A Geo-Spatial Macro-Economic Analysis of Climate Change

Sungno Niggol Seo
Yale University
Phone: 203-432-6452
Email: niggol.seo@yale.edu
230 Prospect Street
New Haven, CT 06511, USA

Independent Institute Working Paper Number 62

August 18, 2005

A Geo-Spatial Macro-Economic Analysis of Climate Change

Sungno Niggol Seo
Yale University

Phone: 203-432-6452
Email: niggol.seo@yale.edu
Office Address: 230 Prospect Street, New Haven, CT 06511, USA

JEL KEYWORDS: VALUATION, CLIMATE, GEOGRAPHICAL ECONOMICS, AND MACROECONOMICS.

JEL CODES: Q51, Q54, R1, E0

Abstract

This paper develops geographical spatial analysis of macroeconomic variables to understand climate change sensitivities and impacts. The approach is promising because it provides a way to overcome partial equilibrium analysis based on specific sectors as well as provides the analysis at a larger scale appropriate for climate change study. In addition, this approach enables researchers to examine non-market sector effects such as ecosystem shifts, human and animal settlements change, and human health related issues. Our results indicate that economic activities as well as non-market factors such as human settlements and animal density are not particularly sensitive to different climates. The analysis indicates that humans as well as animals have adjusted well to different climates. Our results show that geographical adversities such as high mountains, inland without

access to the oceans, very steep locations have the greatest impacts on the lives of the humans and animals.

I. Introduction

There is an ever-increasing body of knowledge that indicates the world is warming and will continue to do so as the concentration of greenhouse gases rises in the future. (Houghton et al. 2001) The potential rise in temperature has been sufficiently alarming that governments have signed and then ratified the Kyoto Protocol to reduce emissions of greenhouse gases over the coming years. However, there remains considerable debate about how harmful climate change will actually be. (Pearce 1996) Specifically, policy makers want to know the magnitude of damages they should expect as temperatures rise.

There have been extensive studies to measure climate change impacts over the past decade. However, most studies are based on a specific sector of the economy such as agriculture, forestry, energy use, etc. General economic equilibrium of the economy has never been analyzed under these studies. Even more serious is that non-market impacts such as human settlements, ecosystem shifts, biodiversity loss, and amenity change have not been examined systematically. (Mendelsohn 2001, Nordhaus and Boyer 2000, Smith 2004)

Because of the large geographical scale of climate change problem, there is a strong need to examine economic and non-economic activities in a larger global scale. However, because of the limitations of proper data sets and analytical tools, researchers have mostly focused on a national analysis. Some studies or methods can only examine a specific region of interest. For example, agronomic studies and controlled experiments are necessarily limited to a certain location. The results are then extrapolated to the globe.

This paper develops geographical spatial analysis of large-scale data sets to overcome obstacles posed by sector-by-sector analysis and market based approaches up to date. We examine political boundaries, altitude and steepness of the geography, dominant soils and texture of the soils. Relevant climate variables are then examined: current temperature and precipitation as well as future temperature and precipitation. Our analysis then proceeds to analyze macroeconomic variables of interests such as GDP per capita, population density as well as animal distributions over the space. By cross-examining these large-scale data sets, we make predictions and conclusions.

Our analysis takes Latin America as an example of this study. However, all the analyses are readily applied to the global scale with proper planning of the research. Latin America is a good place to show this method since the continent cuts across the equatorial zones, but extends long enough to the north as well as to the south making it possible for the continent to have as diverse ecological zones as we need.

II. Geography of Latin America

We start our analysis by examining basic geographic information of the region that is closely related with the livelihood of the living beings. This information can be political boundaries, altitude and slope of the region, dominant soil types and texture of the soil. Of course, our interest lies in climates. We examine current climates as well as future climates in the next section.

Figure 1 depicts the political boundaries of the region.[i] Latin America consists of Central America and South America. South America is again divided into the Southern Cone region and the Andean region. The Southern cone region is shaded in blue color, and the Andean region is shaded in yellow color and slashed. The countries are divided into the second administrative division level, i.e. district level and the figure divides the region by districts. Relatively smaller countries are depicted at the first administrative division level, i.e. provincial level.

The region stretches from 50 degree south of the southern hemisphere to 30 degree north of the northern hemisphere. Equator cuts through Ecuador, Colombia, and the northern part of Brazil. It expands from 35-degree east to 110-degree east in longitude. The figure clearly signals that the region covers a wide range of ecosystem: There are mountain areas and plain areas; The region stretches right from the equator to the north and to the south by more than 30 degree; Some countries are inland such as Bolivia and Paraguay, while other countries are adjacent to the oceans.

Fig 1: Latin America Political Boundaries

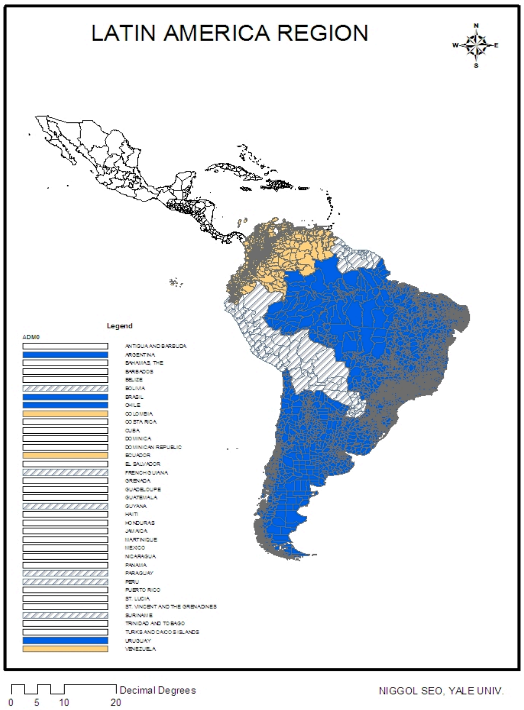
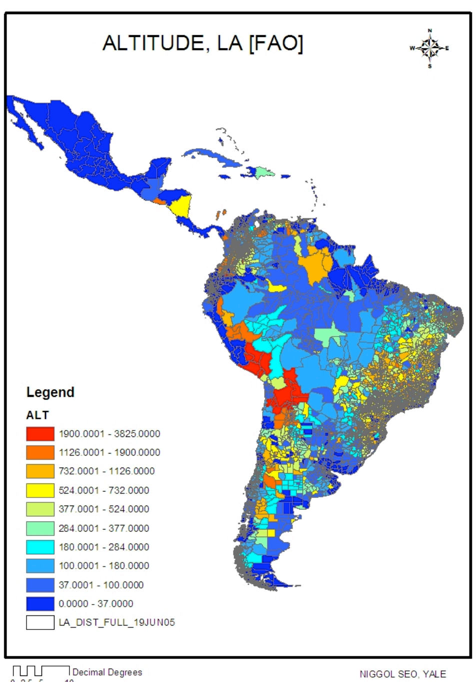


