Volume XI,
No. 2
Summer 2017

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UC SANTA BARBARA | Laboratory of Aggregate Economics and Finance

FROM THE LAB

The Macro and Micro Economics of Climate Change

Presentation Summaries

Note: speakers are highlighted in author listings.

2017 Workshop of the Australasian Macroeconomics Society

Presentation Summaries

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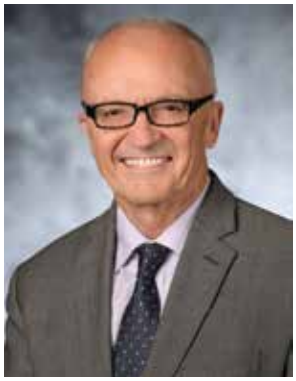


This issue contains summaries of the proceedings of two conferences. One, the conference on "Micro and Macro Economics of Climate Change,"took place in Santa Barbara. The other, the 4th Annual Conference of the Australasian Macroeconomics Society, was co-sponsored by LAEF, but took place in Canberra, Australia. In the latter case, one day of the conference was designated as "LAEF Day." This co-operation is an example of our willingness to branch out to different parts of the world in our quest for scientific progress.

Apropos different parts of the world, at the end of this Director's Message I'll continue the tradition, started two years ago, of listing notable activities such as keynote speeches and other public lectures, participation in panels, and attendance at notable events. Almost all of these listed activities are international. One exception is my lecture at the David Backus Memorial Conference at New York University. Dave and I started working together almost 20 years ago, a research co-operation, along with Patrick Kehoe, that resulted in articles in American Economic Review and Journal of Political Economy, among other places. Most researchers in the arena of international macroeconomics know what a reference to the "BKK model" means. Sadly, Dave died summer of 2016 at a much too young age (63). His intellect, curiosity, and friendship will be sorely missed.

The academic organizers of the climate-change conference were Kyle Meng, UCSB, and Tony Smith, Yale University. The main aim of this conference was to bring together macro economists, who have been advancing the frontier of climate-economy models, with applied micro economists, who have been expanding what we know empirically about climate damages. The idea was that a number of the issues researchers work on could benefit from such a joint gathering. For example, on the applied micro end there is growing interest in thinking carefully through how reduced-form parameters map onto the structural parameters found in macro models. One has been wrestling with how to aggregate damage estimates from many parts of the world onto a global damage function. These are among the examples, as you'll see from the summaries, that were discussed during the two days of conference.

Here's the announced list of the Director's activities, most of them international, from end of June 2016 through end of June 2017:

Keynote Speeches and Public Lectures

June 27: Keynote, conference on "New Power, New Cycle, New Development," Changsha, China

July 7: Keynote, conference on "Fundamental Science and Society," Quy nhon, Vietnam

July 12: Public Lecture, National Economics University, Hanoi, Vietnam

Sep. 16: Lecture, David Backus Memorial Conference, New York University

Sep. 28: Keynote, Baku International Humanitarian Forum, Baku

Oct. 7: Public Lecture, conference on the 20th Anniversary of Nobel Peace Prize to José Ramos-Horta, Dili, East Timor

Oct. 18: Public Lecture, "A Peek Behind the Curtain: Impressions from North Korea," UCSB

Nov. 12: Keynote, Annual Latin American and Caribbean Economic Association Conference, Medellin, Colombia

Dec. 8: Keynote, Asbar World Forum, Riyadh, Saudi Arabia

Jan. 18: Workshop, WHU Otto Beisheim School of Management, Vallendar

Jan. 19: Keynote, Campus for Finance, WHU Otto Beisheim School of Management, Koblenz

Feb. 12: Keynote, Warwick Economics Summit, University of Warwick

April 28: Keynote, Annual Fellows Meeting of IC^2 Institute, University of Texas at Austin

RIYADH, SAUDI ARABIA

EAST TIMOR

June 8: Public Lecture, University of Rioja, Logroño, Spain

June 12: Lecture on the occasion of being inducted into Royal European Academy of Doctors Barcelona

June 21: Keynote, Starmus Science Festival, Trondheim, Norway

Panels and Committees

Feb. 9: Oslo Business for Peace Award, selection-committee meeting, London

June 5-6: Premios Jaime I (prestigious Spanish prize), selection-committee meeting for Economics prize; Valencia

June 19: Panel on "The Role of Science in the 21st Century," Starmus Science Festival, Trondheim

June 21: Panel Discussion moderated by Larry King (well-known U.S. TV personality), Starmus Science Festival, Trondheim

Invited Attendance at Notable Events:

Sep. 5-6: Kavli Prize Award Ceremony and associated events, Oslo

May 15-16: Oslo Business for Peace Award Ceremony and associated events, Oslo

HANOI, VIETNAM

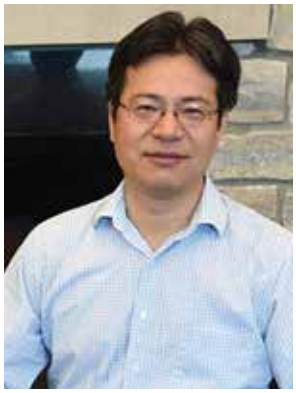
MEDELLIN, COLOMBIA

David Anthoff – UC Berkeley
Lint Barrage – Brown University
Marshall Burke – Stanford University
Yongyang Cai – Ohio State University
Tamma Carleton – UC Berkeley
Jonathan Colmer – University of Virginia
Christopher Costello – UC Santa Barbara
Olivier Deschenes – UC Santa Barbara
Klaus Desmet – Southern Methodist University
Michael Greenstone – University of Chicago
Solomon Hsiang – UC Berkeley
Amir Jina – University of Chicago
Charles Kolstad – Stanford University
Finn Kydland – University of California
Derek M. Lemoine – Arizona University
Gary Libecap – UC Santa Barbara
Kyle Meng – UC Santa Barbara
Frances Moore – UC Davis
Andrew Plantinga – UC Santa Barbara
Peter Rupert – University of California, Santa Barbara
Wolfram Schlenker – Columbia University
Tony Smith – Yale University

Participants and attendees shown at Mosher Alumni House terrace at UC Santa Barbara

Climate Change Economics and Heat Transport across the Globe: Spatial-DSICE

Yongyang Cai, William Brock and Anastasios Xeapapadeas



This paper extends the DSICE (Dynamic Stochastic Integrated Climate-Economy) model to include spatial heat transport and polar amplification of climate change. Although it is well-known that climate change will result in differentiated warming across regions of the globe, this phenomenon has previously been neglected in Integrated Assessment Models (IAMs). Areas closer to the poles will experience the most warming due to climate change, whereas areas closer to the equator are anticipated to warm the least. In addition, exacerbated warming at the poles may trigger irreversible damages, such as massive carbon releases due to melting permafrost in the Arctic Tundra. This paper takes the first step toward including these features in an IAM and reports the direction of the bias due to excluding these features while estimating the Social Cost of Carbon (SCC). The research advances economic models of climate-change towards the frontier of climate science.

The Spatial-DSICE model has two regions, North and South, with each having its own damage function. Damages between the North and South are linked due to an adjustment cost function. The climate system incorporates a two-layer carbon cycle (atmospheric and upper ocean), sea-level rise and temperature changes. Economic damages due to climate change are modeled as a quadratic function of temperature and sea-level rise. Adaptation to climate change is endogenous, and differentiated between the North and South. The model results in an infinite-horizon dynamic maximization problem with 8 endogenous and 8 exogenous variables. The model is solved using parallel dynamic programing on the Blue Waters Supercomputer.

Two sets of results are presented — with and without uncertainty over the risks of irreversible damages due to polar amplification. Without uncertainty, the Social Cost of Carbon is two times higher in the North than in the South. This is because the North is richer and incurs more damages due to warming. Ignoring spatial heat transport and polar amplification underestimates damages and optimal adaptation in the North, and overestimates damages and optimal adaptation in the South. In the stochastic setting, ignoring spatial heat transport and polar amplification results in downward-biased SCC for both the North and South.

