NBER Pre-Doctoral Fellowship Program on Energy Economics
Applicant: Paige Weber

Summary of Research Proposal

During the NBER fellowship year, I will be working on the three chapters of my dissertation in energy economics. As the first two chapters are close to completion and will be finalized during the fellowship year, this research proposal focuses on the third chapter and then briefly reviews the other two chapters.

Distributional Impacts of Dynamic Responses to Climate Policy in the Electricity Industry

OVERVIEW: This research project asks what co-benefits (or damages) exist from local air quality impacts of global climate change policy by examining the electric industry's response to the cap-and-trade program implemented in California. I develop a dynamic model of an electric generating unit's production and investment decisions and use this model to simulate market and local air quality outcomes across alternative emissions trading and climate policy scenarios. The novel modeling approach developed allows for a comparison of social welfare across different policy scenarios acknowledging both the local and global impacts of GHG regulation.

MOTIVATION: California's Assembly Bill 32 (AB 32) passed by the State Legislature in 2006 requires that the state reduce its GHG emissions to 1990 levels by 2020 but does not mandate a policy mechanism to achieve these reductions. During the public policy process managed by the California Air Resources Board (ARB) to design and implement a policy plan to achieve these reductions, the environmental justice community strongly opposed the use of a market mechanism such as cap-and-trade. Their concern was that such a policy would not only fail to address the zones of severe air pollution in California but would potentially increase the pollution in these regions, which are disproportionately inhabited by low-income and minority communities. Despite these objections, the ARB instituted the cap-and-trade program that began in 2013. The program continues to be criticized by the environmental justice community (CEJA 2016), and these criticisms are supported by a preliminary descriptive assessment of the program's equity outcomes that finds that cap-and-trade fails to deliver public health benefits to residents of color and those living in poverty (Cushing et al. 2016). This research project investigates the current and future impacts of climate policy on air pollution across community demographics in CA as a result of the program's impact on the electricity industry by explicitly modeling electric generating units' decisions in a cap-and-trade program and then mapping these decisions to emissions and air pollution outcomes. In doing so, this project will provide meaningful contributions by both evaluating future local air quality outcomes across communities in California and by developing a model that can be used more generally to assess the co-benefits of climate policy from impacts to local air quality.

MODEL: The electric industry's responses to a GHG emissions trading program that are relevant to local air pollution occur via two mechanisms. First, output increases among the units with relatively lower emissions intensities. Second, GHG allowance prices motivate investment in technology that reduces environmental compliance costs. Thus, to answer my research question and quantify changes to local air pollutants in each hour at each unit as a result of the program, I develop a dynamic structural model of electric generating units' production and investment decisions that allows for an assessment of both the redistribution of production and the unit-level emissions intensity improvements across the electricity industry in California.

While static approaches to modeling production decisions made by electric generating units have been useful for understanding these markets (e.g., Borenstein, Bushnell & Wolak

2002), answering my research question requires explicitly considering the inter-temporal components of decision-making by the electric units. The need for dynamics in modeling production decisions is driven by the presence of large start-up costs that are incurred to bring a unit from non-operating to operating state: a static model that ignores these costs would mischaracterize production responses to a GHG pricing program, over (under) estimating responsiveness at lower (higher) GHG prices. I develop a model in the spirit of Rust (1987) and Cullen (2015) to consider the dynamic production decisions made by the firm in the presence of large start-up costs. Adding to the Cullen (2015) model, I also allow the firm to make investment decisions to improve the efficiency of their unit. In the case of a fossil fuel electricity portfolio dominated by natural gas as in California, investments to reduce GHG compliance costs occur through improvements to the unit's heat rate to reduce the amount of fuel burned and associated GHG permits required per unit of electricity produced.

The CA wholesale electricity market is assumed to be competitive in this model, simplifying the modeling approach relative to other work examining dynamic responses to environmental regulation such as in Ryan (2012) and Fowlie, Reguant, and Ryan (2016). While earlier studies find evidence of market power in California electricity markets (Borenstein et al. 2002, Wolak 2003), the structure of the market has evolved since these studies. The Department of Market Monitoring at the California Independent System Operator (CAISO) reports few instances of market power in the years of the project's study period (2013 – 2015) in their annual reports, and the CAISO has initiated a process of on-going market power mitigation through the submission of false bids to alleviate situations where market power may be expected (CAISO 2016). That said, this assumption will be carefully considered in the analysis.