Fig 2: Altitude and Slope



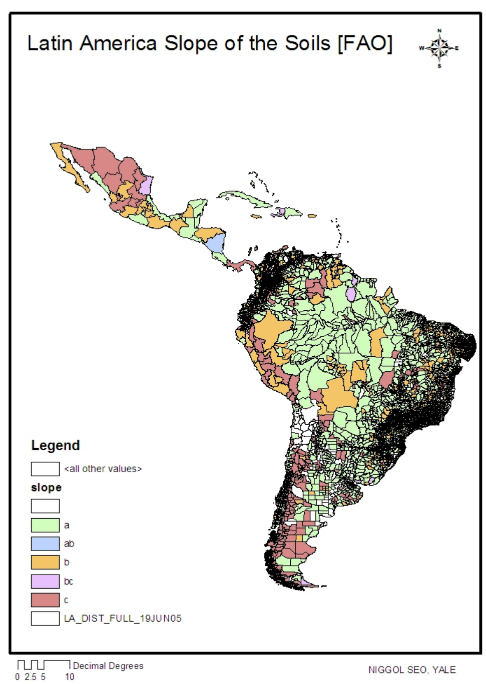


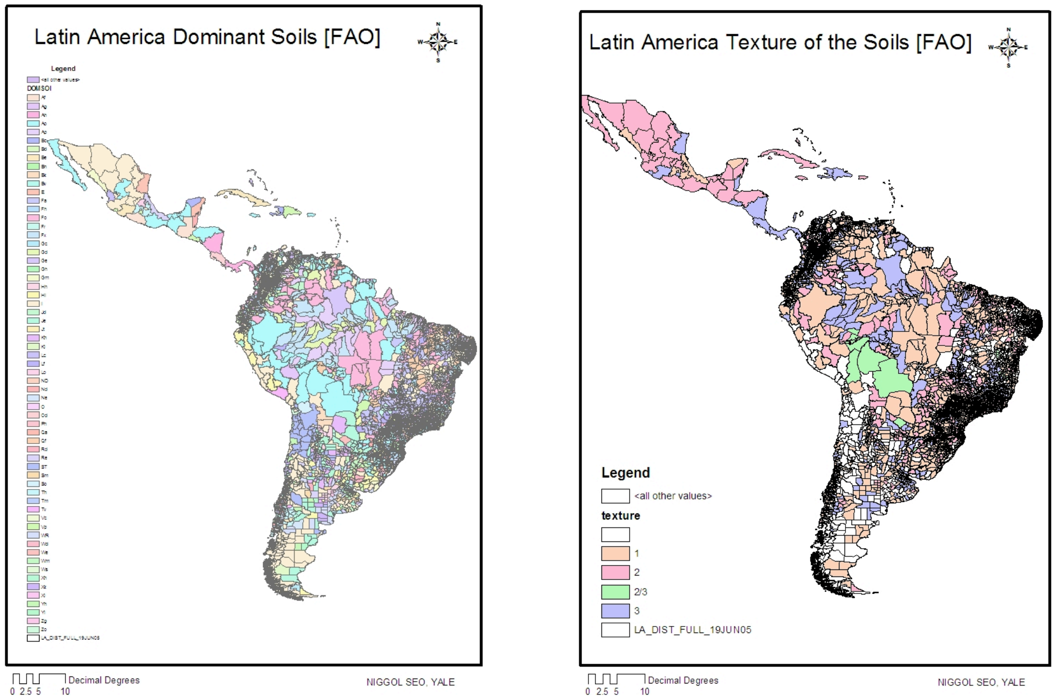
Fig 2 shows the altitude and slope of the region.[ii] We used FAO soil data set and then extracted necessary data such as soil types, slope, altitude, and texture to the district level of the region. Most of the region is located in lower altitudes with the exception of the Andean mountain range stretching along the whole South America covering Ecuador, Peru, Bolivia, and Chile. Southeastern part of Brazil is located in higher altitudes compared with other parts in the country. A part of Venezuela is also located in relatively higher altitudes. The figure also reveals steepness of the soils.[iii] The slope increases as the index changes from a to b to c. Clearly, high altitude regions along the Andean mountain and mountain region in Venezuela are steeper than other parts of the region.

The height and steepness of the place clearly affect the way of living. We might expect that the higher and steeper regions are less densely populated and less economically active because of adverse geographic conditions. However, mountain regions along the equator provide more favorable conditions for living because of less heat and less flooding on the mountain regions.

The type of soils is believed to affect the most important economic activities of the region, i.e. agriculture. The FAO data set records 116 different types of dominant soils, which are classified into 26 broad categories. Dominant soils cover 40% of the mapping unit. Fig 3 dissolves dominant soil types and soil texture at the district level. The figure reveals the soil type is rather uniform on the Andean mountain range that covers Ecuador, Peru, Bolivia, and Paraguay. In contrast, soils are very diverse and mixed in the Southern part of Brazil. Northern part of Argentina also has mixed soil types.

The figure also reveals soil texture. Texture can be interpreted as stickiness of the soil. Texture 1 implies sandy soil, and texture 3 implies clay soil.[iv] Areas around Ecuador, middle of Brazil, portions of Argentina seems to have sandy soils, which makes it difficult to cultivate for crop farming. Southeastern part of Brazil seems to have proper soil textures for farming.

Fig 3: Dominant Soils and Texture



3. Climates

Our main focus in this paper is to see whether climates play a significant role in a way of living and are likely to affect our lives in the future by changing climates. In this section and next section, we examine in detail what current climates are like and what future climates are predicted to be like.

We rely on the data obtained from the US defense ministry satellites. The satellite rotates sun synchronized overpasses and records relevant climate data twice daily. Among many other variables, we present temperature and precipitation data partly due to the past researches that these two variables are most important climate variables that affect our lives. The observations are not daily or yearly weather fluctuations, rather normal climates that are 30-year averages of relevant variables. Satellite data expands from 1988 to 2004.[v]

Satellite observations provide better proxy for temperature since they measure temperature at the center of each district whereas weather station observations are sparse and should be interpolated to a long distance. However, satellite proxy for precipitation, i.e. soil wetness index, is not appropriate to measure rainfall because there can be large distortions from water reflection, snow reflection, evaporation etc. We present WMO rainfall weather station observations instead. WMO recorded rainfall from 1961 to 1990 and provide 30-year average normal rainfall. We then interpolated weather station observations to the districts using geographical information system.[vi]

Fig 4 shows current normal temperature of the region at the district level measured directly at the center of the districts from the satellite. The color scheme is set to change from blue to red as temperature gets higher. Equatorial zones are obviously hotter than the other areas. However, the mountain regions around the equator show colder mean temperatures, indicating the role of altitude. Colder regions are located far south and far north of the equatorial zone such as Argentine and Mexico. Noticeable is that eastern Brazil has very long range of temperature zones covering from very cold region to very hot region. Inland areas such as Bolivia and Paraguay are relatively hotter.

Fig 5 shows 30 year normal rainfall obtained from WMO climate normal data set. The color scheme is set reversibly to the temperature case. The bluer the region is, more rainfall it gets. Obviously, equatorial zones get more rainfall. Mountain ranges get less rainfall. Southern part of Argentina, Eastern most area of Brazil, and Mexico are the driest parts of the region. Southern most part of Brazil is relatively rainfall affluent.

In summary, Latin America can be divided into several regions based on its climates. Hot and wet zones are located along the equator. Hot and dry zones are eastern most part of Brazil. Cold and wet zones are Southern most part of Brazil, Uruguay, and northern most part of Argentine. Cold and dry zones are Argentine, Mexico, and Andean mountain range.

