PROFILE

Profile of William D. Nordhaus

For economist William D. Nordhaus, a decade spent grappling with geophysical models of global economic activity is as satisfying as an evening listening to the Tokyo String Quartet. "Economic modeling is intrinsically fascinating. Even if it involved nothing more than trying to understand social phenomena, that by itself would be enough," he says.

Of course, it helps that Nordhaus' work also has the potential to shape economic behavior and environmental responses on a worldwide scale. He sees his role as an economist as one that can help improve economic well being, particularly through the understanding and design of policies and institutions. These policies can be especially knotty in Nordhaus' own research niche of global warming economics, where poorly understood systems in the natural sciences and social sciences interact in complicated ways.

Nordhaus, a Sterling Professor of Economics at Yale University (New Haven, CT), has for most of his career specialized in the difficult-to-measure costs and benefits of economic activities, particularly technological change and global warming. Nordhaus has served on several committees of the National Academy of Sciences (NAS), including the Committee on Nuclear and Alternative Energy Systems, the Panel on Policy Implications of Greenhouse Warming, and the Committee on Implications for Science and Society of Abrupt Climate Change. He and Paul Samuelson also authored the classic textbook *Economics*, now in its 18th edition, with translations in 17 languages (1).

For the past decade, Nordhaus has worked on the G-Econ project. The G-Econ team at Yale has generated global data with extremely high spatial resolution to measure economic activity by using geophysical scaling. Elected to the NAS in 2001, Nordhaus presented in his Inaugural Article (2), published in a recent issue of PNAS, the first results from the G-Econ project, including new, larger-than-previously-reported estimates of economic damages from greenhouse warming.

New Mexico to New Haven

Nordhaus grew up in Albuquerque, NM, which, he assures visitors to his university web page, is indeed part of the United States. Nordhaus' family had deep roots in the Southwest, with beginnings in the German–Jewish immigrant wave after the Santa Fe Trail opened in 1821. But his parents also had ties to

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the East Coast. So when Nordhaus looked for a college, his father's alma mater, Yale University, seemed a natural place to go.

Nordhaus enjoyed a variety of subjects and activities in college. "I spent most of my sophomore year skiing, as I look back on it," he says. "I got serious after that and spent more time on my studies." Nordhaus spent his junior year in Paris at the Institut d'Études Politiques, where he learned French and studied European history.

Nordhaus' senior year, however, was pivotal. He had decided to major in economics, partly because he had an aptitude for the subject and partly because he was fascinated by how economic policies could influence societies, he says. In his last year at Yale, Nordhaus took courses with Yale economists such as the late James Tobin, NAS member and Nobel laureate. Tobin was a "key intellectual stimulus," Nordhaus says, with whom he would later collaborate.

Dissertation on Side Effects

After his exposure to Yale's great economists and earning his B.A. in 1963, Nordhaus decided to pursue graduate education in economics and chose the Massachusetts Institute of Technology (M.I.T.; Cambridge, MA). "M.I.T. was at that point hands-down the best economics department in the world, and also an intellectual alternative to Yale," Nordhaus says. "It was the easiest decision I've ever made in my life."

Nordhaus worked primarily with three faculty members at M.I.T.: Ed Kuh, Bob Solow (elected to NAS in 1972), and Paul Samuelson (elected to NAS in 1970). Nordhaus studied the economics of technological change, which was "analytically an extremely difficult subject," he says. The work included a core theme that would run throughout his future research, a concept known as economic externalities. Externalities are essentially side effects, costs and benefits of an activity not captured by prices in the marketplace, Nordhaus says. "In the case of technology, if somebody invents a valuable new product, such as a microprocessor or a telephone or Windows, then the inventor gets some financial reward. But actually most of the reward goes to consumers, in terms of new products, new processes, and lower prices," he explains.

In particular, Nordhaus explored "endogenous theories of technological change" for his dissertation research (3). After three and a half years at M.I.T., he graduated in 1967 with his Ph.D. in economics. He returned to Yale as an assistant professor and continued to study technological change, until the 1970s took America and Nordhaus in a different direction.

Warming to His Subject

The years 1968 to 1970 marked an exciting period in American economics and politics, Nordhaus recalls, particularly at universities. "There was much ferment in general, but the thing that caught my eye in 1970 was the environmental revolution," he says. Nordhaus first touched on these issues in his research with James Tobin, published in the article *Is Growth Obsolete?* (4). Their work became known for its pioneering research on national economic accounts for the environment and natural resources, a method sometimes referred to as "green accounting."