The audience had many questions regarding the modeling choices made by the authors. An audience member asked how they avoided unrealistic investment flows to the South, a problem previously encountered in Nordhaus' RICE and DICE models. The response was that an investment border-tariff was included to avoid this problem.

There was considerable discussion of the treatment of climate tipping. One audience member asked why damages due to climate tipping were treated separately than damages due to warming. The response was to capture the difference between reversible and irreversible damages. Another question was why climate tipping was the only uncertain element in the model. The presenter responded that although many elements of the model are uncertain, only tipping points modeled as stochastic to avoid the curse of dimensionality.

Another line of questions concerned the use of Negishi weights in the social planner's problem. Audience members asked why the weights are country-specific and change over time, and whether the weights imply different interest rates across regions. The presenter responded that the tariff on investment flows implies that the marginal utility of investment need not be the same across regions instantaneously, thus different interest rates in the North and South are possible in the model. The weights used are simply the marginal utility in each region at a given time. The authors solved for the weights recursively, by guessing them, calculating marginal utilities, and plugging those in for the weights. The presenter mentioned that this process converged quickly. Further, the presenter maintained that their solution approach of time-variant Negishi weights follows the existing literature. ◊

The Marginal Product of Climate

Solomon Hsiang and Tatyana Deryugina

The authors develop an approach to value marginal changes to a climate in terms of total market output given optimal factor allocation in general equilibrium. This approach accounts for both expectations about climate and for unobserved heterogeneity. Using this approach, the authors can derive the marginal product of climate by only exploiting idiosyncratic weather variation using a reduced form estimator. In cases with a large number of small macro-economies that are densely packed in climate-space (such as US counties), estimates of nearby local marginal effects can be integrated to recover the entire value function describing the total product of climate in these economies, which characterizes the economic impact of nonmarginal changes to the climate. This value function captures the net effect of all adaptive adjustments in the economy.

To quantify the marginal product of a climate, the authors must be able to compute the economic value generated by an economy facing that climate relative to the same economy when it faces a slightly different climate, including the adaptation measures taken in response to the different climate. The central challenge is to find a framework that translates climate and other inputs into economic output while simultaneously accounting for endogenous adaptation to any changes in climate. Two assumptions underlie the analysis. First, the total revenue in an economy is a maximized quantity. Second, total revenue is continuous and differentiable in all endogenous control variables in the economy.

Climate can affect social outcomes through two channels. Climate can directly influence what weather events actually occur, called the direct effect. Climate can influence beliefs over what will happen in the future and what preemptive adjustments should be made, this is called the belief effect. The interaction of these two effects are usually referred to as measurements of adaptation. To identify the effect of climate using weather, the authors use the envelope theorem to show that if agents are optimizing an outcome and all adaptation technologies and actions are continuous, then weather variations exactly identify the effect of marginal climate changes. Utilizing the gradient theorem, the authors also show that if the climate is continuous, a sequence of marginal climate effects can be integrated to compute the effect of a non-marginal climate change.

This approach is applied a panel of US counties, which plausibly satisfy the above criteria when the authors examine their local response to small deviations in the annual distribution of daily temperatures. The authors find a strong and stable relationship between temperatures and production across space, seasons, and over time. The authors also show that large investments in human adaptations, mainly air conditioning and urbanization, appear to be partial substitutes for climate in production. However, climate continues to have a large contribution to output even in extremely urbanized setting and into the twenty-first century, suggesting a high net value of certain climates despite numerous margins of adaptation. The authors find that daily income declines 1.7 percent for each 1°C increase in daily average temperature above 15°C. Accounting for adaptation reduces marginal damages of hottest days when location experience more than forty days above 30°C. Using the RCP8.5 climate scenario to 2100 the net present value of cost due to climate in the United States accounting for adaptation is estimated to be $5-10 trillion. ◊

Inequality and the Social Cost of Carbon

David Anthoff and Johannes Emmerling

The authors present a novel way to disentangle inequality aversion between region over time in the computation of the Social Cost of Carbon. They develop an analytical approach to incorporate sub-regional inequality and derive the Social Cost of Carbon. They present quantitative estimates of the Social Cost of Carbon that utilize the disentangling of different types of inequality aversion using two integrated assessment models, the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) and the Regional Integrated model of Climate and the Economy (RICE). Their results suggest that inequality considerations lead to a higher SCC in high income regions and lower SCC in low income regions relative to the efficiency based approach. However, this effect is less strong than the effect found in previous studies that use equity weighting.

A modified social welfare function that is based on separate parameters for inequality aversion over time and inequality aversion between individuals or regions is proposed by the authors. This new approach is able to nest both a purely efficiency based approach that ignores distributional questions between individuals and the existing equity weighting approach as special cases of a more general welfare function. When the parameter for inequality aversion between regions is set equal to the parameter for inequality aversion over time, the social welfare function specializes to the standard utilitarian social welfare function. When the parameter for inequality between regions is set to zero the social welfare function specializes to a welfare function of global per capita consumption. This welfare specification allows both inequality aversion between regions and inequality aversion over time to be incorporated into the computation of Social Cost of Carbon in a way consistent with past empirical literature that finds vastly different estimates for these two parameters.

The authors also develop a new way to incorporate detailed distribution data and assumptions about income and damages into coarse regional integrated assessment models. Most integrated assessment models divide the world into 10 to 16 separate regions, but assume away any income inequality within each region of the model. The authors present analytic expressions that incorporate different distributional assumptions on the sub-regional distribution of income and climate impacts. These analytical results are then combined with a typical integrated assessment model to compute an equity weighted Social Cost of Carbon that takes inequality at a sub-regional level into account.

Using this new approach, the authors present Social Cost of Carbon estimates and compares them to the existing equity weighting and efficiency based Social Cost of Carbon estimates. For the numerical exercise, the authors used the integrated assessment models FUND and RICE. For the value of the Social Cost of Carbon, the authors find that the equity weighting increases the estimated value however the effect is less pronounced than in past studies. They find that the Social Cost of Carbon increases by approximately a factor of 2.5 when their approach is used. These findings reconcile the result that equity weighting implies a higher Social Cost of Carbon with the view that due to convergence, inequality should give rise to a higher discount rate and thus a lower Social Cost of Carbon. ◊

Weather in Origin Country Significantly Affects Asylum Applications to the European Union

Wolfram Schlenker and Anouch Missirian

Recently, there has been a large influx of migrants into the European Union. An important consideration is to determine what is responsible for this large spike. In "Weather in Source Country", the authors examine the role that weather and climate play in the decision to migrate. Weather shocks may indirectly affect an individual's preference for leaving their country through conflict or economic related channels. If weather does play a role, then it is important to account for it in decision making with respect to immigration policy. Further, if climate change induces a higher frequency or severity of weather shocks, then these indirect effects should be accounted for in more general discussions of climate change.

The authors model the decision to migrate by comparing an indirect utility function that depends on prices, incomes, and conflict levels in both source and destination country. They incorporate a constant cost of migration, making it possible only to those who can afford it. Weather in source country can influence a decision to migrate either through income or conflict. Weather shocks (defined as instances of extreme temperatures) are assumed to decrease source country income which could make migration a more attractive choice. But this reduction of income could also make migration less affordable.

Higher levels of source country conflict increase the attractiveness of migration. The effect of weather on conflict is ambiguous. If extreme temperatures lower the return to agricultural production, then there may be fewer opportunities available for work. This will decrease the opportunity cost of joining the conflict, which may cause the conflict to become worse ("factor conflict"). In contrast, these lower returns to production will result in a smaller surplus that is less likely to be worth fighting for, decreasing conflict levels ("output conflict"). There may also be a more direct effect of severe weather on aggression which could lead to an increase in the level of conflict.