Figure 4: Current annual mean temperature

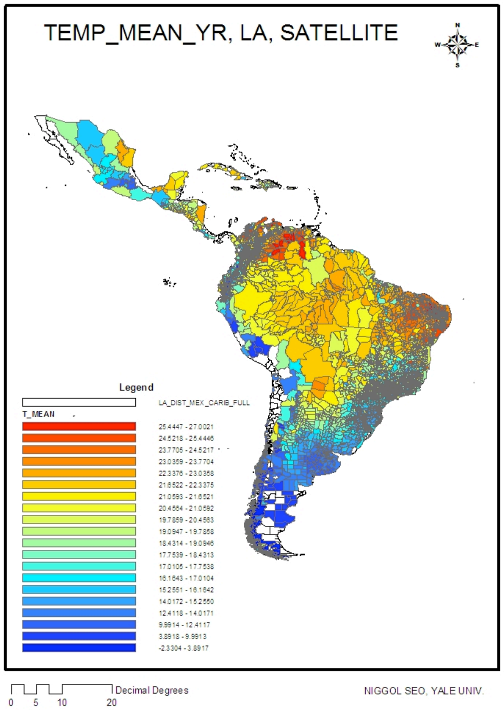
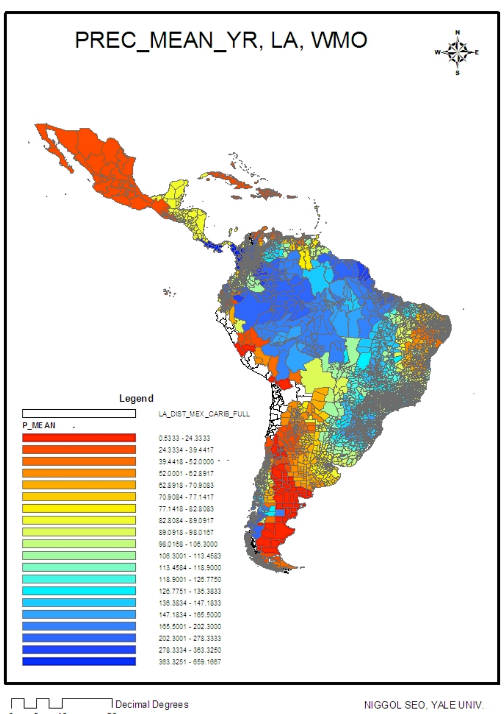


Figure 5: Current Annual Precipitation



4. Climate Predictions

We intend to show climate predictions for Latin America from existing runs of climate models.[vii] We will rely on established Atmospheric Ocean General Circulation Models (AOGCM's) that are widely used in climate change research. We specifically intend to use the following three models:

PCM: National Center for Atmospheric Research, USA
CSIRO: Australia's Commonwealth Scientific and Industrial Research Organization
CGCM2 (also called CCC): Canadian Center for Climate Modeling and Analysis, Canada

These three models generate a wide range of climate predictions over the next century and so provide a defendable range of possible future impacts.

For each prediction, we add the change of monthly temperature predicted by each model onto the existing monthly temperature in each location (district or province). We also take the percentage change in monthly precipitation predicted by the each climate model and multiply it by the monthly precipitation in each location. We examine 2020, 2060, 2080, and 2100.

Figure 6 presents the country level predictions in 2100 by the three AOGCMs. The color code remains the same as in Figure 4. The PCM model predicts the mildest warming scenario. Countries get only slightly warmer than they are now. CSIRO predicts a stronger warming signal and countries clearly get much hotter. The warmest predictions come from the CCC model. Many of the equatorial countries fall into the hottest range under the CCC scenario. The figure reveals the range of temperature predictions of the three different models. However the figure does not reveal the exact dynamics of change, the exact change in temperature change, or how it is distributed across districts.