The book had a short section in which Nordhaus and Tobin argued that global ecological catastrophes such as global warming warranted greater research. "When Tobin and I did our book, we were aware of global warming. We thought that it might be important, but we didn't know how economists could tackle it," Nordhaus says.

This is a Profile of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 3510 in issue 10 of volume 103.

He began to tackle this question a few years later, when in 1974 he spent a year at the International Institute of Applied Systems Analysis (IIASA) in Vienna, Austria. The interdisciplinary group there included a variety of experts, including Howard Raiffa, a well known decision theorist elected to the National Academy of Engineering (NAE) in 2005; the late Nobel-laureate economist Tjalling Koopmans, who was elected to NAS in 1969; Allan Murphy, a distinguished meteorologist; and Wolf Hafele, a German physicist, elected to NAE in 1977, who headed IIASA's program on energy systems.

This institute was just the right environment for Nordhaus to study the complexities of climate change science. "The component parts were there. What we did over that year was put the parts together into economic models." The result was a pioneering model of the economics of global warming, published in 1977 (5), with a more complete treatment in a book on energy economics in 1979 (6).

Over the next two decades, Nordhaus continued to broaden and deepen his global warming work. Because of the analytical complications in climate science and economics, it took 25 years to develop a full dynamic general equilibrium model that encompassed both the economics and a small slice of the geosciences. This effort culminated in the publication of two books. The first, *Managing the Global Commons: The Economics of Climate Change* (7), integrated economics and energy with emissions, the carbon cycle, and the global climate system in an aggregate framework. Over the next 6 years, Nordhaus, collaborating with Zili Yang and Joseph Boyer, introduced a detailed, regional model of the economics and geophysics in *Warming the World: Economic Modeling of Global Warming* (8).

Two Data Traditions

After more than two decades of building economic models of global warming, Nordhaus became concerned about the spatial resolution of the models. In general, economic models of global warming use countries and aggregations of countries to estimate emissions and impacts. All existing environmental models organize economic activity by country.

The most obvious problem with this approach, Nordhaus says, is that countries have widely varying geographic scales. For example, models might include both Russia and Singapore, which are vastly different in size. Geographic location is also crucial, Nordhaus says, especially along the north–south axis. Countries such as the United States, which stretches from Hawaii to Alaska across a span of 53 latitude degrees, cannot be well summarized by climatic averages.

Nordhaus decided to turn economic global warming modeling on its head and instead measured economic activity on a geophysical scale. Not only would this approach solve many existing problems, such as country-scale differences, but it would also allow for more detailed regional investigations. For example, Nordhaus says, to study why North America is more economically successful than South America, researchers need data that will allow them to separate "country effects," such as national economic policies, from "geographic effects," such as climate or distance from markets.

Nordhaus' G-Econ project compiles data on economic activity for every one-degree-latitude by one-degree-longitude plot of land on the planet.

Thus Nordhaus' decade-long G-Econ project was born, a compilation of data on economic activity for every one-degree-latitude by one-degree-longitude plot of land on the planet. To embark on this question, Nordhaus first needed to answer the thorny question of how to measure economic output on each plot. After some debate, he and his team settled on the Gross Cell Product concept, based on the same accounting principles as the Gross Domestic Product. Still, this measure covered only land areas, not water. Nordhaus nevertheless needed a method for dealing with the oceans' economic activities, such as offshore oil production. The further problem of rescaling the data from political boundaries to geophysical boundaries was handled by Nordhaus through work developed by mathematical geographers.

Story for Every Country

The most challenging aspect of the G-Econ project, Nordhaus says, was the quality of the data. Finding high-quality information about the economic productivity for each one-degree grid cell—approximately the size of a typical U.S. county—was not easy. It required examining the details of the national income accounts of every country, "a kind of statistical house-to-house combat," he says.

In the United States, for instance, gross output is measured at the state level. Yet spreading the economic activity of California over the entire state, including forests and deserts and Hollywood, would be misleading. "If there were uniform density, then we'd have no trouble," Nordhaus explains, "but of course it wouldn't be very interesting." Nordhaus' solution for studying the United States was to construct gross output data for each county based on government data on income and output.