The empirical analysis examines the relationship between weather shocks and migration using data on asylum applications from the United Nations High Commissioner for Refugees for years 2000-2014. Weather data is collected from the University of Delaware Air Temperature and Precipitation data set. It includes monthly measures of temperature and precipitation at the 0.5 degree longitude and latitude resolution. This weather data is aggregated by country and includes averages for each full year (and for each growing season restricted to agricultural areas in some specifications). They examine the effect of weather on the number of asylum applications to EU countries from each source country in each year. Their results suggest that extreme temperatures (primarily extreme heat) do appear to increase the number of asylum applications. The number of applications is lowest for source country temperatures in the low 20s (Celsius), with the number increasing non-linearly as temperatures depart from this moderate optimum. There is not much evidence of heterogeneity across source countries including; by low/high latitude, levels of corruption, share of the economy in agriculture, or population. Using weather data only during the growing season and in agricultural areas of countries, the estimated effects are larger. The effects are also larger for the richest half of EU destination countries in the sample compared with the poorest half. These results are consistent with a factor conflict hypothesis. Holding all else constant, asylum applications by the end of the century are predicted to increase, on average, by 28% (98,000 additional applications per year) under representative concentration pathway (RCP) scenario 4.5 and 188% (660,000 additional applications per year) under RCP 8.5.

During the presentation, there was some concern among participants that weather shocks could also affect prices which enter the indirect utility function. The author replied that production in source countries is too small to have a large effect on world commodity prices. Nonetheless, there was a suggestion to condition the analysis to land-locked countries that might affect world prices less. Participants suggested the possibility that individual migration decisions could be based on their expectations of the effects of climate change and their ability to observer, learn, and alter their expectations. Syria was excluded from the analysis as it would likely fuel most of the results if included. Participants wondered if this omission was arbitrary and whether it might be reasonable to omit other countries for similar reasons. A participant was interested in the heterogenous effect by rural versus urban areas of source country. There was also discussion of how host countries would react to different amounts of asylum seekers in the receiving country. ◊

Evaluating the Economic Cost of Coastal Flooding

Klaus Desmet, Robert Kopp, Davis Nagy, Michael Oppenheimer, Esteban Rossi-Hansberg

The authors seek to quantify the global economic costs of sea-level rise, and contribute to the literature by introducing a model of endogenous spatial and temporal development and high spatial resolution. Specifically, they measure the local effects of flooding while taking in to account the global economic linkages between cities and the long term global dynamics. The presenter gave the following example: if Miami gets flooded, where will the people move to? When some economic clusters get destroyed, where do new ones develop?

The authors utilize a grid of the world that is one degree by one degree in resolution in tandem with several probabilistic sea-level rise projections corresponding to different emissions scenarios through the year 2200. The authors feed the grid and the different projections into their model to construct scenarios in which people living in the flooded areas must move. In doing so they can project where these people move, how the global economy evolves, and ultimately recover estimates of the costs of flooding in terms of both real income and welfare.

The presenter made a clear point in outlining the several assumptions about the nature of flooding the paper makes. First, the model does not feature any mitigation or adaptation tools that limit the impact of flooding, such as additional dykes or seawalls. The only adaptation strategies available are migration and trade. Also, sea-level rise is treated as exogenous. One conference attendee asked about whether the model takes in to account the effects flooding has coupled with hurricanes or other extreme events. The presenter responded by specifying that they are only looking at the effect of permanent land inundation and not temporary flooding or individual weather events.

The model can be briefly summarized as beginning with a continuum of locations on a two-dimensional plane. Each location has a level of amenities, productivity, and geography. Each location also has firms that produce, trade, and innovate, as well as a set of agents who hold utility over consumption and amenities. Agents can migrate and hold a flow-utility cost of migration. Amenities are exogenously given, but are subject to congestion costs that increase with population. This creates population dispersion forces. Technological innovations diffuse across space and across time, which renders zero profits for firms in the long run. The presenter contended that this feature simplifies the dynamic profit maximization problem to a sequence of static problems.

Utilizing probabilistic sea-level rise projections for over 1000 measuring stations across the world, the authors run Monte Carlo simulations to find a joint distribution of sea-level rise and the economic implications that follow from the model. All uncertainty in this model comes from the sea-level rise. They find an average decline in real GDP of .22% each year (compared to a world in which nothing happens to the sea level), and a displaced population in 2200 of .79%.

One conference participant asked whether one could test how good their model is. The presenter responded by noting that the authors compare amenities levels projected by the model to measures of subjective well-being available in the literature, and they correlate quite nicely. They also backcast the model into the past and compare the model's implications for past populations with actual data, and those correlate nicely as well. ◊

Weather, Labor Reallocation, and Industrial Production: Evidence from India

Jonathan Colmer

How do economic agents respond to weather shocks and how do they adapt? Are there constraints to adaptation? Can labor reallocation attenuate the economic consequences of weather driven changes in agriculture productivity? Are workers able to find work in other sectors or locations, or do labor market frictions impede this reallocation, inextricably coupling the livelihoods and welfare of these workers to changes in the natural environment? The author attempts to answer these questions, which are extremely relevant in developing countries given the role that agriculture plays for the economic lives of the poor, by combining worker-, firm- and district-level data with high-resolution meteorological data in India. Professor Colmer follows a bottoms-up approach where he first tries to understand what are the effects of weather shocks on agriculture, then on employment and wages and finally, how this translates into other sectors in the economy.

Using a panel specification with crop-district and crop-year fixed effects, the author finds that a 1°C increase in temperature is associated with a 12.7% reduction in yield and 12.6% reduction in the value of agricultural production. In contrast neither temperature nor rainfall has an economic effect on agricultural prices, suggesting that Indian districts are reasonably well integrated with other markets, and can be considered as small, open economies. Consequently, a reduction in agricultural production should be associated with a reduction in the demand for agricultural labor, resulting in an outflow of workers into other tradable sectors of the economy due to a change in local comparative advantage. The data confirms the

theoretical result that the reduction in the share of agricultural employment (11% per 1°C increase in temperature) is offset by an increase in the share of manufacturing employment (7.61% per 1°C increase in temperature). Moreover there are no changes in unemployment or migration, suggesting that workers in India are relatively unconstrained in their ability to move across sectors in response to transitory labor demand shocks.

Professor Colmer proceeded to answer the question on where do displaced workers go and how they affect the productivity of firms and labor market outcomes of incumbent workers. Using a triple-difference approach and exploiting spatial variation in weather, in firm-level exposure to India's labor regulation environment and whether firms are regulated or not under the Industrial Disputes Act (IDA) (based on size), the author teases out this labor reallocation effect. The idea is that across India there are differences in the rigidity of labor markets and so in more rigid ones there are little incentives to hire workers who move in response to short-term transitory shocks. The main identification assumption is that there are no confounding factors across labor regulated environments that differentially affect regulated firms but not unregulated firms. In support of this assumption, the author finds that there are limited differential effects of temperature on unregulated firms across labor regulation environments.

In contrast, an increase in temperature is associated with a negative impact on firm performance in rigid labor market environments in regulated firms (9.7% contraction per 1°C increase in temperature in total output, 5.0% in items produced and 17% in employment contracts). In flexible labor market environments, firms experience a relative increase in employment (21.1%) and output (15.3%), with new entrants moving into casual manufacturing activities (less skilled). This expansion offsets the adverse effects of temperature. These results provide support for the premise that firms in flexible labor market environments are more able to absorb workers in response to agricultural productivity shocks. Additionally a relative increase in the average wage of permanent workers, manufacturing productivity (TFP and output per worker) and the number of items that the firm produces is observed, suggesting that the activities that casual and permanent workers engage in are complementary to production.

Counterfactual exercises examining the impact of temperature in total GDP suggest that in the absence of labor reallocation total aggregate economic losses would be up to 40% larger. These results indicate that the reallocation of labor across sectors could play an important role in attenuating the economic consequences of agricultural productivity shocks. At this point, a participant asked about the external validity of the results. Professor Colmer answered that these are likely context specific and they should not transfer explicitly to China or countries in Sub-Saharan Africa. However, the effects observed should shed some light on what can happen elsewhere given the theoretical structure that the paper follows. Another participant mentioned that recent research in Tanzania supports this finding, since seasonal migration is observed in response to bad weather.

