A temperature shock may reduce agricultural yields, but once temperature returns to its average value, agricultural yields bounce back. By contrast, the growth effect appears during the climate shock and is not reversed: a failure to innovate in one period leaves the country permanently further behind. Taking the logs of equation (2.1):

$$g_t = \theta_1(T_t + E_t) + g_{At} + \alpha g_{Lt} \quad (3)$$

The growth effect is identified in (3) as the summation of the climate effects over time. To estimate the effects of temperature and carbon emission on economic growth, I run regression of the form:

$$g_{it} = \alpha_1 T_t + \alpha_2 E_t + \alpha_4 g_{Lt} + \varepsilon_i \quad (4)$$

where $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are estimates of the effects on GDP per capita growth of the growth rate of temperature, CO2 emission and population, respectively. From this regression model, I hypothesize that the temperature and carbon emission growth rates (the difference between the natural log of temperature and emission from year *t-1* and year *t*) negatively affect economic growth.

## IV. Data

In an exhaustive review of literature on this topic, Dell et al. (2014) found that most often used in climate-economics literature are gridded datasets, which a balanced panel of weather data for every point on a grid. The most frequently used gridded datasets in the studies reviewed here are the global temperature and precipitation data produced by the Climatic Research Unit (CRU) at the University of East Anglia with spatial resolution of 0.5x0.5. In this paper, I chose to use the World Bank group's data set for three independent variables from year 1972 to 2012 to maintain the consistency of all observations. Given the complexity of data manipulation and problem with accessibility of the ideal datasets from the University of East Anglia, I averaged out monthly temperature data from the World Bank Climate Change Knowledge Portal to get annual temperature data and then find the difference between the natural log of the temperature from year to year to get temperature growth rate. I manipulated similarly CO2 emissions as metric tons per capita data from the World Bank. I used Indian annual real GDP per capita and population growth rates data from the OECD dataset (OECD, 2016).

The descriptive statistics from Table 1. suggest that India's growth rates of temperature change, CO2 and GDP per capita fluctuate wildly. The variation of the growth rate of GDP per capita is the most notable, from a decrease of 7.4 percent to an increase of 8.7 percent. This variation is Co2 emission decreases by 2.4 metric tons per capita in one year and increase 4.3 metric tons per capita in another. Climate literature suggests that the average global temperature on Earth has increased by about 0.8° Celsius (1.4° Fahrenheit) since 1880 (NASA Earth Observatory, 2010). However, the mean annual temperature from 1972 to 2012 decreases by 0.001° Celsius. Its minimum and maximum values nonetheless suggest that temperature fluctuates from decreasing 0.7 degree Celsius to increasing almost 1° Celsius. The data indicate that the growth effects certainly cannot be ignored in order to answer this research question.

## V. Evidence

I estimate the dependent variable which is annual growth of GDP per capita on the following independent variables: growth rates of temperature, CO2 and population. Since my empirical model uses ordinary least squares estimates on time series data, it suffers from Gauss-Markov assumptions. Table 3 in section VI. Appendix summarizes the tests used and results to evaluate the violation of these assumptions. First, the Ramsey's test was used to test for omitted variables bias, which determines whether there are neglected nonlinearities in the model. The *p*-value for this test is less than 5% for my model, meaning that the correct functional form to estimate the independent variable the model was used. Second, time series data are often subject to the correlation its past and future values. Nonetheless, my model passes the Durbin-Watson test for autocorrelation for time series data, with a test statistics equals to 2.29. To test for multicollinearity to make sure two or more predictor variables in a multiple regression model are not highly correlated, I used the variance inflation factor (VIF). The VIF statistics (Table 3) for all three of my independent variables show that the variance of the estimated regression coefficients are not inflated (values are close to 1) as compared to when the predictor variables are not linearly related. The Breusch-Pagan test for heteroscedasticity tests the null hypothesis that the variance of the error is the same for all individuals. My model did not pass the because my *p*-value is slightly higher than 0.05. This means that the variance around the regression line is not the same for all values of the predictor variables. The violation of homoscedasticity can be fixed using a robust standard error, based on the covariance matrix estimates which are consistent in the presence of arbitrary forms of heteroscedasticity. I used the ‘,robust’ command on STATA after my original regression command to fix the problem.