Figure 6: Predicted Temperatures in 2100

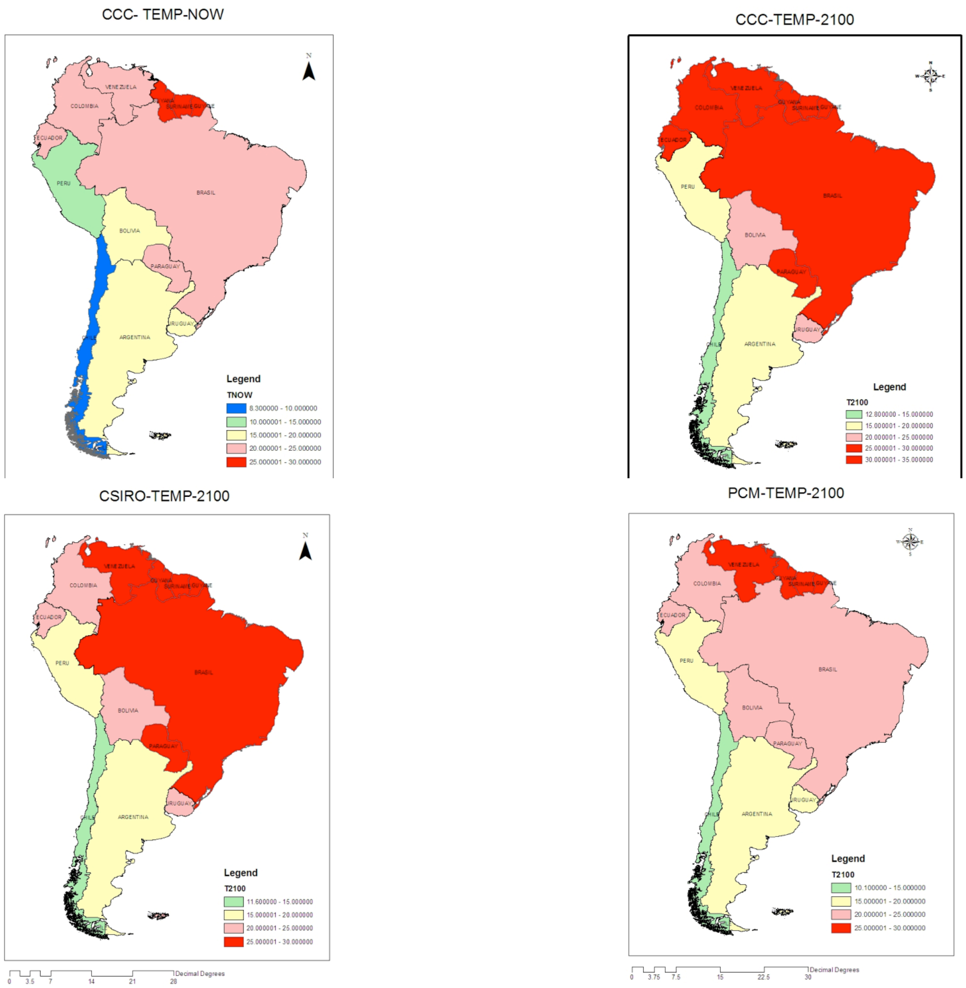


Fig 7: CCC Model Temperature Time Series

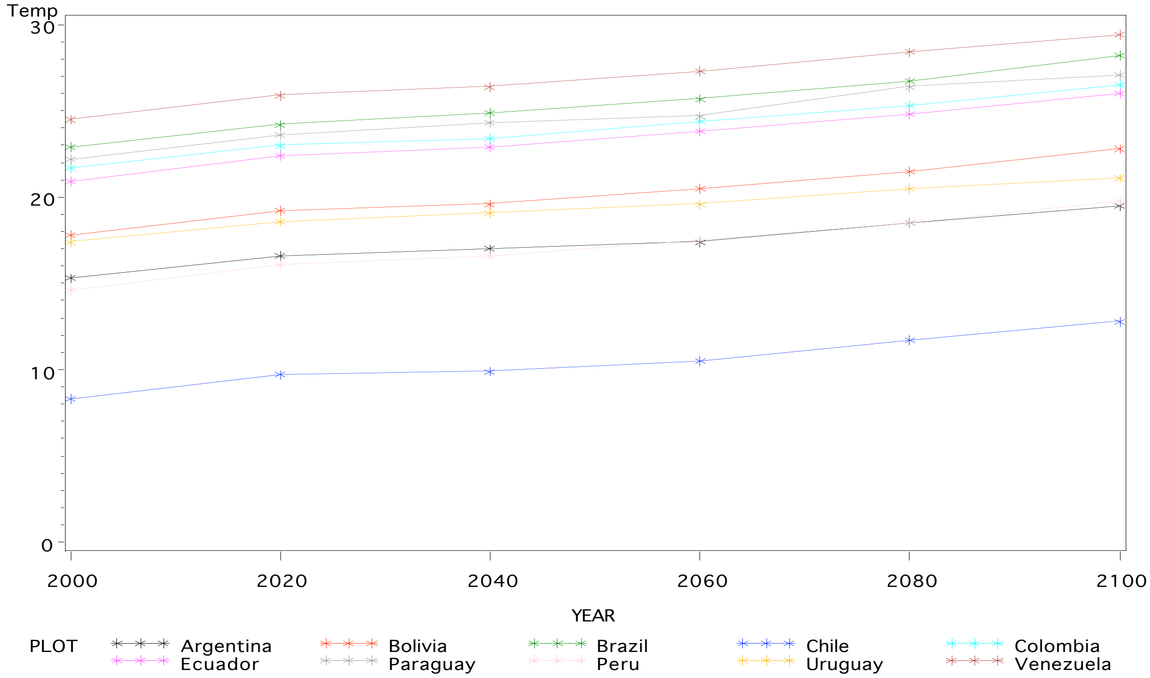


Fig 8: Mean Temperature Time Series

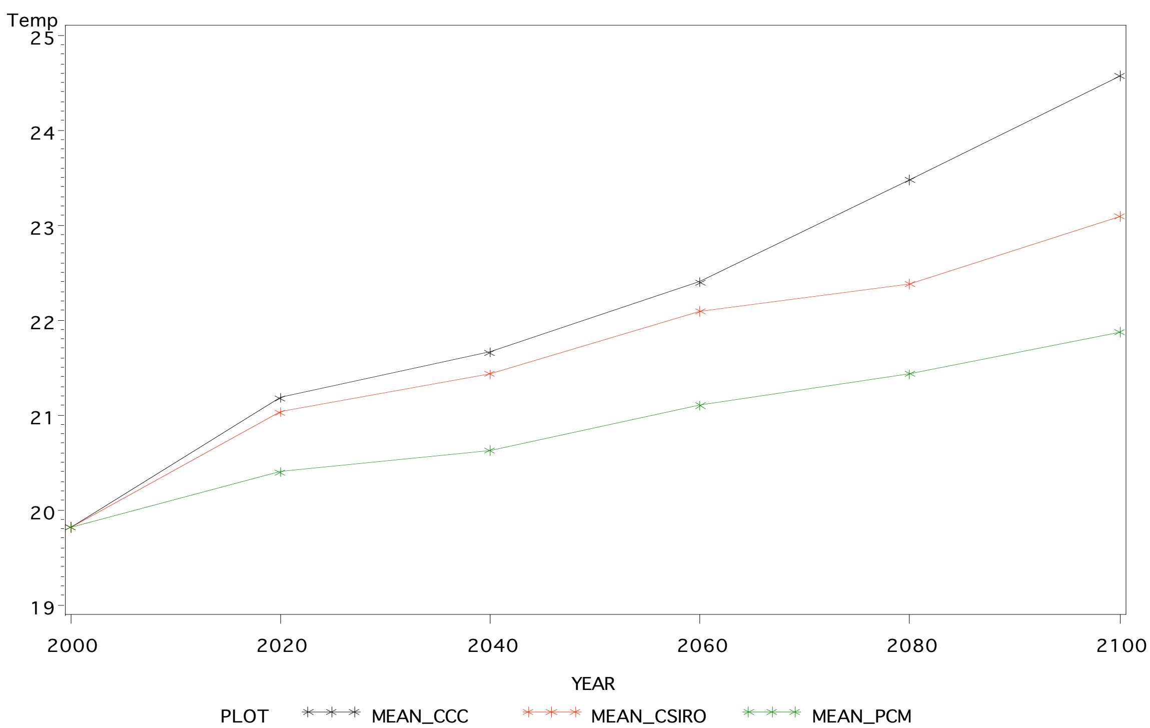


Figure 7 depicts how temperatures in each country are predicted to change from 2000 to 2100 according to the CCC scenario. The figure shows a trend of gradual increase for every country in the region. Temperature trends are quite similar for other scenarios as well. There are only subtle differences. The temperatures tend to warm steadily with slight changes each decade.

Figure 8 places the three models together by the average temperature prediction for Latin America. CCC predicts the largest temperature increase and PCM predicts the smallest temperature increase, while CSIRO predicts values that lie between the two. The PCM model predicts the slowest increase in temperature throughout the century. The CSIRO and CCC predictions start together and only begin to diverge after 2060 when the CCC scenario warms considerably faster.

Figure 9 depicts the predicted precipitation in 2100 in each climate scenario. The PCM prediction suggests that Brazil will get wetter but otherwise there will be little change. The CSIRO prediction suggests that Ecuador and Uruguay get more rain but otherwise there is little change. In the CCC prediction, Colombia, Guyana, and Bolivia get drier but Argentine and Uruguay get more rain. The three models make different precipitation predictions.

Figure 10 provides a dynamic view of the precipitation changes in the CCC model. The figure reveals that rainfall predictions are not uniform across countries as is the case in temperature. Some countries are predicted to experience a decline, and other countries an increase. However, In general, the precipitation is stable over time in each country. However, in the PCM scenarios, Surinam gets considerably wetter through 2080 and then returns to its 2000 levels. Venezuela also gets wetter through 2080 and returns to its 2000 levels but the changes are not as dramatic. In the CSIRO model, Uruguay and Paraguay get slightly wetter toward the end of the century. In the CCC model, the high rainfall countries follow a declining trend whereas the drier countries experience a rising trend in precipitation. However, this is not the case for the two other scenarios.