A participant was concerned about the degree to which institutions adapt in places where weather shocks are more common. Professor Colmer clarified that the labor regulation environment was defined based on state level amendments to a federal regulation, where the timing and direction of these amendments were not correlated with agricultural productivity or temperature. However, spatial variation in temperature alone is not enough to identify the labor reallocation effect, so this is why additional variation in firm-level exposure is required. An additional question came up inquiring about the robustness of the results to a different definition of the markets for commodities other than district level, since the spatial extent of one product market may be different to the spatial extent of the market for another. Professor Colmer answered that there is evidence to suggest that district level is appropriate. There was also concern about the quality of some of the data used, especially measuring migration, as to which Professor Colmer replied that he used the best available.

Professor Colmer concluded by mentioning that results are robust to different specifications, non-linearities, alternative definition of firm-level exposure to labor environment regulation and instrumental variable exercises. Moreover, it seems that results are mostly driven by changes in temperature rather than rainfall and by the fact that most workers in India are landless and potentially more mobile. He stressed the importance of accounting for adaptation behavior, as failing to do so may lead to an overestimation of the damages associated to future climate change. Workers in India seem to be able to move from one sector to another and there are some positive effects for some sectors in the economy, which counteract the negative effects of weather shocks in agriculture. Market integration and diversification can play an important role in attenuating the aggregate consequences of sectoral productivity shocks. However, much more work is required to understand how different institutions, systems, technologies, and policies may moderate the short-run and long-run environmental change so that we are better able to understand the constraints that economic agents face in managing such change. ◊

Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits

Michael Greenstone

To construct reliable climate change damage function two criteria must underlie the function. Damage functions should be derived from empirical estimates that are free of sources of unobserved heterogeneity and are plausibly causal. Damage functions should also reflect that agents choose optimal adaptation opportunities and incur the costs of compensatory investments.

The first step to construct a climate change damage function is to estimate the causal relationship between climate and mortality. The authors do this using historic temperature and rainfall data. Next, the authors estimate an age-specific interaction model using long-run average climate and income to quantify the degree of adaptation historically. The authors create a set of spatial units on which they interpolate temperature-mortality sensitivities globally. Using the response surface and income and climate covariates, the authors generate temperature-mortality sensitivities for all regions globally. The authors find that as areas become wealthier, their response to extreme heat becomes more muted.

Once the response functions are constructed, the authors next develop a way to measure the costs of adaptation using a revealed preference approach. Adaptation reduces the sensitivity to temperature, but it requires costly investments. Because costs of adaptation cannot be directly observed, revealed preferences are used to create bounds of the adaptation costs. Using a predicted climate sensitivity function, projections of temperature, average climate, and income a region-specific response function that evolves through time is developed. These total mortality costs are then converted to dollars using the value of a statistical life. The responses are then projected into the future using high resolution climate projections. Two assumptions are imposed on the future evolution of the response function. First, full adaptation is defined as a flat response curve and second, higher incomes cannot make temperature variation more damaging.

Using the constructed response functions, the authors are able to obtain empirical damage functions accounting for multiple sources of uncertainty. To construct the empirical damage functions the total deaths attributable to climate change in every impact region and year are estimated. Then, using the value of a statistical life equal to $2.1million and an income elasticity of one the impact region-by-year VSLs are calculated. Damages can then be calculated by multiplying the total number of deaths in a region by the population-weighted mean VSL across all regions for each time period.

To construct a climate change damage function, the authors estimated the age-specific causal relationship between climate and mortality for data covering approximately 40% of the global population. They then model the benefits of adaptation to climate using income and average climate. These response function are interpolated spatially and temporally to cover the entire globe. Finally, the costs of adaptation are measured using revealed preferences. Utilizing these, the authors estimate the total global cost of climate change. The authors find that by 2100 global climate change amounts to an increase in all-age mortality rate of approximately 13%. ◊

Climate Change, Cyclone Risks, and Economic Growth: A 'Business Cycles' Approach

Lint Barrage and Laura Bakkensen

The purpose of this paper is to quantify how changes in the probability distribution of cyclone frequency and intensity effect changes in economic growth and welfare. This paper uses a structural approach inspired from the business cycle literature that treats natural disasters as shocks to income, depreciation, and productivity, with climate change being a change in the probability distribution of these shocks. The point of this approach is to recover not only direct losses from disasters but also meaningful general equilibrium effects that may take place.

Focusing on Vietnam, the paper first empirically estimates the cyclone impacts on household income risks, aggregate capital losses, and total factor productivity using available Vietnamese household and aggregate data. Along with simulated future cyclone state probabilities, estimated cyclone impacts can be integrated into Kreb's stochastic endogenous growth model, which will be used to project the relevant effects on growth and welfare. The Kreb's model is reinterpreted in this paper in which cyclone level is an exogenous state variable, and instead of having human and financial capital, agents have two assets, both vulnerable to aggregate cyclone shock risk with one also subject to idiosyncratic risk.

The authors find that higher cyclone activity increases the variance of income shocks, especially in more vulnerable sector such as agriculture and forestry. High cyclone activity also increases capital depreciation, but has no effect on TFP. Also, a higher probability of cyclone activity will cause agents to increase precautionary savings but also decrease investment

in vulnerable sectors, switching to lower return, safer assets. The net effect on the long-run GDP growth rate is estimated to be a decrease of .07-.14 percentage points, which is of similar magnitude to estimates on the effects of US business cycle risks on growth. In welfare terms, the model finds agents would be willing to give up 1-2% in their initial consumption to avoid the climate change-induced changes in the probability distribution of cyclone activity.

Conference attendees has several questions about the welfare figure. The presenter furthered explained that the 1-2% is taken from initial consumption today to avoid changes in the distribution in 2100. It only takes in to account the changes from the initial steady state to the 2100 steady state, and not any welfare changes stemming from the transition.

Conference attendees had concerns regarding the lack of a true risk free asset, given that theoretically cyclone risk in Vietnam could be effectively insured against with a combination of global financial assets. Some suggested the addition of a third asset class. The presenter defended the exclusion quite well by noting the lack of explicit catastrophe insurance in a less developed country such as Vietnam, and that the observed lack of explicit insurance would be grounds to hypothesize an even greater lack of implicit insurance as well. ◊

Learning about Macro Climate Impacts from Micro Data

Marshall Burke and Solomon Hsiang

Despite the efforts to estimate aggregate damage functions, there is still debate on the appropriate way to do so. Some of the literature has focused on a bottom-up approach to construct empirical damage functions, where different outcomes are measured at the micro level in different sectors and subsequently, aggregated. Alternatively, a top-down approach focuses on measuring damages and welfare using aggregate outcomes typically from national accounts data. In this latter stream of papers, Professor Burke alluded to one of his recent papers where taking the approach from Dell, Jones and Olken (2012), non-linear specifications and national accounts data, he and coauthors showed that overall economic productivity is nonlinear in temperature for all countries, with productivity peaking at an annual average temperature of 13°C and declining strongly at higher temperatures.

However, using national accounts data may be problematic for three main reasons. First, numbers in national accounts tend to be more political than economic, especially in poor countries. Second, standard welfare calculations are based on consumption rather than GDP. Lastly, national accounts are not appropriate if the purpose is the analysis on distributional effects of climate change, since within country variations are not observed.

Professor Burke presented a new project in which they aim at overcoming these limitations by obtaining aggregate measures from consumption data at the country level, as gathered in household surveys. The World Bank and Statistical offices around the world collect expenditure surveys to construct international poverty measures, most of them stored in an interactive computational tool called PovcalNet. Though the underlying data is not available, the authors managed to recover income distributions for approximately 940 country surveys since 1977. This results in an unbalanced panel (roughly every two years), with good country coverage except for Africa that is underrepresented. Some countries have income data, while most poor countries collect consumption data. Since households are not geo-referenced it is necessary to assign the same temperature to every household in each country.