With the price-taking assumption, each electric generating unit can be treated as an individual firm, and in the model firms make production and investment decisions in each hour to maximize the sum of expected discounted future payoffs. The state space for the firm's dynamic programming problem includes the hour of the day, the hourly price of electricity, the cost of a GHG emissions permit, the firm's operating state in the prior period, and the firm's heat rate, which determines the emissions generated per unit of electricity produced (emissions intensity). The marginal costs of electricity production and environmental compliance are calculated from the data, and the structural parameters to be estimated are firm-specific start-up costs and the fixed and variable costs of investment. Start-up costs are identified by the willingness of the firm to operate in two states that differ only in the firm's operating status in the prior period. Investment costs are identified by differences in unit-level heat rates across different marginal costs of production and environmental compliance.

DATA: Estimation of this model requires hourly prices, detailed unit characteristics, and hourly production and emissions quantities for all electric generating units regulated by the cap-and-trade program in California. Hourly prices will be obtained from publicly available data maintained by the CAISO. Unit-characteristics and hourly production and emissions quantities will be obtained from the subscription-based Energy Platform provided by the data provider SNL Financial. The SNL platform compiles data collected through various federal reporting requirements, including continuous emissions monitoring systems installed at the units.

ESTIMATION STRATEGY: The two-step estimation approach developed in Bajari, Benkard, and Levin (2007) applied to a single-agent setting will be used to estimate the firm's policy functions and recover the unknown structural parameters of the model. Market outcomes in counterfactual scenarios that adjust the GHG allowance price path will be considered by using the observed relationship between electricity and allowance prices to estimate wholesale

electricity prices under counterfactual GHG price paths. Then, the recovered policy functions will be used to simulate counterfactual firm production and investment decisions under alternative GHG price paths. I will also be reviewing an alternative estimation approach that uses value function iteration with a parametric approximation of the value function such as in Fowlie et al. (2016), which may provide computational advantages for estimation of this model.
INTENDED RESULTS & CONTRIBUTIONS: A first goal of this work is to consider the impact of the program on local air pollution outcomes across neighborhood demographics. This objective is similar to that pursued in Fowlie, Holland, and Mansur (2012), but here the cap-and-trade program is used to regulate GHGs instead of local air pollutants regulated under RECLAIM. Next, the project will explore how air pollution outcomes differ in a more stringent policy setting that leads to higher GHG prices, as well as in a command-and-control type of emissions policy. This project will estimate the hourly quantities of emissions of local air pollutants generated at each electric generating unit in California, and these results will provide the basis for an estimation of ambient air pollution concentrations and the resultant damages to human health across the scenarios. In particular, the estimates of spatially disaggregated hourly emissions provide inputs to an integrated assessment model that maps emissions to pollution exposure and damages to human health such as Muller and Mendelssohn's (2007) Air Pollution Emission Experiments and Policy analysis model (APEEP). The results of the APEEP model provide estimates of the monetary damages from impacts to human health. Together with a calculation of the total costs to meet California's electricity demand and the climate benefits of GHG emissions reductions using a social cost of carbon, I will be able to assess the impact of market-based GHG policy on social welfare across policy scenarios, including the benefits and costs from the program's impact on both global climate change and local air pollution.

Overview of Other Projects

In another dissertation chapter, I examine how energy use from one of the nation's largest sources of greenhouse gas emissions, the transportation sector, is impacted by the local built environment. I assess the relationship between urban form and travel by matching micro-level travel data and vehicle characteristics to characteristics of drivers' local built environments. Using multiple approaches to overcome the identification challenge in estimating the relationship between urban form and travel that arises from residential sorting, the preliminary results for a subset of the data indicate that traditional measures of urban form such as population and household density are not significant determinants of driving. However, the index of walkability from Walkscore.com does play a meaningful role, with a 10 point increase in Walk Score leading to a decrease in daily vehicle miles traveled (VMT) by 600 miles annually on average per driver in MA.

There has been a marked increase in the past decade of energy audit and retro-commissioning requirements in cities across the country. In my third dissertation chapter I estimate the impact of one such policy, Local Law 87 (LL87), on energy use for large commercial buildings in New York City (NYC). The study takes advantage of a unique natural experiment, where the LL87 compliance requirements were randomized across commercial buildings. I find that audits and retro-commissioning play a meaningful role in improving building performance in NYC, reducing natural gas energy use intensity by 7 percent. However, I find that the policy does not have an effect on electricity use.