Figure 9: Predicted Precipitations in 2100

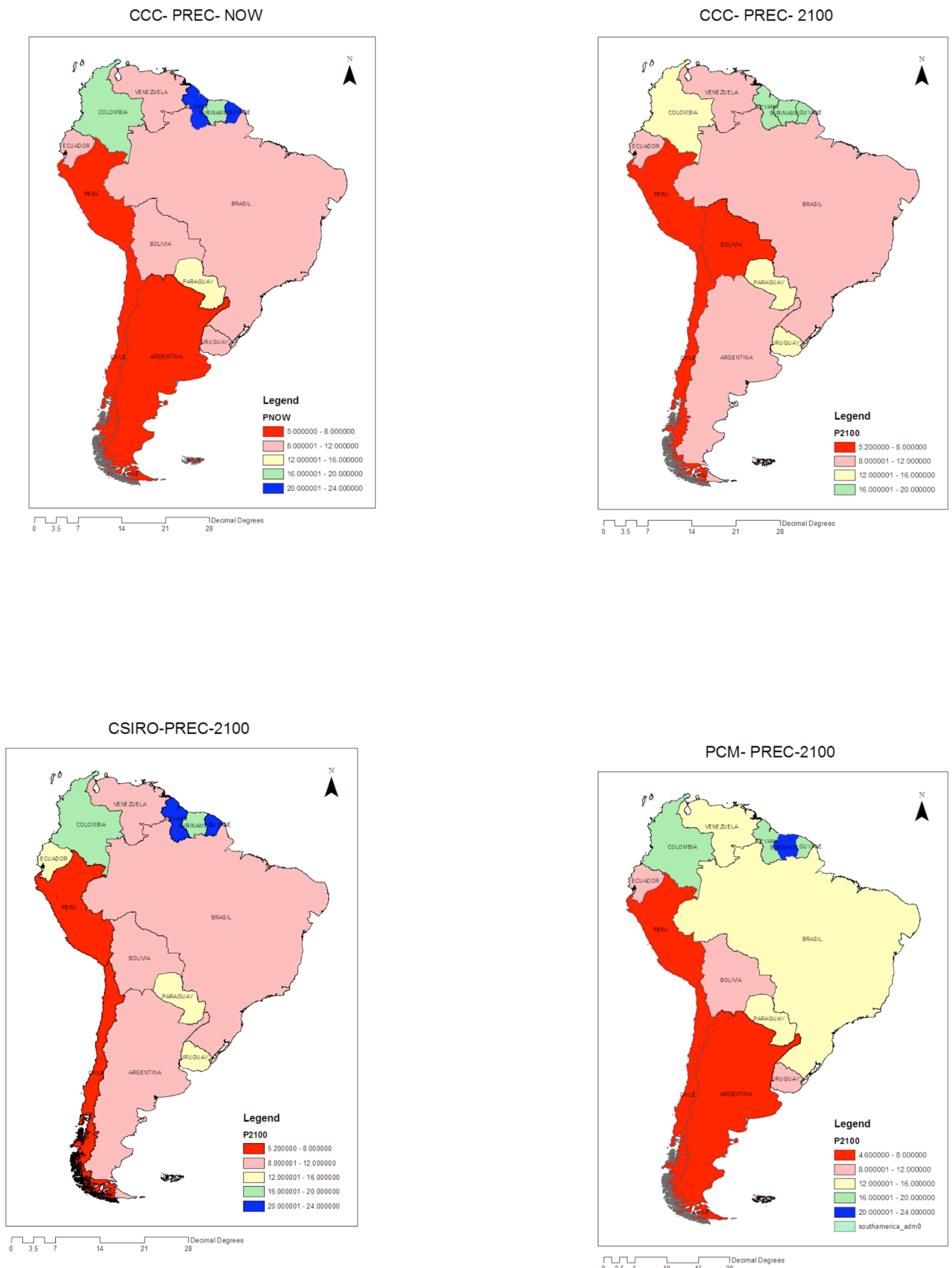


Fig 10: CCC Precipitation Time Series

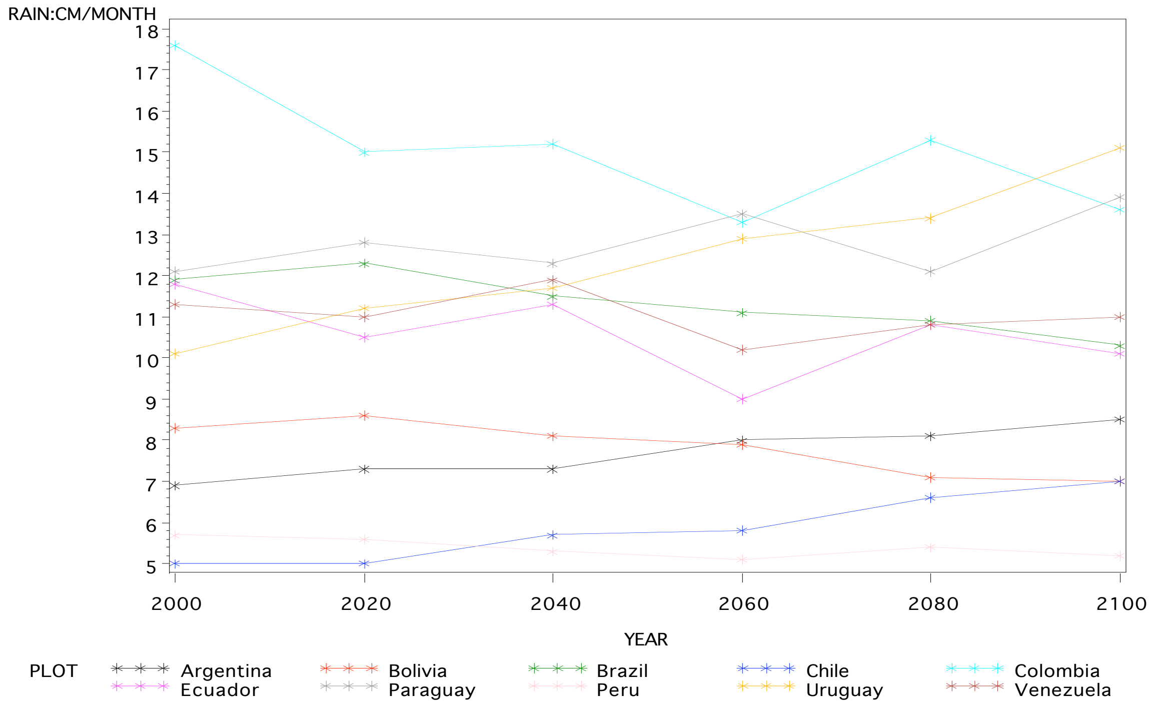


Fig 11: Mean Precipitation Time Series

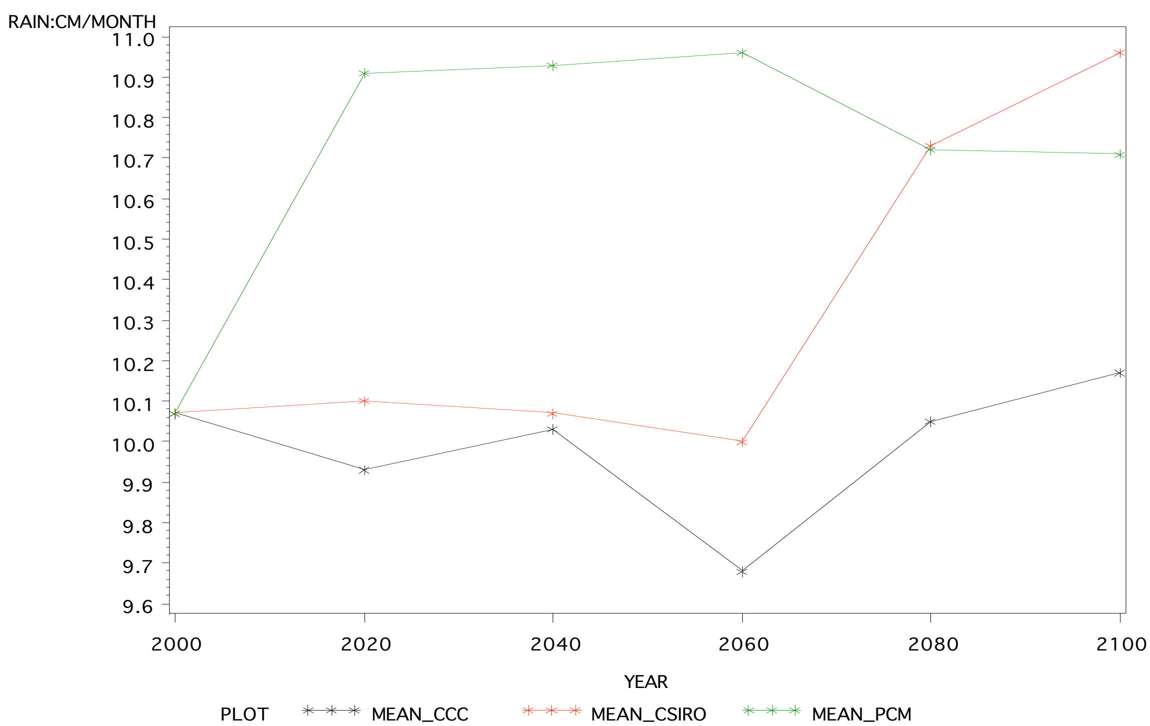


Figure 11 shows a dynamics of average precipitation the three models. Models predict different trajectories of rainfall. CCC model predicts gradual reduction of rainfall until 2060 and increase thereafter. CSIRO model predicts more or less no change in rainfall until 2060 and then increase rapidly thereafter. PCM model predicts a rapid increase until 2020, then stabilize until 2060, and then decline thereafter. The figures indicate climate models still do not agree on the rainfall trajectories over the next century.