With this new data set, Professor Bruke presented an initial set of results of specifications similar to the ones in Burke, Hsiang and Miguel (2015). They regress growth rates between available years in the panel over a quadratic relationship with temperature on those years. Fixed effects for every year in between two survey years were also included to subtract off global effects in between sample years. A participant asked whether it could be more appropriate to first perform the non-linear transformation and then average over the time between surveys, rather than the approach the authors took. Another participant suggested that a careful thought of the panel specification should be considered, as well as the appropriate way to include the lag structure.

After collapsing the data to country-year, Professor Bruke showed that visually the response function is non-linear in temperature and very similar to the one obtained using national accounts data. However, the marginal effects are much larger when estimated with household surveys, especially in the poorer part of the distribution. The authors ruled out that these differences are explained by the fact that the sample is different between national accounts and consumption data, or a result of the unbalanced panel. Moreover, using consumption or income, or controls for income deciles does not seem to explain the differences. In this regard, a participant suggested that they could estimate the response function only for countries with income data and for this same sample with national accounts, to determine whether results are the same in that setting or not. A participant also asked if this difference could be consistent with the precautionary savings hypothesis, as to which Professor Burke replied that it might be the case.

Having established there are no obvious reasons why could results differ between household and national accounts data, Professor Burke proceeded to discuss differential effects across the income distribution. Defining income quintiles or deciles

relative to own country, they find that marginal effects get shallower with higher income quintiles. But, unlike previous literature, the effect of warming will still be negative even for the richest quintiles. A participant asked if it was possible to look at shifting income distribution over time, as to which Professor Burke replied that they could look into that.

Professor Burke concluded by presenting a welfare analysis for different individuals in the income distribution and using the appropriate response functions. The exercise consisted of comparing utility with fixed temperature versus utility with temperature evolving according to the Coupled Model Intercomparison Project Phase 5 (CMIP5). For different initial temperature endowments and discount rates, they find a welfare loss in permanent consumption between 25% and 30%. Impacts depend much more heavily on initial temperature endowment rather than on the discount rate.

The newest part of the paper introduced a potential liquidity trap as a result of the bubble bursting. To microfound the zero lower bound, entrepreneurs choose a cash holding. When the bubble bursts, the interest rate overshoots, causing a liquidity trap. The liquidity trap only lasts one period, as in prior literature. The deflated price level exacerbates the wage rigidity.

Another participant suggested the cash in advance could be held as collateral. If that was the case, it might mitigate some of the effect of the bubble bursting. ◊

Climate Change Around the World

Tony Smith and Per Krusell

This research develops a macroeconomic model of global climate change and provides quantitative estimates of the distributional economic impacts of climate change and mitigation policies designed to curb fossil fuel emissions. The paper advances the state of the art of 'Integrated-Assessment' climate-economy models through incorporation of modern heterogeneous agent macroeconomics and spatially differentiated warming and associated damages. The main finding is that climate change and mitigation policies have large distributional impacts. Across a range of modelling scenarios, carbon taxes induce modest welfare gains compared to the status-quo — but roughly one third of regions actually experience welfare losses. The authors conclude that large transfer payments from winners to losers will be necessary for a global climate agreement.

Following the Integrated Assessment literature, the model developed in this research consists of a linked climate-economy system. In the model, forward-looking consumers choose consumption and savings paths over an infinite time horizon. Energy is treated as an input to production and is initially produced from coal, but is gradually replaced by green alternatives. Burning coal produces emissions that enter the atmosphere and induce warming. Increased temperatures cause economic damages, via a drag on Total Factor Productivity (TFP). The presenter mentioned that this damage function has little theoretical motivation and could be improved upon by future research. The damage function is consistent with the existing literature, namely Nordhaus' RICE and DICE models. The damages in this paper are designed such that when aggregated across all regions, net damages due to warming are equivalent to those of Nordhaus's single-region models.

The model's substantial heterogeneity in endowments and climate warming leads to a difficult optimization problem. The authors took several steps to simplify matters. Initially they began with a grid of 19,235 square tiles laid over the earth's surface. To avoid a scenario with thousands of state variables, they use only one state variable for global temperature and used a set of coefficients to calculate how temperature in each tile would respond to a warming global temperature. Second, they cut the number of tiles down to 700 and used splines to interpolate the results to the finer grid. To solve the model, they guessed the temperature path, solved for agents' decisions, and then ran it forward to check the initial guess. This process benefited from a well-informed initial guess for the global temperature path.

Audience members had several questions regarding the model set-up and solution approach. One question was whether it was appropriate to use time-invariant coefficients to map global temperature to the individual grid-cells. The presenter responded that they worked with climate scientists to produce the coefficients and that it was not important to allow them to vary over time. Another question was how could each of the 700 cells be solved independently of one-another. The response was that each actor takes temperature and price paths as exogenous and make their own choices accordingly.

Another question was whether the model allows for migration. The presenter said that, unfortunately, the model does not allow for migration, due to the modelling complexity. However, the model results do lend insight as to where migration pressures will form.

The remaining portion of the presentation was dedicated to the results of several modelling experiments. The first experiment involved two distinct world trade regimes, autarky and unrestricted borrowing and lending. Under autarky, the global climate externality is the only link between counties. With unrestricted borrowing and lending, the world interest rate clears the global market. The authors thought these two trade environments would have important implications on the model results. However, there was, in fact, almost no difference. Audience members were curious why this was the

case. The presenter suggested that the infinite time horizon provides enough flexibility under autarky such that international borrowing and lending is unimportant. Instead of borrowing from one another, counties can adjust over time to achieve similar optimal consumption and savings paths. An audience member asked if this result would be maintained if agents had differentiated growth in Total Factor Productivity. The response was no, potentially not.

The second set of modelling experiments involves optimal climate adaptation. The authors used a carbon-tax as the policy response because it would be a least-cost mechanism to mitigate warming. Two carbon-tax scenarios were modelled: in the first, all countries implement a carbon tax, while in the second, only the U.S. and China implement a tax. Both experiments had qualitatively similar results. Climate change mitigation led to modest aggregate welfare improvements but had substantial distributive impacts. For example, developing countries in Africa close to the equator will surely benefit from a global carbon tax. These countries will experience significant damages from warming due to the fact that they are already very warm. In addition, they contribute little to global warming, therefore they will benefit immensely from efforts to curb emissions elsewhere in developed countries.

Another interesting modelling experiment involved how the optimal mitigation strategy was determined. When each region has a single vote on climate policy, only 56% of the world's population experiences a welfare gain as a result of mitigation. However, if every person were to vote on climate policy, 84% of the world population would be better off under a carbon tax versus business as usual. ◊

The Spatial Structure of Endowments, Trade, and Inequality: Evidence from the Global Climate

Kyle Meng, Jonathan Dingel and Solomon Hsiang

Local economic outcomes depend, in part, on local endowments that are unevenly distributed across space. However, local outcomes might also depend on the global spatial distribution of endowments. In this paper the authors explore the latter hypothesis and address the question on whether the spatial arrangement of endowments alone can influence local economic outcomes through their interaction with the global trading system. Can spatial arrangements of the world's productivity distribution shape the distribution of welfare across the globe? If climate change will rearrange spatial productivities around the world and countries trade, what are the local and general equilibrium consequences of these changes?

To understand the general equilibrium effects of changes in spatial productivities potentially induced by climate change and mediated by the global trading system, the authors develop an empirical technique based on standard models of international trade. Professor Meng first introduced the conceptual framework and established the theoretical implication to validate empirically. In particular, in any trading equilibrium, a location's welfare can be stated as the sum of its welfare under autarky and its gains from trade. A location's welfare under autarky depends only on its own productivity. Its gains from trade depend on the entire distribution of productivities across the trading network. Thus, the variance of welfare across locations depends not only on the variance in productivity and gains from trade but also the covariance between these two components.

The authors investigate how the productivity distribution's spatial correlation may influence the covariance between a location's productivity and its gains from trade. Intuitively, when productivity is spatially correlated, a location with higher welfare under autarky also has larger gains from trade, due to the fact that its own high productivity is accompanied by the benefits of nearby trading partners simultaneously having high productivity. Conditional on the mean and variance of the global productivity distribution, an increase in its spatial correlation will tend to increase global welfare inequality. Professor Meng highlighted the importance of this condition, first and second moments of the productivity distribution fixed, given some questions that were raised.