References

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Borenstein, Severin, James B. Bushnell, and Frank A. Wolak. "Measuring market inefficiencies in California's restructured wholesale electricity market." *The American Economic Review* 92.5 (2002): 1376-1405.

California Environmental Justice Alliance (CEJA). "New Report Highlights Equity Flaws in in California's Cap-and-Trade Program." 14 September 2016. http://caleja.org/2016/09/new-report-highlights-equity-flaws-in-californias-cap-and-trade-program/.

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Cullen, Joseph A. "Dynamic response to environmental regulation in the electricity industry." unpublished working paper (2015).

Cushing, Lara, Madeline Wander, Rachel Morello-Frosch, Manuael Pastor, Allen Zhu, and James Sadd. "A Preliminary Environmental Quality Equity Assessment of California's Cap- and-Trade Program". Research Brief (2016).

Fowlie, Meredith, Mar Reguant, and Stephen P. Ryan. "Market-based emissions regulation and industry dynamics." *Journal of Political Economy* 124.1 (2016): 249-302.

Fowlie, Meredith, Stephen P. Holland, and Erin T. Mansur. "What do emissions markets deliver and to whom? Evidence from Southern California's NOx trading program." *The American Economic Review* 102.2 (2012): 965-993.

Muller, Nicholas Z., and Robert Mendelsohn. "Measuring the damages of air pollution in the United States." *Journal of Environmental Economics and Management* 54.1 (2007): 1-14.

Rust, John. "Optimal replacement of GMC bus engines: An empirical model of Harold Zurcher." *Econometrica: Journal of the Econometric Society* (1987): 999-1033.

Ryan, Stephen P. "The costs of environmental regulation in a concentrated industry." *Econometrica* 80.3 (2012): 1019-1061.

Wolak, Frank A. "Measuring unilateral market power in wholesale electricity markets: the California market, 1998-2000." *The American Economic Review* 93.2 (2003): 425-430.

Paige Elizabeth Weber

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EDUCATION

Yale University, School of Forestry & Environmental Studies, New Haven, CT, 2014 – present
Doctoral Candidate in Environmental Economics (PhD) - *in progress*
Adviser: Dr. Kenneth Gillingham

Yale University, School of Forestry & Environmental Studies, New Haven, CT, 2012 – 2014
Master of Environmental Science (MESc)
Master's Thesis: "The Impact of Urban Form on Driving Demand"

University of California, Berkeley, CA, 2005 – 2009
B.A., Political Economy of Industrialized Societies, with High Honors
Honors Thesis: "Who is Global Warming Policy Accountable To? The AB 32 implementation process as demonstrative of the undefined responsibilities of contemporary global warming policy."
B.A., Music, with Distinction in General Scholarship

University of Cape Town, South Africa, 2008

University International Menendez Pelayo, Barcelona, Spain, 2007

RESEARCH

Interests

Environment & energy economics, industrial organization, public economics, electricity markets, transportation economics, urban economics

Selected Work-in Progress

"Distributional Impacts of Dynamic Responses to Climate Policy in the Electricity Industry"
Understanding how climate change policy impacts human health due to changes in local air quality

"The Impact of Urban Form on Driving"
Quantifying the role of the local built environment on transportation decisions in Massachusetts

"The Impact of Energy Audits and Retro-Commissioning on Building Energy Use in NYC"
Understanding the impact of New York City's Local Law 87 on building energy efficiency

Discussion Paper

Burtraw, D., Palmer, K. L., Munnings, C., **Weber, P**., & Woerman, M. (2013). Linking by degrees: Incremental alignment of cap-and-trade markets. Resources for the Future DP, 13-04.