5. Macro-Economic Indicators

We want to know whether people and other beings have responded to different climates by choosing to live in a specific climate zones or by different economic activities. As well, we want to discern whether climate changes are likely to have any impact on the way we live. However, it has been troublesome for the researchers to do general equilibrium analysis of economy because of the sectoral approaches to this problem. In addition, non-market effects have been particularly hard to understand due to the analytical reasons.

Geographic spatial analysis of macroeconomic activities as well as key statistics of non-market activities can reveal a broader perspective on this issue. We have seen throughout this paper that relevant statistics can be analyzed by geographical spatial examination, widening up researcher's eyes to the broader areas and issues. To understand the sensitivities and vulnerabilities from climate change, we introduce macroeconomic variables in geospatial forms.

(1) GDP per capita

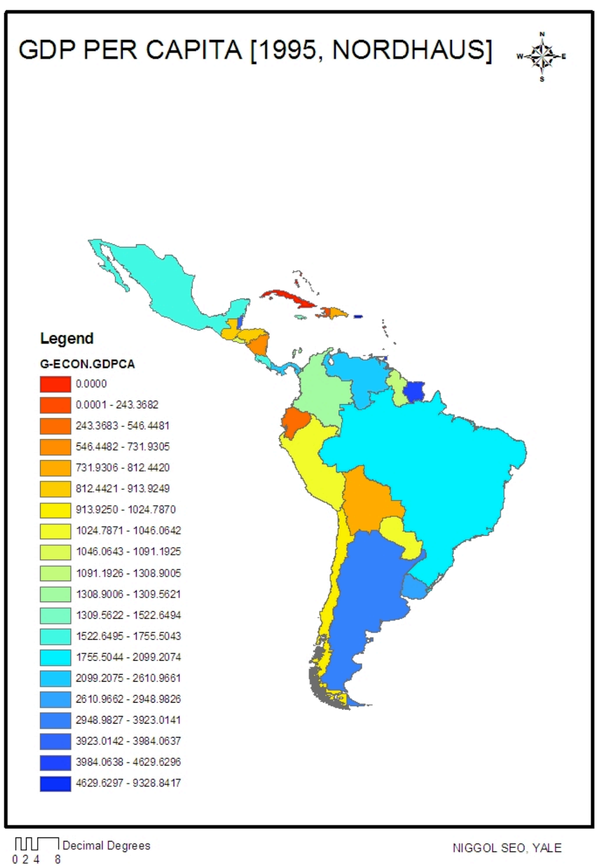
The sensitivities of economic activities to climates can be examined broadly by observing macroeconomic variables on a wide scope. While many key statistics can be examined, we take GDP per capita to measure economic activities of the region. Figure 12 plots GDP per capita for each country in the region.[viii] Mexico, Venezuela, Brazil, and Argentina belong to a relatively high-income category. Countries along the Andean mountain range belong to a low-income category. These countries are Ecuador, Peru, Bolivia, Paraguay, and Chile.

Most outstanding feature is the role of altitudes. Mountain regions are generally poor, and less economically active. The access to the oceans is also revealed to be important.

Inland countries such as Bolivia and Paraguay generate low income. Given the high correlation between climates and altitudes and inland characteristics, some general interpretations emerge. Cold and dry areas of the Andean mountain range are less economically lively, whereas hot and wet areas such as Brazil, Colombia, and Venezuela have higher incomes. This possibly tells that warming might be beneficial to the region in generally.

However, Argentina provides a counter example. Even though Argentina is relatively cold and dry, the country generates almost highest income in the region. Thereby, concluding warmer climates play a beneficial role to the economy is not justified. A more relevant interpretation seems to be that geographic characteristics play a more significant role in determining liveliness of economic activities than climates do.

Fig 12: GDP per Capita (USD)



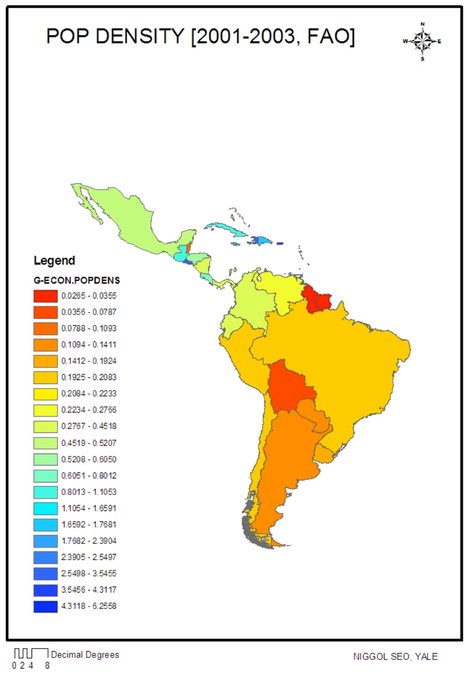
The figure, however, reveals humans can adjust to warmer temperatures. Although geographic adversities are hard to overcome, humans do well in economic terms whether they are located in cold temperature such as Argentina or whether in hotter temperature such as Brazil and Venezuela.

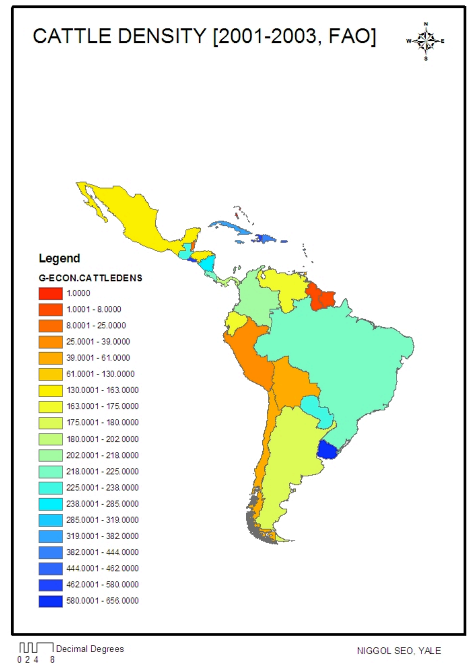
(2) Non-Market Effects

It has been of great interests to the researchers of climate change whether people prefer a certain type of climate, whether human settlements depend on climates, recreational activities depend on climates, or whether human health and mortalities rely on climates. (Cline 1992, Pendleton and Mendelsohn 1998, Maddison 2001) Although some authors have examined these issues, it has been revealed that it is particularly difficult to perform the analysis at global scale. In addition, many areas of non-market effects are not known well at this stage. However, non-market effects can be revealed by examining geographical distributions of key statistics of interests such as disease outbreaks, population densities, etc. This analysis can be conducted at a large scale.

Among the many possible key statistics, figure 13 shows population density in the region. If people have preferred a certain type of climates, more favorable climate zones are likely to be more densely populated. Figure 13, however, does not confirm this assumption. Most countries in South America are almost equally densely populated. Population densities are quite low for all the countries. Central American countries are relatively more densely populated. This figure again reconfirms our interpretation of GDP per capita in the previous section. People seem to adjust to different climates, which enable people to live in any climate zones in the region.