Studying the spatial distribution of the gains from trade therefore requires an observable outcome that identifies gains from trade. These are revealed by the share of expenditures a location devotes to its own output across a broad class of trade models (Arkolakis, Costinot and Rodriguez-Clare, 2012). The less a location spends on its own output, the larger its gains from trade. In autarky, all expenditure is on its own output. In the trade equilibrium, this expenditure share, when combined with the "trade elasticity" governing how consumers substitute across consumption sources, summarizes the welfare gain from exchange with other locations. Through a sufficient statistics analysis the authors determine that the object of interest is thus the covariance between a location's productivity and its domestic share of expenditure. Moreover, the relationship between share of expenditure and productivity should become flatter when the spatial correlation of productivity across the entire trading network increases.

The empirical validation of the theory is challenging since typically, global patterns of natural endowments cannot exogenously be rearranged. To address this, the authors study trade in agriculture and exploit a naturally occurring climatic phenomenon, El Niño – Southern Oscillation (ENSO), that exogenously reorders the spatial structure of agricultural productivities around the planet. Essentially El Niño induces the formation of blocks in which hotter places are clustered around

the tropics and cooler locations are clustered in mid latitudes. Using this source of variation, a Moran's I statistic for spatial correlation and a simulated instrumental-variable strategy, the authors find that over the 1961-2013 period, a one-standard deviation increase in the spatial correlation of agricultural productivities increases the dispersion of welfare attributable to agricultural consumption by 4% to 7%.

At this point, a participant asked if this result should be interpreted as an upper bound of an exercise that would allow adaptation of locations to gradual changes in climate that would be permanent, given that El Niño is a cyclical event that happens every certain amount of time. Professor Meng answered that this was correct and in this sense, their paper is not too different to panel data analysis which uses year-to-year variation as a means to think about climate damages. However, their intention is to make a point about the spatial dimension that if disregarded could undermine the global welfare dispersion of climate change.

Professor Meng concluded by presenting an application that illustrates the importance of changes in the spatial correlation of productivities for projections of future climate impacts. Using the estimated reduced form parameters from the empirical validation the authors obtain climate projections that account both for local and general equilibrium effects. They show that the change in the spatial structure of productivities under climate change has an important consequence for global inequality. Specifically, climate impact projections that include the projected changes in spatial correlation of agricultural productivity due to climate change predicts a 9% higher increase in the inequality of welfare. ◊

The Climate Risk Premium: How Uncertainty Affects the Social Cost of Carbon

Derek Lemoine

Uncertainty is fundamental to climate change. Today's greenhouse gas emissions will affect the climate for centuries. The optimal emission tax that internalizes the resulting damages depends on the uncertain degree to which emissions generate warming, on the uncertain channels through which warming will impact consumption and the environment, on the uncertain future evolution of greenhouse gas stocks, and on uncertain future growth in total factor productivity and consumption. How do these uncertainties affect willingness to pay for emission reductions? Do they increase or decrease the social cost of carbon (the marginal external benefit of emission reductions)? Do they increase or decrease it by a big or small amount? Are some types of uncertainties more important than others? How do these interact with each other?

To address these questions the author estimates the social cost of carbon through a valuation approach based on asset pricing theory. Emission reduction is treated as the risky asset that increases consumption in all future periods by a stochastic amount. Valuation under this scenario is understood; so pricing emission reductions follows through from the theory. Three interacting sources of uncertainty are introduced in the model. Consumption evolves stochastically and generates greenhouse gas emissions. Greenhouse gas emissions increase the atmospheric stock of carbon dioxide, which causes gradual warming. Higher temperatures reduce the expected growth rate of consumption. This approach allows the author to explore these uncertainties simultaneously, unlike conventional dynamic general equilibrium models that are often times determinist or limited to numerically exploring only a single type of uncertainty at a time.

First using a two-period setting and later describing a full, continuous-time theoretical model the author formally demonstrates that uncertainty affects the social cost of carbon through the following channels: (i) precautionary saving motives, (ii) the tendency of damages to scale with consumption and (iii) the covariance between future consumption and the effect of today's emission reductions on future consumption growth. Moreover, under conventional power utility specifications, the assumption that the coefficient of relative risk aversion is greater than one and if climate change reduces the growth rate of consumption, uncertainty about the warming generated by emissions and uncertainty about the consumption losses due to warming each increases the social cost of carbon.

At this point, some participants raised questions concerning the specifications of the model. One asked weather the results would hold if instead of assuming a concave relationship between temperature and cumulative emissions a linear one were to be specified. Professor Lemoine answered that with a linear functional form a zero growth insurance channel would result, though the sign of the effect would remain unchanged. In this regard, concavity is essential for the results on the insurance channel to hold. Another participant asked if the author had considered Epstein-Zin-Weil preferences rather than power utility, since the intertemporal elasticity of substitution could be greater than one. Professor Lemoine mentioned that he is considering it for an extension, but since he has done several sensitivity analysis to various values he speculates that increasing the elasticity of intertemporal substitution should work directly to increase the social cost of carbon.

Professor Lemoine concluded by presenting the results from the calibration exercise. In the base specification uncertainty increases the social cost of carbon from $14.63 per tCO2 to

$23.40 per tCO2. Uncertainty about damages has nearly nine times as great an effect on the social cost of carbon as uncertainty about business-as-usual consumption growth, which in turn has twice as great an effect as uncertainty about warming. Interactions among sources of uncertainty are critical: uncertainty increases the social cost of carbon by $8.77 per tCO2 in the full model, but summing the adjustments from settings with only a single source of uncertainty would have led one to expect uncertainty to increase the social cost of carbon by only $4.78 per tCO2 in the full model. These results not only highlight the importance of accounting for uncertainty, but also to simultaneously evaluate multiple sources within a single setting, in contrast to the approach taken by recently developed recursive integrated assessment models.

The discussion in the last part of the presentation centered on the calibration assumptions. Porfessor Lemoine specified that preference parameters were taken from the Dynamic Integrated Climate Economy Model 2007 (DICE-2007) (Nordhaus, 2008), GDP and population from the World Bank, warming parameters are consistent with the scientific literature and the feedback factor is drawn from a truncated normal distribution following common practice. The distribution of the damage parameter, however, was calibrated somewhat differently to the literature and the approach could be debatable. The author follows a log-normal distribution that results from the survey in Pindyck (2016). At this point a participant suggested a calibration close to Nordhaus (2008) because if the results hold using the same probability distribution for damages and similar calibration parameters, then the author's conclusion would be more powerful. ◊

Li Anpeng, Australian National University
Antonio Bellofatto, University of Queensland
Martin Berka, Massey University
Zachary Bethune, University of Virginia
Christine Braun, University of California Santa Barbara
Elena Capatina, UNSW Business School
Francesco Carli, Deakin University
Arpita Chatterjee, University of New South Wales
Karsten Chipeniuk, Indiana University
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Maciej Dudek, Vistula University and IBRKK
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Alfred Haug, University of Otago
Stella Xiuhua Huangfu, University of Sydney
Takashi Kano, Hitotsubashi University
Munechika Katayama, Waseda University
Ian King, University of Queensland
Robert Kirkby, Victoria University of Wellington
Mariano Kulish, University of New South Wales
Gianni La Cava, Reserve Bank of Australia
Jorge Miranda-Pinto, University of Virginia
Solmaz Moslehi, Monash University
Giovanni Pellegrino, University of Melbourne
Peter Rupert, University of California Santa Barbara
Christie Smith, Reserve Bank of New Zealand
Serene Tan, National University of Singapore
Satoshi Tanaka, University of Queensland

Duc (Brian) Tran, University of Melbourne
Lawrence Uren, University of Melbourne
Yuichiro Waki, University of Queensland
Jiao Wang, the Australian National University
Liang Wang, University of Hawaii Manoa
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Dennis Wesselbaum, University of Otago
Sylvia Xiao, University of Wisconsin-Madison
Taojun Xie, Singapore Management University
Yiyuan Xie, University of New South Wales
Jianhuan Xu, Singapore Management University
Pei Cheng Yu, University of New South Wales
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Canberra, Australia

Crime and the Minimum Wage

Christine Braun

In this paper, Braun addresses the impact that changes in the minimum wage have on property crime committed by young workers. She constructs a model in which workers search for jobs and are occasionally given the option to commit a property crime knowing that they will be caught with some probability. Because a worker's propensity to commit a crime depends on the value of remaining in the labor market, policies that affect compensation or the unemployment rate, like the minimum wage, may alter the aggregate crime rate. The model predicts that the minimum wage has a non-monotonic impact on the crime rate, a finding that is replicated in the data between 1980 and 2012. With the calibrated model, she finds that the optimal minimum wage is close to the current federal level.