After fixing for heteroscedasticity with robust standard errors estimates, I am able to obtain the best linear unbiased estimators. According to my regression results (Table 2), the coefficient on temperature is positive and statistically significant. I find that the temperature change significantly affect growth rates of GDP per capita at the 5% significance level. Holding other independent variables constant, one degree Celsius increase in temperature decrease GDP per capita growth by 0.71%. In addition, population growth significantly affect GDP per capita growth at the 1% level, with a one percentage point increase in population growth decreases GDP per capita growth by 4.4%. Given the average 1.9% current growth rate of population (Table 1), the Indian economy has to growth at approximately 8.7% to make up for its population growth. Yet, in 2015 the economy is only growing at a rate of 7.57% (World Bank). The economic growth and climate dichotomy is apparent in India.

## VI. Conclusion

I find one degree Celsius increase in temperature decrease GDP per capita growth by 0.71% and 1% increase in population growth decrease growth by 4.4%. My techniques could have affected my results in several ways. First, I only used data from India with only 42 observations from 1971 to 2012. I averaged the mean annual temperature from monthly data to match the GDP per capita and the CO2 emission annual data. The results could have been improved I could find quarterly data for all independent variables. Moreover, the weather data set used in this paper is not ideal. A gridded spatial weather data might improve the accuracy of weather results.

Second, I employed a very simple version of the Solow growth model to estimate my data. As suggested in Frankhauser and Tol (2005), the Solow model's emphasis on physical capital accumulation makes it less sensitive to climate change. The authors suggested using the Mankiw-Romer-Weil and Romer models for future research, which emphasize human capital and knowledge accumulation, respectively, as they are more sensitive to climate change. A more elaborate endogenous growth model might improve the results of this paper. Third, the model used in this paper and other papers in the literature review section only examined this hypothesis in a closed economy. Globalization may exacerbate the negative impact in one place and alleviate the positive benefits in another because climate change would affect the supply of capital as well as the relative rates of return on investment (Frankhauser & Tol, 2005). Finally, the objective of answering this research question is to figure out policy recommendations and/or ways to internalize this problem to best improve social welfare. The goal of the growth model chosen is to maximize aggregate social welfare. However, there are ethical concerns with this approach to welfare, especially when it comes to climate policy (Sen, 1979).

It is important to note that, the negative relationship between growth and temperature change found in this paper implies a challenge in the reality of the Indian economy. Policymakers in India realize this challenge, and have been implementing significant actions. India has taken steps on renewable energy with increasing installed capacity[5]. The renewable energy goals require continued effort, strong implementation, and improved utilization of capacity, but there are favorable signs. In 2008, India launched its NAPCC, featuring eight national missions, ranging from R&D to sustainable agriculture, with centerpiece programs to scale up solar power

[5] Central Electricity Authority, "Executive Summary: Power Sector," January 2014,

and energy efficiency[6]. With respect to renewable energy, there are great opportunities for India and its international partners. In an Ernst & Young report, in emerging markets "renewable energy potential is attracting high levels of foreign investment, generating new jobs and creating local supply chains.... For investors, renewable energy assets are generating robust returns." [7]Thirdly, with challenges come opportunities, especially for government-government cooperation, public-private partnerships and so on. There are endless opportunities if everyone works together to combat this issue.

The solution for this negative externality is not as simple as simply creating a carbon tax, cap-and-trade, or use property rights, as most economics models typically show. As mentioned in the introduction, the idea of a green economy show great potential for delivering a "triple bottom line" of job–creating economic growth coupled with environmental protection and social inclusion. Admittedly, there are obstacles to realize this potential on a multinational level and in practice. Building a green economy that is not only sustainable but also equitable requires carefully designed policies and investments towards developing countries to benefit from this transition. As suggested by a report by the World Resources Institute report (2012), of particular importance is the need for governance and policy reforms that extend to poor people secure rights over the environmental assets that underpin their livelihoods and well-being, and that ensure a greater voice in decisions affecting how these assets are managed. At the same time, policies and measures such as green protectionism and aid conditionality that

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[6] Neha Pahula et al., "GHG Mitigation in India: An Overview of the Current Policy Landscape," World Resources Institute (WRI), WRI Working Paper, March 2014,

[7] "Renewable Energy Country Attractiveness Index (RECAI)," EY, February 2014.

could adversely impact low and middle-income countries and people living in poverty must be avoided if the benefits of an inclusive green economy are to be realized.