At the other extreme are countries such as Somalia, the populations and statistical systems of which have been ravaged by civil conflict. Somalia has no centralized government, Nordhaus says, and possesses no regional economic records. Fortunately, a member of Nordhaus' research team was from Somalia and had fled to the United States after living in a refugee camp in Ethiopia; he was able to construct a rudimentary set of accounts for his homeland.

Nearly every nation in the G-Econ study required special treatment of some sort, Nordhaus says. For example, the Angolan government possessed no regional economic measures, but it politely asked Nordhaus to send back whatever regional accounts his team constructed for the country. Ukraine had regional economic records but hesitated to turn them over, for reasons Nordhaus never figured out. "There's a story about every country," he says.

In his PNAS Inaugural Article (2), Nordhaus presented the first description of G-Econ data, as well as results from a few applications of the data. The first effect, which he calls the "climate output reversal," was puzzling, he says. He found that the relationship between temperature and economic productivity was negative when measured on a per capita basis and strongly positive on a per area basis. That is, cold regions generated high economic output with respect to their sparse populations but not in regard to the vast amount of land. Although some hypotheses can be ruled out, Nordhaus concludes, "I still haven't sorted that one out."

One of the important applications of the new data sets is the ability to investigate the role of geography, particularly climate, in economic activity. In this area, Nordhaus investigated the controversial question of the role of geography in the poverty of tropical Africa, which has been much debated among economists. Using the G-Econ data, Nordhaus found that Africa's geography imposes a significant handicap on its economic productivity compared with temperate regions such as the United States, western Europe, and Australia. Yet geography does little to explain tropical Africa's low per capita productivity compared with other low-latitude regions outside of Africa. These results would not be possible without extensive data on output within countries as well as a good match between economic and geophysical data.

Lastly, Nordhaus used the G-Econ data to develop estimates of the economic impact of greenhouse warming. He explored two warming scenarios—global warming with no change in precipitation and warming with midcontinental drying—and found clear negative effects in both. In fact, he says, these estimates were significantly larger (that is, more negative) than impacts previously estimated by him and others.

Mapping the Future

Over the course of the G-Econ project, Nordhaus has seen dramatic changes in how economic geography studies are carried out. Ten years ago, many calculations were performed manually, whereas today almost all of Nordhaus' analyses rely on geographical software and information systems. Not only have researchers continued to develop better electronic data libraries, Nordhaus says, but software systems have also rapidly improved.

In fact, Nordhaus says, computerized mapping tools known as graphical information systems (GIS) have tremendous potential that is just starting to be realized in economics. Not only does the mapping technology allow for analysis of regional data, but it also provides an intuitive interface. "We are visual animals, so you can see relationships on a map that are difficult to extract otherwise," he says.

Likewise, the deep spatial resolution and cross-linked information in G-Econ data make new interdisciplinary analyses possible. Nordhaus hopes that the project will help integrate a variety of fields: economics, social sciences, geophysics, and environmental sciences. Geographical analyses fell out of favor in economics a half century ago, Nordhaus explains, but a renewed interest in global warming and in the geographic determinants of economic development over the past decade has revived its importance.

Still, Nordhaus is not sure how and where databases like G-Econ will be further developed. Yale and other research institutions do not have the data or resources necessary to optimally extend G-Econ, such as extending coverage to different industries and over time, he says. However, government agencies such as the U.S. Bureau of Economic Analysis might be able to undertake the project as part of national statistical systems.

For now, the next step for Nordhaus is to develop new ways to put the information in this vast data set to good use. "One area where I suspect the answer is pretty important is in the field of abrupt climate change. There are concerns about the reversal of the north Atlantic thermohaline circulation, which warms the northeast Atlantic as compared to Alaska." Current models of the impact of global warming lack the spatial resolution to deal with localized effects. But G-Econ data can match economic activity and population with impacts that a change in ocean circulation patterns might bring.

In any case, Nordhaus hesitates to predict the eventual fate of the G-Econ data approach. "Maybe it will catch on. Maybe it won't. We went through a delayed reaction when we did our first work on environmental accounting," he says. "Nobody was interested in it then, but 20 years later it took off." Wherever it leads, though, Nordhaus considers his exploration of economic activity on Earth's 27,079 parcels of land to be a fascinating way to spend a decade.

Regina Nuzzo, *Freelance Science Writer*

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