Fig 13: Population Density per Hectare and Cattle Density per 1000 Hectares





Note: FAOSTAT, 2005.

(3) Ecosystem Effects: Animals

Understanding the effects of climate change on ecosystem has been particularly difficult. No author has provided a reasonable analysis on this regard. (Nordhaus and Boyer 2000, Mendelsohn 2003) However, it is clearly crucial to fill this gap of knowledge because it is likely to affect policy decisions in a great deal.

As in the previous analysis, we take animal density, especially cattle density, as a proxy for ecosystem. The cattle density is defined as the heads per 1000 hectares of land. A cattle is one of the most important animals for humans for providing nutrition and are raised widely around the world. However, similar analysis can be done to other animals such as goat, sheep, pigs, chicken, etc.

Figure 13 reveals that cattle density is high in Argentina, Brazil, and Colombia. Uruguay has the highest density. This result indicates that cattle are not different from humans: They can be raised along the different climate zones covering from relatively cold areas such as Argentina to relatively hot areas such as Colombia and Brazil. This strongly suggests that animals are not very sensitive to climates and they can adjust to different climates to live.

The figure also reveals the significant role of altitudes. Countries around the Andean mountain range such as Ecuador, Peru, Chile, and Bolivia have low densities of cattle. Note that cattle are less densely populated in the high regions of Venezuela as well as in Mexico.

6. Conclusion

This paper develops geographical spatial analysis of macroeconomic variables to understand climate change sensitivities and impacts. The approach is promising because it provides a way to overcome partial equilibrium analysis based on specific sectors as well as provides the analysis at a larger scale appropriate for climate change study. In addition, this approach enables researchers to examine non-market sector effects such as ecosystem shifts, human and animal settlements change, human health related issues, etc.

We analyze relevant geographic information to understand the region geographically. Relevant variables are political boundaries, altitude and slope, dominant soil types and soil texture, climates composed of temperature and rainfall, climate predictions for the next century. We then provide analysis of macroeconomic variables such as GDP per capita, population density, and animal density.

Our results indicate that economic activities as well as non-market factors such as human settlements and animal density are not particularly sensitive to different climates. The analysis indicates that humans as well as animals have adjusted well to different climates. Our results show that geographical adversities such as high mountains, inland without access to the oceans, very steep locations have the greatest impacts on the lives of the humans and animals.

References

Adams, R., Rosenzweig, C., Pearl, R., Ritchie, J., McCarl, B., Glyer, J., Curry, R., Jones, J., Boote, K. and Allen, L. 1990. "Global Climate Change and US Agriculture," Nature 345: 219-224.

Adams, R., Fleming, R., Chang, C., McCarl, B. and Rosenzweig, C. 1993. "A Reassessment of The Economic Effects of Global Climate Change in US Agriculture," US Environmental Protection Agency, Wash. D.C.

Adams, R., M., McCarl, B., A., Segerson, K., Rosenzweig, C., Bryant, K., Dixon, B., Conner, R., Evenson, R., Ojima, D. (1999), "The economic effects of climate change on US agriculture." in Mendelsohn and Neumann (*eds.*), *The Impact of Climate Change on the United States Economy*, Cambridge University Press; Cambridge, UK.

Adams, R.M., McCarl,B. (2001). "Agriculture: Agronomic-Economic Analysis" in Mendelsohn (ed) *Global warming and the American economy: A regional analysis*, Edward Elgar Publishing, UK.

Basist, A., C.Williams Jr., N.Grody, T.E. Ross, S. Shen, A.T.C. Chang, R. Ferraro, M. J. Menne. (2001), "Using the Special Sensor Microwave Imager to monitor surface wetness", *J. of Hydrometeorology*. 297-308.

Cline, W. (1992), " Estimates of the Damage from Global Warming", in W. Cline, *The Economics of Global Warming*, Washington DC, Institute of International Economics.

Cline, W. (1996), "The impact of global warming on Agriculture: Comment", *The American Economic Review*, Vol. 86, No.5, pp. 1309-1311.

Darwin, R., Tigras, M., Lewandrowski, J. and Raneses, A. (1995), "World Agriculture and Climate Change: Economic Adaptations", U.S. Dept. of Agriculture, Economic Research Service, Publication # AER-703, Washington, D.C.

Easterling, W.E., P.R. Crosson, N.J. Rosenberg, M.S. McKenney, L.A. Katz and K.M. Lemon (1993). Agricultural Impacts of and Responses to Climate Change in the Missouri-Iowa-Nebraska-Kansas Region. *Climatic Change*, 24(1-2), 23-62.

Emori, S. T. Nozawa, A. Abe-Ouchi, A. Namaguti, and M. Kimoto. (1999), "Coupled ocean-atmospheric model experiments of future climate change with an explicit representation of sulphate aerosol scattering", *J. Meteorological Society* Japan 77, 1299-1307.

Fankhauser**,** S., J.B. Smith, and R.S.J. Tol, (1999), "Weathering climate change: some simple rules to guide adaptation decisions", *Ecological Economics*, vol.30(1), pp.67-78.

Gordon, H. and S. O'Farrell. (1997), "Transient climate change in the CSIRO coupled model with dynamic sea ice" *Mon. Weather Research* 125, 875-907.

Gordon, C., C. Senior, H. Banks, I. Gregory, T. Johns, J. Mitchell, and R. Wood (2000), "The simulation of SST, sea ice extents, and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments" *Climate Dynamics* 16, 147-168.

Houghton, J., L. Meira Filho, B.Callander, N. Harris, A. Kattenberg, and K. Maskell, (eds.) 1996, *Climate Change 1995: The State of the Science*, Intergovernmental Panel on Climate Change, Cambridge University Press: Cambridge.

Houghton, J., Y. Ding, D. Griggs, M. Noguer, P. Van der Linden, X. Dai, K. Maskell, and C. Johnson (eds.) 2001, *Climate Change 2001: The Scientific Basis,* Intergovernmental Panel on Climate Change, Cambridge University Press: Cambridge.

Hurd, B., M. Callaway, J. Smith, and P. Kirshen. (1999) "Economic effects of climate change on US water resources" in R. Mendelsohn and J. Neumann (eds) *The Economic Impact of Climate Change on the Economy of the United States*. Cambridge University Press, Cambridge, UK.

Hurd, B. and M. Harrod, (2001), "Water resources: Economic Analysis" in Mendelsohn, R. (ed) *Global Warming and the American Economy: A Regional Analysis*, Edward Elgar Publishing, UK.

Johns, T. (1996), "A description of the Second Hadley Centre Coupled Model (HADCM2)" *Climate Research Technical Note 71*. United Kingdom Meteorological Office, United Kingdom.

Kaiser, H. M., S. J. Riha, D. S. Wilkes, and R. K. Sampath. (1993a) "Adaptation to Global Climate Change at the Farm Level." In H. Kaiser and T. Drennen, (*eds*), *Agricultural Dimensions of Global Climate Change,* Delray Beach, Fla.: St. Lucie Press.

Maddison, D. (2000). "A Hedonic Analysis of Agricultural Land Prices in England and Wales", *European Review of Agricultural Economics*, vol.27, pp.519-532.

McCarthy, J., O. Canziani, N. Leary, D. Dokken, and K. White (eds.) 2001, *Climate Change 2001: Impacts, Adaptation, and Vulnerability,* Intergovernmental Panel on Climate Change Cambridge University Press: Cambridge.