While my paper show the benefits of having a sustainable economic growth agenda, future research might examine the costs of a green path for grow to actually suggest practical policies for countries in this climate-conscious world. Another interesting question could be to use econometrics techniques to predict the rate of output growth under the predicted rate of temperature growth and constant carbon emission. Moreover, in this paper I only examined the two channels of climate change on economic development. However, there are more indirect and interdisciplinary channels that temperature can affect long-term economic development. For example, Hsiang, Burke and Miguel (2013) conducted a meta-analysis of studies on the link between climate variability and conflicts from disciplines such as psychology, political science and economics, and found that increase from normal rainfall and temperature increase the intergroup violence by 4% and interpersonal violence by 14%. A country under conflicts is very likely to not involve in meaningful economic activities that contribute to growth. Future research can look at this intersection between disciplines to even further quantify the effects of global warming and economic growth.

In the grand scheme of things, understanding the problem of global warming is crucial in today's interrelated world because this is a problem that carries across disciplines, nations, and generations.

VII. Appendix

*Table 1: Descriptive Statistics*

| Variable | Mean | Std. Dev | Min | Max |
|---|---|---|---|---|
| Temp change | -.001 | .344 | -.704 | .989 |
| CO2 Growth (%) | 1.593 | 1.275 | -2.413 | 4.311 |
| Population Growth (%) | 1.918 | .375 | 1.27 | 2.361 |
| GDP Growth (%) | 3.704 | 3.004 | -7.383 | 8.755 |

*Table 2. Regression Results*

| | Dependent variable: GDP per capita annual growth (in %) |
|---|---|
| Intercept | 12.207 |
| | (1.810) |
| Temp change | -.705 |
| | (.263)* |
| CO2growth | -.003 |
| | (0.172) |
| Population growth | -4.391 |
| | 1.087** |
| R-squared | 0.358 |

Robust standard errors are in parentheses.
*significant at 5%, **significant at 1%

*Table 3. Tests for Gauss-Markov assumptions*

| Assumption | Test Used | Test Statistics | Rejection Rule | Results |
|---|---|---|---|---|
| Omitted variables | Ramsey | 0.41 | p-value = 0.74 > 0.05 | Passed |
| Heteroscedasticity | Breusch-Pagan | 7.68 | p-value = 0.0056 > 0.005 | Did not pass |
| Autocorrelation | Durbin-Watson | 2.29 | dL = 1.098<br>dU = 1.518<br>(4-d) > dU | Passed |
| Multicollinearity | Variance Inflation Factors | Population: 1.05<br>Co2: 1.05<br>Temp: 1.03 | < 10 | Passed |

Bibliography

Adger, W. Neil. "Vulnerability." Global Environmental Change, 16(3) (2006): 268–81

Alberini, Anna, Aline Chiabai, and Lucija Muehlenbachs. "Using Expert Judgement to Assess Adaptive Capacity to Climate Change: Evidence from a Conjoint Choice Survey." Global Environmental Change, 16(2) (2006): 123–44.

Almond, Douglas and Janet Currie. "Killing Me Softly: The Fetal Origins Hypothesis," the Journal of Economic Perspectives, 25(3) (2011), 153-72.

Currie, Janet and Johannes Schmieder. "Fetal Exposure to Toxic Releases and Infant Health," American Economic Association Papers and Proceedings, 99(2) (2009): 177-83.

Dell, M., B. Jones, and B. Olken. "What do we Learn from the Weather? the New Climate-Economy Literature." *Journal of Economic Literature* (2014).

