Research Proposal for NBER Pre-Doctoral Fellowship Program on Energy Economics

Cristián Hernández *

Purpose In 1982, Chile was the first country in the world to deregulate its electricity industry. This restructuring of the Chilean electricity industry consisted of the privatization and unbundling of generation, transmission, and distribution. As a result, the state owned electricity company was sold, and since then, the market has been dominated by three private firms: Endesa, Colbun, and AES Gener.[1] At the same time, a law was passed approving the regulation of water, and water rights were issued. Since Endesa, Colbun, and AES Gener were the only electricity companies in existence when the law was passed, they were granted the best water rights for electricity generation at a time when hydroelectricity was the main source of energy.

As a result, in the 1990s, investment in hydroelectricity was rather slow and its fraction of total output plummeted from about 80% to a steady 40-50%. This coincides with the introduction of cheap Argentinian natural gas in 1996 that made generators abandon the development of hydroelectricity until the Argentinian government decided to curtail natural gas exports to Chile in 2004. Following this event, the expansion of the main power system has been based on a mix of coal, diesel, and hydroelectricity, but investments in hydroelectricity are happening more slowly than expected: before privatization the government had an ambitious investment plan in hydroelectricity based on cost effectiveness[2] and an estimate of the supply curve of hydroelectricity based on the data on unused water rights (Figure 1) indicates that the three companies own water rights that allow them to build hydroelectric power plants that are cost effective, i.e., their levelized cost of energy is lower than the levelized cost of coal. Moreover, right after the tax for the holding of unused water was established, Endesa released a fraction of its water rights, but still has many water rights for building power plants that are not being used.[3] This suggests that generators are strategically choosing their investment sequence in hydroelectricity.

Reforms in this industry didn't stop there. In 2010, Chile introduced a renewable portfolio standard where the (recently modified) law mandated that generators must produce at

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[1]See Fischer, Gutierrez, and Serra (2003) for a detailed description of the privatization in Chile.

[2]The state owned electricity company surveyed the whole country looking for sites to build hydroelectric power plants and evaluated the projects. Those projects happen to be the ones that have been developed after privatization.

[3]The tax was implemented to foster the development of profitable hydroelectric power plants.

least 20% of their output with renewable energy (any kind, except hydroelectric plants over 20MW) by 2025. That means that in 2015 generators have to produce 4.3% with renewable energy. This triggered significant investment in renewable energy: there are 2110 MW of renewable energy out of a total of 16164 MW in Chile's main power system. The idea of the target is to comply with the commitment of reducing CO_2 emissions and also to help with local pollution.

Motivated by the extensive restructuring of the Chilean electricity industry that started in the 1980s, I propose a research agenda that studies the welfare effects of renewable energy policies in Chile. First, I want to estimate the efficiency loss caused by the initial allocation of water rights and identify if the slow rate of investment in hydroelectricity after privatization has been caused by strategic behavior. Through this setup, we can learn about the dynamic implications of the initial allocation of property rights that come from a somewhat unexpected type of market power. Second, I want to quantify the effects that the introduction of renewable energy have had on power plant productivity, congestion, costs, and avoided emissions. Although there is a substantial literature on estimating the costs and the benefits of renewable energy,[4] the richness of the Chilean data that I have collected and the rules of the electricity market allow me to measure the effects of renewable energy in power plant productivity and congestion in transmission lines as well as identify how many MWh of other technologies are being displaced by renewable energy. Therefore, I am able to measure more precisely how many tons of each pollutant are actually being avoided. Moreover, I can identify the location where the pollutant is being avoided, which allows me to quantify the marginal benefit of avoided emissions of local pollutants.