PROFESSIONAL EXPERIENCE

The White House Council of Economic Advisers, Washington D.C., January – August 2016
Staff Economist
Provided economic analysis to support the Executive Office of the President on energy and environment-related issues

Yale College, New Haven, CT, 2014
Teaching Fellow
Weekly section lectures for undergraduate course, International Political Economy

Yale University, School of Forestry & Environmental Studies, New Haven, CT, 2012 - 2015
Research Assistant
Environmental economics research in energy and transportation sectors

Metropolitan Area Planning Council, Boston, MA, 2014
Data Services Intern
Data analysis in travel activity and land and property uses in MA

World Resources Institute EMBARQ, Bangalore, India 2013
Sustainable Transportation Research Consultant
Analyzed impact of the built environment on energy and emissions from transportation for residential communities in Bangalore

Resources for the Future, Washington, D.C., 2012
Research Assistant
Analyzed linkage of cap-and-trade programs for greenhouse gas markets

Pacific Gas & Electric Company (PG&E), San Francisco, CA, 2009 – 2012
Greenhouse Gas Commercial Strategy Senior Analyst, 2012
Project manager for cap-and-trade implementation within Energy Procurement department; developed strategy to incorporate GHG allowances prices into PG&E's electric portfolio
Greenhouse Gas Implementation Analyst, 2011
Analyzed integration of cap-and-trade into electricity markets; supported development of PG&E's policy positions for California's cap-and-trade regulation
Rotational Analyst Program in Energy Procurement, PG&E, 2009 – 2010
Renewable Energy Policy & Strategy Analyst
Contract Management Analyst
Structured Transactions Analyst

PG&E Grassroots Green Network, President, San Francisco, CA
First President of PG&E's volunteer employee green team of 300 employees

Redefining Progress, Oakland, CA, Aug 2008 – Jan 2009
Sustainable Economics Intern
Researched and analyzed effects of implementing California's climate change bill, Assembly Bill 32, on low-income and disproportionately polluted communities in California.

GRANTS & AWARDS

- Yale Institute for Biospheric Studies Research Fellowship (2015)
- Switzer Fellow (2013)
- Carpenter Sperry Research Fund Award (2013)
- Sobotka Research Grant Recipient for Student/Faculty Collaborative Research in Business and the Environment (2013)
- Richard A. Clarke Annual Environmental Leadership Award, Finalist (2011)
- Edward Kraft Scholarship (2006)

YALE UNIVERSITY
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December 4, 2016

Dear NBER Pre-Doctoral Fellowship Committee:

I am very pleased to write this recommendation letter in support of Paige Weber's proposal for the Pre-Doctoral Fellowship Program on Energy Economics. I am Paige Weber's academic advisor at Yale and have known her since she began in the program in September 2012. She has also been a research assistant for me during her entire time at Yale and she also worked for me for six months in her stint as a staff economist at the White House Council of Economic Advisers. She is an exceptional student who has impressed me from the beginning. I have no doubt that she is on her way to writing a top-notch dissertation in energy economics.

Paige came highly recommended to me from colleagues at UC Berkeley, where she did her undergraduate degree, and Resources for the Future, where she had previously worked. All emphasized her maturity and eagerness to dive into rigorous coursework. I have not been disappointed. Indeed, Paige has a real desire to dive into research and even as a masters student (before she joined the PhD program) she was taking a rigorous set of courses to build her skillset to do top-notch research. From real analysis and statistics as a masters student to the economics PhD coursework from the Yale economics department, she has performed very well in her coursework. I would unquestionably put her among the top of my PhD students in terms of her performance in courses.

But where Paige distances herself from her peers is her enthusiasm and capability in research. She began as a research assistant for me, helping with working on improving a VIN decoder, running regressions, and documenting the progress. From this she moved on to her own research, with an exciting master's project on identifying the relationship between urban form and travel demand, with clear implications for energy use. Her project brought new spatially disaggregated data on driving and key indicators of urban form to help disentangle this relationship. At the core of her dataset is vehicle registration and inspection test data from the Boston-area Metropolitan Regional Planning Council. She knows where the vehicle is registered and whether the owner moved in each year in the dataset (2005-2011). As indicators of urban form, she acquired "Walkscores" (from walkscore.com) that capture the distance of the location to shops, restaurants, etc. In addition, she has developed several further indicators using her GIS skills, such as population density, distance to transit stop (bus and train separately), and age of housing stock. All at an extremely fine geographic level.

The project builds upon papers like Bento et al. (2005) in the *Review of Economics and Statistics* by first directly estimating the relationship between travel demand and the indicators of urban form, although at a much finer geographic scale than papers like Bento et al. and using a much larger dataset than similar papers in the urban planning literature. There is still an inherent identification issue in this approach: self-selection into locations. For this, she develops several

identification strategies to help identify how the form of an urban area influences regional travel demand, a key indicator of economic activity. For example, we can example people who move (using a strategy much like a *Journal of Political Economy* article by Matthew Gentzkow). Another strategy examines situations where new transit lines are added and their location is arguably exogenous.