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century." *American Economic Journal: Macroeconomics* 4, no. 3 (2012): 66-95.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. "Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates." American Economic Review 99, 2 (2009): 198-204.

Fankhauser, Samuel and Richard SJ Tol. "On Climate Change and Economic Growth." *Resource and Energy Economics* 27, no. 1 (2005): 1-17.

Hanna, Rema and Paulina Oliva "The Effect of Pollution on Labor Supply: Evidence from a Natural Experiment in Mexico City." NBER Working Paper 17302. (2011).

Hsiang, S. M. "Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America." Proceedings of the National Academy of Sciences 107(35) (2010): 15367-15372

Hsiang, Solomon M., and Amir S. Jina." The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones". No. w20352. National Bureau of Economic Research, 2014.

Hsiang, S. M., M. Burke, and E. Miguel. "Quantifying the Influence of Climate on Human Conflict." *Science (New York, N.Y.)* 341, no. 6151 (Sep 13, 2013): 1235367.

Maddison, David J. “The Amenity Value of the Climate: The Household Production Function Approach.” Resource and Energy Economics, 25(2)(2003): 155–75.

Mendelsohn, Robert O., Wendy N. Morrison, Michael E. Schlesinger, and Natalia G. Andronova. . “Country-specific Market Impacts of Climate Change.” Climatic Change, 45(3– 4)(2000): 553–69.

Mendelsohn, Robert O., Michael E. Schlesinger, and Lawrence J. Williams. “Comparing Impacts across Climate Models.” Integrated Assessment, 1(1)(2000): 37–48.

NASA Earth Observatory. "Fact Sheet: Global Warming" (11, 2010). http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php

Nordhaus, William D. “Geography and Macroeconomics: New Data and New Findings.” Proceedings of the National Academy of Science, 103(10) (2006): 3510–17.

Rehdanz, Katrin, and David J. Maddison. “Climate and Happiness.” Ecological Economics, 52(1)(2005): 111–25.

Sen, Amartya. "Personal Utilities and Public Judgements: Or what's Wrong with Welfare Economics." *The Economic Journal* 89, no. 355 (1979): 537-558.

Stern, Nicholas. "What is the Economics of Climate Change?" *World Economics-Henley on Thames-* 7, no. 2 (2006): 1.

Smit, Barry, and Johanna Wandel.. “Adaptation, Adaptive Capacity and Vulnerability.” Global Environmental Change, 16(3) (2006): 282–92.

Tol, Richard S. J. “Climate, Development, and Malaria: An Application of FUND.” Climatic Change, 88(1) (2008): 21–34.

Tol, Richard S. J., and Gary W. Yohe. “The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test.” Global Environmental Change, 17 (2007): 218–27

Tsigaris, Panagiotis and Joel Wood. "A Simple Climate-Solow Model for Introducing the Economics of Climate Change to Undergraduate Students." *International Review of Economics Education* 23, (9, 2016): 65-81.

Vale, Petterson Molina. "The Changing Climate of Climate Change Economics." *Ecological Economics* 121, (1, 2016): 12-19.

Weitzman, Martin L. "On Modeling and Interpreting the Economics of Catastrophic Climate

Yohe, Gary W., and Richard S. J. Tol.. “Indicators for Social and Economic Coping Capacity—Moving Towards a Working Definition of Adaptive Capacity.” Global Environmental Change, 12(1) (2002): 25–40.

Yohe, Gary W., and Michael E. Schlesinger. “The Economic Geography of the Impacts of Climate Change.” Journal of Economic Geography, 2(2002): 311–41.

Zivin, Joshua Graff and Matthew Neidell. “The impact of pollution on worker productivity,” American Economic Review, 102(7) (2012)

Zivin, Joshua Graff & Matthew Neidell. "Environment, Health, and Human Capital," Journal of Economic Literature, American Economic Association, vol. 51(3), pages 689-730, (9, 2013)

World Resources Institute, "Building an Inclusive Green Economy for All." *Poverty-Environment Partnership*, (6, 2012). http://www.wri.org/sites/default/files/pdf/building_inclusive_green_economy_for_all.pdf.