Empirical considerations I am developing a dynamic model of the electricity industry to analyze the effects of the initial allocation of water rights. I will follow a structural approach to simulate a counterfactual where water rights are divested, and hence there is no strategic behavior in investments in hydroelectricity. The investment decision of the three big players can be modeled as an extensive form game, where Endesa, AES Gener, and Colbun simultaneously choose their optimal investment sequence in hydroelectric power plants and then the fringe firms decide their sequence of investment. The latter problem can be modeled as a dynamic competitive equilibrium, where a social planner builds power plants to maximize the expected present value of social surplus, taking as given the sequence of investment of the big players. For this purpose, I will use the model of competitive equilibrium of Gowrisankaran, Reynolds, and Samano (forthcoming) that builds up from Joskow and Tirole (2007) as a starting point. The Chilean electricity industry is well suited for this type of modeling because production is determined via marginal cost dispatch by the system operator.

To answer my research questions, I need to first characterize supply and demand in the Chilean power system with particular detail in the supply of hydroelectricity. For this purpose, I have collected an extensive data set with hourly data on demand in each bus (location

[4]See for instance Borenstein (2008), Cullen (2013), and Gowrisankaran, Reynolds, and Samano (forthcoming).

for the system operator), disaggregated production, and disaggregated marginal cost (generators are mandated to report their marginal cost).[5] Estimates of the price elasticity of demand are available for residential and industrial customers.[6] Power plant characteristics data includes nameplate capacity, fuel, type of turbine/boiler, heat rate, connection bus, and commissioning year. Reservoir data include reservoir levels, water inflow statistics, and diagrams with the chains of reservoirs.[7]

To model the supply of hydroelectricity, I have collected a data set with the characteristics of all unused water rights that include, owner, geographic location, vertical distance between intake and outlet, and water inflow distributions. This allows me to estimate the cost and the capacity of power plant that should be built to maximize profits for each water right. Table 1 provides summary statistics of this data set. Note that the water rights of Endesa, Colbun, and AES Gener are on average larger than the ones of other firms, measured in MW. This suggests that they have the most efficient resources available because they can benefit from economies of scale in both generation and transmission. In addition, my access to the environmental evaluation system data that will allow me to disentangle the effect of bureaucracy on investments.

To measure the effects of renewable energy on plant productivity I will estimate the effect of additional solar and wind generation on the capacity factor of the other power plants, conditional on the variables that affect the economic dispatch (fossil fuel prices, demand profiles, levels of reservoirs, and heat rates). The effect on congestion can be measured by exploiting the local variation of demand, renewable generation, and power flows in transmission lines.[8] Then, I can estimate the effect of renewables on emissions by simulating the economic dispatch with transmission constraints in a counterfactual without renewable energy. The website of the system operator provides a model of the power system in DigSilent PF format and the software that the system operator uses to dispatch power plants can be purchased. From this exercise, I will identify the power plants that are being displaced by renewables and estimate the benefit of reduced emissions by relating the fuel type of displaced generation with power plant characteristics (location and emission intensity factors), estimates of the marginal damage of local pollutants (NOx, SOx, and PM) of Cifuentes et al. (2010), and estimates of the marginal damage of CO_2.[9]

Deliverables Each of these two research questions will result in a research paper. I expect to write the two papers during the first year of the fellowship. Through the NBER Pre-Doctoral Fellowship Program on Energy Economics, I will be able to develop my proposed research into papers that will serve as my dissertation in Economics at the University of Wisconsin-Madison. The focus on industrial organization and energy economics will enable me to be competitive when looking for a faculty position in these subfields upon graduation.

[5] I have demand and production data from 2004 to 2015 and the disaggregated marginal cost data is from 2013 to 2015. From 2004 to 2013 I observe the system marginal cost only (equilibrium marginal cost).

[6] See Benavente, Galetovic, Sanhueza, and Serra (2005).

[7] The output of downstream hydroelectric power plant depends on the output of upstream reservoirs.

[8] I have power flow data from 2004 to 2015.

[9] See Tol (2005) for a survey on estimates of the marginal damage of CO_2.

References

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Borenstein, S., (2008), "The Market Value and Cost of Solar Photovoltaic Electricity Production," CSEM Working Paper 176, University of California, Berkeley.