Mendelsohn, R., W. Nordhaus and D. Shaw. (1994), "The Impact of Global Warming on Agriculture: A Ricardian Analysis", *American Economic Review* 84, pp 753-771.

Mendelsohn, R., W. Nordhaus, and D. Shaw. (1999), "The Impact of Climate Variation on US Agriculture" In Mendelsohn, R. and Neumann, J. (eds). *The Economic Impact of Climate Change on the Economy of the United States*, Cambridge University Press, Cambridge, UK.

Mendelsohn, R. and A. Dinar. (1999), "Climate Change Impacts on Developing Country Agriculture" World Bank Research Observer 14: 277-293.

Mendelsohn, R. and J. Neumann (eds) 1999 *The Impact of Climate Change on the United States Economy*. Cambridge University Press, Cambridge, UK.

Mendelsohn, R. (2000) "Efficient Adaptation to Climate Change", *Climatic Change* **45**, pp 583-600.

Mendelsohn, R. (ed) 2001, *Global Warming and the American Economy: A Regional Analysis*. Edward Elgar Publishing, UK.

Mendelsohn, R., A. Dinar and A. Sangh (2001), "The Effect of Development on the Climate Sensitivity of Agriculture", *J. Environment and Development Economics* **6**, pp 85-101.

Mendelsohn, R. and A. Dinar (2003), "Climate, Water, and Agriculture", *Land Economics* **79:** 328-341

Mendelsohn, R, A. Dinar, and L. Williams (2005), "Impacts of Climate Change on Poor Countries", Forthcoming in *J of Environment and Development Economics*.

Niggol Seo, S., R. Mendelsohn, and M. Munasinghe. (2005) "Climate Change and Agriculture in Sri Lanka: A Ricardian Valuation", *Environment and Development Economics* 10: 1-16.

Nordhaus, W., D., and J. Boyer (2000), *Warming the World: Economics of Global Warming*, MIT press, Massachusetts, USA.

Nordhaus, W. D (1992), "An Optimal Transition Path for Controlling Greenhouse gases", *Science*, Vol 258, pp 1315-1319.

Parry, M., C. Rosenzweig, A. Iglesias, F. Fischer, M. Livermore (1999), "Climate Change and World Food Security: A New Assessment" *Global Environmental Change* **9**: S51-S67.

Pearce, D.W., W.R. Cline, A. Achanta, S. Fankhauser, R. Pachauri, R. Tol and P. Vellinga (1996), "The social costs of climate change: greenhouse damage and the benefits of control", in Bruce, J., H. Lee and E. Haites (eds.) *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Cambridge University Press, Cambridge, 183-224.

Pendleton, L. and R. Mendelsohn (1998), "Estimating the economic impact of climate change on the freshwater sport fisheries of the northeast United States", *Land Economics* **74:** 483-496.

Reilly, J., N. Hohmann, and S. Kane (1994), "Climate Change and Agricultural Trade: Who Benefits, Who Loses?" *Global Environmental Change* 4(1): 24-36.

Reilly, J. (1994), "Crops and Climate Change", *Nature*, 367:118-119.

Reilly, J. (1995), "Climate Change and Global Agriculture: Recent Findings and Issues" *American Journal of Agricultural Economics*, 77:727-733.

Reilly, J., et al. (1996), "Agriculture in a Changing Climate: Impacts and Adaptations" in IPCC (Intergovernmental Panel on Climate Change), Watson, R., M. Zinyowera, R. Moss, and D. Dokken (eds.) *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses*, Cambridge University Press: Cambridge.

Rosenzweig, C., and M. Parry (1994), "Potential Impact of Climate Change on World Food Supply", *Nature* 367, pp133-138.

Smith, J. (2004), "A Synthesis of Potential Climate Change Impacts on the US", Pew Center on Global Climate Change, Washington, D.C..

Sohngen, B., R. Mendelsohn and R. Sedjo (2002) "A global model of climate change impacts on timber markets", *Journal of Agricultural and Resource Economics* **26:** 326-343.

Schimmelpfennig, D., J. Lewandrowski, J. Reilly, M. Tsigas, and I. Parry (1996), "Agricultural Adaptation to Climate Change" Economic Research Service, USDA, Agricultural Economic Report Number 740, Washington, DC.

Schneider, S. (1997), "Integrated Assessment Modeling of Global Climate Change: Transparent Rational Tool for Policy Making or Opaque Screen Hiding Value-Laden Assumptions" *Environmental Modeling and Assessment* **2**, 229-248.

Washington, W.M., J. W. Weatherly, G. A. Meehl, A. J. Semtner Jr., T. W. Bettge, A. P. Craig, W. G. Strand Jr., J. Arblaster, V. B. Wayland, R. James, and Y. Zhang (2000), "Parallel Climate Model (PCM): Control and Transient Simulations" *Climate Dynamics* 16, 755-774.

Watson, R., M. Zinyowera, R. Moss, and D. Dokken (eds.) 1996, *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses*, Intergovernmental Panel on Climate Change Cambridge University Press: Cambridge.

Williams, C., A. Basist, T. C. Peterson, and N. Grody (2000), "Calibration and Verification of Land Surface Temperature Anomalies Derived from the SSMI", *Bull. Of the Amer. Meteor. Soc.*, pp 2141-2156.

Winters, P., R. Murgai, E. Sadoulet, A. de Janvry, and G. Frisvold (1999), "Climate Change and Agriculture: Effects on Developing Countries" in F. Frisvold and B. Kuhn (eds.), *Global Environmental Change and Agriculture*, Edward Elgar Publication, UK.

Endnotes

---

[i] Political boundaries and relevant GIS maps were obtained from the International Potato Center at http://www.cipotato.org/DIVA/data/DataServer.htm

[ii] The data was extracted from FAO 'Digital Soil Map of the World and Related Soil Properties' CD ROM.

[iii] There are three slope classes: (a) level to gently undulating, with generally less than 8 percent slope, (b) rolling to hilly with slopes between 8 and 30 percent and (c) steeply dissected to mountainous, with more than 30 percent slope. Where two or three slope classes are indicated, each is taken to apply to 50 or 33 percent respectively of the dominant soil unit. The slopes are given for the dominant and associated soils when relevant.

[iv] Textural classes reflect the relative proportions of clay (fraction less than 0.002mm), silt (0.002 - 0.05mm) and sand (0.05 - 2mm) in the soil. Three textural classes are recognized: coarse (1): sands, loamy sands and sandy loams with less than 18 percent clay and more than 65 percent sand; medium (2): sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams and clay loams with less than 35 percent clay and less than 65 percent sand; the sand fraction may be as high as 82 percent if a minimum of 18 percent clay is present; and fine (3): clay, silty clays, sandy clays, clay loams, with more than 35 percent clay. The textural class given in the mapping unit refers to the upper 30 cm of the dominant soil. Where two or three texture classes are indicated, each is taken to apply to 50 or 33 percent respectively of the dominant soil unit.

[v] The Defense Satellite provides channel measurements from the special microwave sensor on three separate polar orbiting satellites. The satellites orbit sun synchronized overpasses at 6 am and 6 pm daily and the observations are processed into 1/3 by 1/3 degree pixels and archived at the National Climate Data Center (NCDC). Data is available for a 17- year period from 1988 through 2004.

[vi] Rainfall data was extrapolated to the districts from WMO (World Meteorological Organization) Climate Normals CD ROM.

[vii] Climate scenarios were provided by the Electrical Power Research Institute

(EPRI) through Robert Mendelsohn.

[viii] GDP data comes from Nordhaus and Boyer (2001). Population data comes form FAOSTAT, 2005.