To quantify the impact that the minimum wage has on crime, she constructs a model of labor market search in which workers receive exogenous job offers as well as crime opportunities. Workers are heterogeneous with respect to unemployment utility and find crime opportunities while both employed and unemployed. Upon meeting, a match-specific productivity is drawn from an iid distribution and workers and firms bargain over compensation, subject to the minimum wage. Once employed, jobs separate both exogenously with some probability and if a worker is caught committing a crime. If caught, a worker enters prison and receives an exogenous "prison" utility stream, and is released stochastically. In equilibrium, firms choose to offer wages to deter matches above a productivity threshold from committing crimes. Imposing a minimum wage causes firms to offer worse matches the crime deterring wage, but simultaneously restricts the set of acceptable productivities to be smaller in the case of a binding minimum wage. Comparing these two effects is key to determining efficiency.

She calibrates the model using simulated method of moments, targeting a set of equilibrium crime and labor market outcomes. She uses labor market outcomes for 16 to 24 year olds in 1998, a year in which many states had the same minimum wage as the federal minimum wage. For crime, she matches the likelihood of being convicted conditional on committing a crime as well as the average loss from a crime, restricting the sample to property crimes in both cases. Externally, the calibrated model generates elasticities consistent with estimates from the empirical literature. Using the calibrated model, she estimates the number of crimes committed per million individuals for various levels of the minimum wage. She finds that in 1998, increasing the minimum wage from $5.24 to $6.20 would have cut the crime rate among 16 to 24 year olds by about 66%. However, increasing the minimum wage above $6.20 causes the crime rate to increase; above $7.50, the crime rate is higher than under the initial $5.24 minimum wage regime. To further validate the model, she estimates the changes in property crimes among states with different minimum wages in 1998. What she finds is that increasing the minimum wage from the lowest levels in the sample initially decreases the rate of property crimes, but increases them at higher levels of the minimum wage. This suggests that the non-monotonic relationship generated by the model is also present in the data.

The audience questioned the consequences of ignoring long-term effects on employment prospects from committing a crime. Braun said that she doesn't build that feature into the model, but that most of the crimes considered are small, so unlikely to have long-term effects. Another audience member was concerned that employer entry in the labor market. One noted that the number of jobs may fluctuate as the minimum wage changes. Braun argued that the entry margin would change the magnitudes, but not the overall results, because it would depend on the surplus from the match. ◊

A Macroeconomic Theory of Banking Oligopoly

Stella Xiuhua Huangfu, Mei Dong, Honfei Sun and Chenggang Zhou

In this paper, the authors study the impact of market imperfections in the credit, labor, and goods market, and their implications for competition among financial institutions as well as economy-wide welfare. Most models study either a continuum of perfectly competitive banks, or a single monopolistic bank, neither of which accurately characterize the banking sector. To address this, they construct a model in which microfoundations support the existence of oligopolistic banks in equilibrium. Liquidity constraints that are inversely related to the number of banks in the economy limit the number of loans that can be given out in aggregate by banks. This means that additional competition among banks can have a non-monotonic effect on welfare, as well as important aggregates such as unemployment and output. They show that there exist multiple equilibria, and that among the equilibria the one in which the number of banks is smallest obtains the highest welfare of the three.

The model features search frictions in credit, labor, and goods markets, liquidity constraints on the loans that banks give out, and equilibrium existence of oligopolistic banks arising

from market imperfections. In the model, banks operate as financial intermediaries, taking deposits from workers and lending to goods-producing firms so that they can enter the goods market. These banks face liquidity constraints because borrowers repay stochastically throughout the period, causing the banks to occasionally be unable to provide credit to a potential entrant firm. This means that while additional banks may increase the incentives for banks to make loans to firms, it decreases their funds available for such loans and can negatively affect important aggregates in the economy, namely output and unemployment. Depending on the severity of the liquidity constraints, competition among banks may decrease rents accrued to banks, while having a minimal effect on aggregates, or severely limit the ability of goods-producers to enter and have large negative effects on consumption. The labor market is modeled using standard random search a la Diamond-Mortensen-Pissarides, while the credit and goods markets are constructed using a day-night structure, which limits the state space of the decision rules. A firm must find a creditor before producing, and thus, firms may be in one of 3 states: entrant without a firm or loan officer; firms with a loan officer, but no workers; and firms with both loan officers and workers. Matched firms and workers last until they receive an exogenous separation shock.

The authors characterize the potential equilibria depending on inflation levels and bank entry. In particular, they compare the equilibria resulting from fixed measures of banks, as well as endogenous entry of banks. Welfare is determined by entry of banks as well as the inflation rate in the economy. Inflation causes the real value of money to decline, meaning that higher levels of inflation decrease the real value of loanable funds of the banks. Larger number of banks, likewise, decrease the likelihood that a meeting between a bank and goods-producers results in loans. High levels of inflation lead to stable equilibria with lower welfare than low inflation equilibria, all else equal. Intermediate levels of inflation may result in the pareto dominant equilibria (the low inflation equilibria), the bad high inflation equilibria, or an intermediate unstable equilibrium, for which any perturbation will push the economy to the bad equilibria. With a fixed number of banks, fewer banks results in the good equilibrium, while higher numbers result in the intermediate and bad equilibria, though these cutoffs depend on the level of inflation. With endogenous entry, there are unique equilibria both for zero inflation economies and high inflation economies, while intermediate levels result in unstable equilibria that may converge to either of the limiting equilibria if there is a perturbation. Bank entry is lowest in the good equilibrium, and highest in the bad equilibrium.

The audience was skeptical that each component of the model was necessary to address the central question of the paper. Dong noted that they sought to both present a model that could address the topic at hand, but also to introduce a model that could be applied to a number of other related questions. One member noted that the concerns modeled were misplaced: bank runs were a source of problems, not loan sizes. Dong said that they modeled it this way in the paper because they don't have enough data to try an alternative. ◊

Productivity Network Density and Aggregate Volatility

Jorge Miranda-Pinto

In this paper, Miranda-Pinto considers the impact of sector-specific shocks on output and unemployment in a model that features networks of production. In the model, output is created using a mix of intermediate goods and labor. He analyzes the impact that production network density, or the interconnectedness of intermediate good production, has on the production of a final good. When the aggregate good producer employs a technology in which labor and intermediates are gross substitutes, network density mitigates the impact of sector-specific shocks; for economies in which labor and intermediates are gross complements, sector-specific shocks are amplified by the production network density. He provides a set of regularities that demonstrate the presence of such effects in the data, calibrates the model, and then addresses the impact of production network density on the magnitude of business cycle fluctuations.

Existing multisector models produce counterfactual predictions about network density and aggregate fluctuations. Miranda-Pinto documents a positive correlation between network density and aggregate volatility in manufacturing oriented economies, and a negative relationship in service oriented economies, and then constructs a model that can account for these regularities. In the model, there are N sectors with a continuum of homogeneous firms, each of which operates a constant elasticity of substitution (CES) production technology. Each sector uses materials from the other sectors, weighted by their importance in the production process, and then produces using a combination of these materials and labor. A representative household in this economy consumes a weighted average of each sectors production, and receives disutility from work. Prices for each good and input in the economy are determined competitively. His key departure from the previous literature is that he allows non-unitary elasticities of substitution between labor and materials. This allows the structure of the input-output matrix to impact aggregates differentially, because firms do not simply spend a fixed share of income on each input.