From this master's thesis work, Paige has continued to improve the paper as the first chapter of her dissertation. Her results are very promising, and they find a strong and well-identified relationship between the walkability/density of neighborhoods and driving demand. She is then applying these insights to better understand the implications of urban form for energy demand, which has clear local policy implications. When fully complete, I expect this article will be sent to a journal like the *Review of Economics and Statistics*.

Paige's second dissertation chapter also aims to provide new evidence on an important question in energy economics. It uses a unique natural experiment in New York City to examine the effect of Local Law 87, which requires commercial buildings to have a mandatory energy audit. The amazing part of the natural experiment is that New York City randomized who receives the energy audit based on tax ID. This provides an perfect opportunity to rigorously identify the effect of mandatory energy audits and voluntary retro-commissioning on energy use. Paige finds that this intervention reduces natural gas usage by 7 percent, which decreases, but still persists in subsequent years. At the same time the intervention did not seem to affect electricity usage at all. Paige is working to understand the mechanisms underlying these results and to verify the results with additional years of data. I see very strong potential for this paper in a general interest economics journal as well, for it has clean identification on an important energy policy question that has not yet been previously analyzed.

Paige's third chapter is her planned job market paper, which is where she will be focusing most of her effort in the next two years, as the other two papers are already far along. My understanding is that her proposal for this fellowship primarily discusses on this third chapter. This chapter asks the question: what are the local air quality implications of market-based greenhouse gas policies, with a focus on California's AB 32 cap-and-trade program. This research question is particularly important because environmental justice advocates have been harshly criticizing market-based mechanisms for reducing greenhouse gases, such as the AB 32 cap-and-trade program or the carbon tax proposed (but was voted down) in Washington State. The core of the critique from the environmental justice community is that the programs do not prevent "hot spots" of local air pollution in underprivileged communities.

There is a growing literature on this question of the market outcomes of market-based mechanisms for other pollutants, including Fowlie, Holland, and Mansur (AER 2012) and Fowlie (AER 2010). Paige would be the first to examine these questions for greenhouse gases. She has acquired very detailed data on all electricity generating units and permit/electricity prices from SNL Energy and the Energy Information Administration. She will be using these data to estimate a dynamic model of electricity firm responses, following the work of Ryan (Econometrica 2012), Fowlie et al. (JPE 2016), and Cullen (2015). The dynamics are particularly useful for modeling the start-up decision of many generators that have substantial start-up costs. The structural model Paige is developing is a new model that can be thought of as combining

some of the best of Cullen (2015) and Bajari, Benkard, and Levin (2007) approaches to model the market equilibrium. The goal will then be to estimate counterfactual simulations of market-based greenhouse gas mitigation policies to examine the effect on market outcomes, including local air pollutant emissions in different regions of California where environmental justice concerns are particularly relevant.

I believe that this primary dissertation project has great potential. Paige worked for several years at Pacific Gas & Electric on energy procurement and compliance with the cap-and-trade program, so she has deep knowledge of electricity markets in general and California's electricity markets in particular. While working at the White House, she was also instrumental in moving forward a Council of Economic Advisers report on integration of renewables into the electricity grid. These experiences set her up for a very successful job market paper.

Besides myself, Paige is being advised by Steve Berry, who brings to the table incredible expertise in cutting edge models in industrial organization, and Matt Kotchen, who has worked extensively with Erin Mansur on electricity markets (in their electric vehicle work). Her work is on the path to better inform and perhaps entirely change the conversation about local air pollution and market-based policies to reduce greenhouse gas emissions in the United States. Moreover, I see potential for a top-tier general interest publication coming from this work.

There is no question that Paige has the drive to succeed in her research and from experience I find that the most successful Ph.D. students are more often those with a real passion for their work than simply those with innate brilliance. Paige is unquestionably very smart, but where she really shines is in her passion as a researcher. I believe that this will serve her incredibly well and you could not go wrong by offering her one of the NBER Fellowships in Energy Economics.

Sincerely,



Kenneth Gillingham
Assistant Professor of Economics
Yale School of Forestry & Environmental Studies
Yale Department of Economics
Yale School of Management