His model predicts that when an economy produces goods using a technology that can readily employ either intermediate goods or labor (i.e., the inputs are substitutes), then production

density mitigates the effect of shocks on the aggregate economy. On the other hand, when labor and intermediate goods are complements, less densely connected production networks lead to less volatile economies. Economies with larger service sectors are less volatile in economies with a high degree of substitutability between goods and labor, while the converse is true for manufacturing oriented economies. He demonstrates these two cases analytically by specifying a "sparse input-output network," where firms employ materials from only one other sector in the economy, and a "dense input-output network," in which the elasticity of substitution is constant between all firms in all sectors. To make quantitative predictions, Miranda-Pinto uses the observed input shares across countries from the OECD in 2005 to calibrate the production network, and the consumption shares using consumption data by sector. He uses log utility with linear labor disutility, and calibrates an aggregate productivity series using an AR(1) process parametrized from Horvath (2000). With this parametrization, model-produced data replicates the regularities observed in the data.

The audience was concerned with the dearth of data used to establish the empirical regularities. Miranda-Pinto argued that while a longer series would be preferable, the results were very robust to inclusion of other explanations. Another member of the audience questioned the calibration of the productivity process form the previous paper. They noted that the previous paper may not have featured an identical production sector, so aggregate shocks may be over or understated. Another audience member noted that for many of the countries studied, international trade was a substantial component of their production, which Miranda-Pinto agreed with, but said he wasn't addressing it in this paper. ◊

Declining Trends in the Real Interest Rate and Inflation: The Role of Aging

Ippei Fujiwara and Shigeru Fujita

Fujita and Fujiwara study the impact of changing demographics on the interest rate in a model economy. Japan has experienced a long-term decline in the real interest rate between the 1980s and 2000s; this was preceded by a decline in labor force participation in the 1970s. They show that these phenomena are related: when the standard New Keynesian model is extended to incorporate search and matching in the labor market, an aging labor force can account for 40% of the overall decline in the real interest rate. Initially, a slowdown in labor force entry is associated with a rise in consumption, as the average worker becomes more experience. However, as the relative size of the young population declines, there are fewer sources of growth in the model economy, leading to longer-term declines in the GDP growth rate and the real interest rate when the monetary authority follows a Taylor Rule.

The model expands on the standard New Keynesian model. Monopolistically competitive firms produce a set of differentiated goods using a linear production technology that combines experience and un-experienced labor. They face a decision each period to adjust prices at a small cost, or let their price remain fixed at a potentially suboptimal level. A representative household maximizes the utility of all workers in the economy, who differ in terms of age and experience. In the labor market, unemployed workers search randomly for vacancies posted by firms. If a worker and firm meet, they negotiate a stream of future wages using Nash Bargaining. When employed, a young worker faces a probability that they will gain experience and "age," i.e., transition from young to old. They also face a probability that they will separate exogenously each period and return to the pool of unemployed workers. For an old worker, this entails a stochastic loss of experience, making them possibly less productive in future matches. During each period, new workers are born, and old workers die with some probability. Following the New Keynesian literature, they assume that a monetary authority follows a "Taylor Rule," and alters monetary policy in response to differences in realized inflation from a target. This changes the nominal interest rate on bonds that are sold to households by the government to finance expenditures.

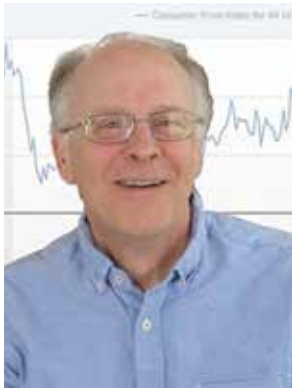
They calibrate the model to a steady state in 1970s Japan, and allow demographic parameters to fluctuate over time. For model parameters, they use commonly accepted values within the macro literature, and parameters from related papers to match characteristics of the labor market. To match the decline in labor force participation, they use data on the birthrate 20 years prior to estimate the size of young cohorts prior to 1970, and after 1970. For the initial steady state, they use the birth rate prior to 1970. Then, they analyze the transition after birthrates decline. What they find is consistent with the Japanese experience: the economy initially experienced substantial labor productivity growth, before stagnating once the size of the old cohort was much larger than the young cohort. Further, they find that the decision rules of the monetary authority cause deflation by the mid-2000s. The reason is that the monetary authority does not internalize the long-term change in the real inflation rate that results from a slower growth rate in per-capita consumption. Overall the model accounts for roughly 40% of the decline in consumption growth and the real interest rate.

The audience was skeptical that a New Keynesian model was able to provide conclusive evidence for this channel. They noted that the Taylor rule was deliberately sub-optimal, and

that an optimal monetary policy would result in minimal effects through this channel. Fujiwara argued that such a policy rule was consistent with observations in Japan, and that ex ante responses to underlying trends seems unlikely. The audience also argued that the case of Japan warranted an open economy model, because the country engages in a great deal of trade. Fujiwara noted that the model was already computationally difficult enough. ◊

Inflation Control: Do Central Bankers Have it Right?

Stephen D. Williamson



Williamson began the LAEF day of the WAMS conference by delivering a plenary talk on inflation modeling approaches taken by central banks. He summarized the history of thought on modeling inflation, the current approaches, and the problems that are still faced in understanding the sources and consequences of inflation. The overarching theme was that many of the current modeling approaches assume that inflation causes changes to the nominal interest rate, while causality runs in both directions in current models. More specifically, these models make predictions that appear to be misunderstood by policy-makers.

He starts by showing that a canonical New Keynesian model generates the same inflation dynamics as a class of segmented markets models, and that these predictions are not necessarily those espoused by central bankers. Specifically, these models exhibit a "Fisher Effect," which drives the response of the nominal interest rate in the opposite directions from what is predicted by bankers. He first shows the 3 equilibrium conditions of a standard NK model: an IS-curve, Phillips curve, and Taylor Rule. The IS curve gives the dynamic response of consumers to changes in the interest rates, while the Phillips curve shows the relationship between inflation and unemployment, and the Taylor Rule is an imposed policy response by the Federal Reserve. He first shows that in the long-run, under standard assumptions, the New Keynesian model allows for multiple equilibria with the same steady-state level of inflation. When using the model to consider the short-run, however, he notes that conventional wisdom is inconsistent with predictions of the model: traditional Keynesian models predict that an increase in the interest rate decreases output and inflation. However, in the dynamic models employed by central banks, current output does not respond to changes in the nominal interest rate, but expectations over future output increases, which causes a counter-intuitive increase in inflation. While this is inconsistent with the conventional wisdom employed by bankers, it's consistent with the textbook "Fisher Equation," which relates an increase in inflation with increases in the nominal interest rates. He then describes the set of assumptions necessary for this class of models to achieve the "conventional wisdom."

After discussing the misunderstanding in standard New Keynesian models, Williamson shows how a segmented market approach produces the same equilibrium outcomes. He notes that bankers should take note that in a variety of approaches, "Fisher Effects" are present: increasing inflation increases the interest rate. The basic set-up is similar, but the Euler Equation allows for both a liquidity channel and a Fisher channel. He shows that through liquidity effects, inflation and the nominal interest rate can move in the opposite direction, but that the Fisher Effect will dominate in this class of models as well and make similar equilibrium predictions. Thus, he argues, this isn't simply a characteristic of a single model, but a broad prediction.

Members of the audience were interested in how this finding translates into policy. One asked what advice Williamson would give to policymakers, and he said that specifying rules for gradual nominal interest rate increases would be best in his opinion. Another wondered how to think about this practically, since central banks are not in direct control of the interest rate. Williamson said that it's possible for central banks to adjust their balance sheets to achieve a nominal target, rather than through open market operations. He finally noted that the largest problem to achieving policy goals is to specify a target and then repeatedly not meet it. ◊

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