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Cullen, J., (2013), "Measuring the Environmental Benefits of Wind-Generated Electricity." *American Economic Journal: Economic Policy*, 5, 107-33.

Fischer, R., Gutiérrez, R. and P. Serra, (2003), "The Effects of Privatization on Firms and on Social Welfare: The Chilean Case," Research Network Working Paper #R-456, Inter-American Development Bank.

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Joskow, P. and J. Tirole, (2007), "Reliability and Competitive Electricity Markets," *RAND Journal of Economics*, 38, 60–84.

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Figure 1: Estimate of the supply curves of hydro, coal, and natural gas

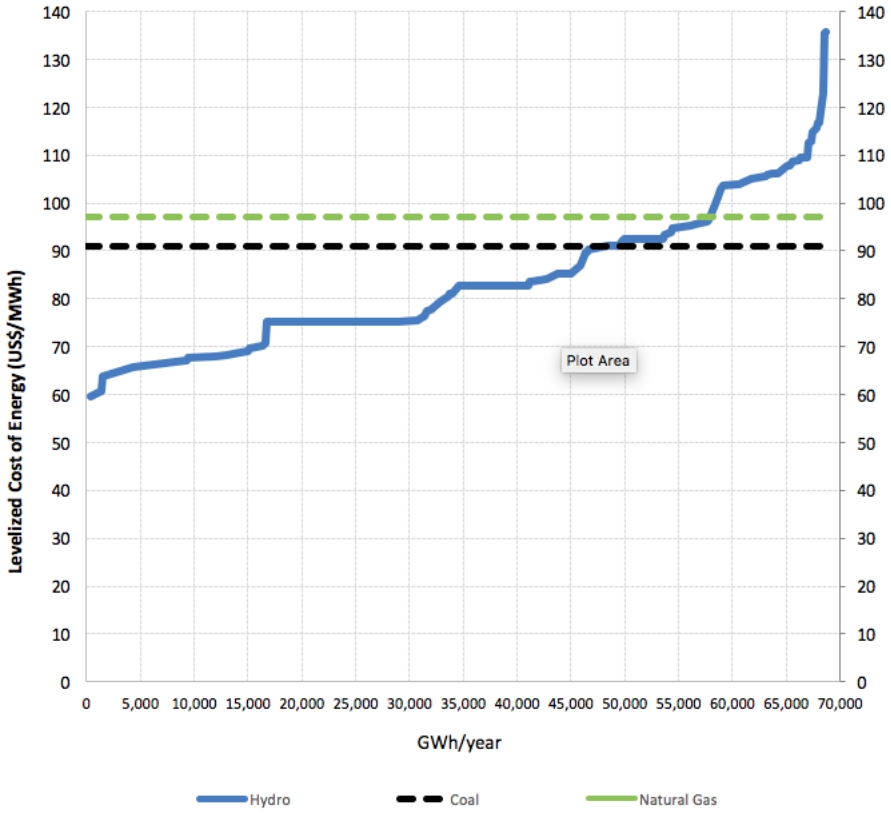


Table 1: Potential capacity in MW

Firm	Mean	Std. Dev.	Min	Max	Total	N
AES Gener	18.73	25	0	133	1499	80
Colbun	30.60	34	0	129	765	25
Endesa	54.77	183	0	1156	2465	45
Other	4.23	29	0	913	9409	2,225

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Curriculum Vitae

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EDUCATION

University of Wisconsin–Madison, Economics Department, Madison, WI
Doctor of Philosophy, Economics, 2013-2018 (expected)
Master of Science, Economics, 2015

Pontificia Universidad Católica de Chile, School of Engineering
Electrical Engineer, *with maximum distinction*, Santiago, Chile, 2009
Graduation ranking: 5th among 383 students

RESEARCH EXPERIENCE

University of Wisconsin–Madison, Economics Department, Madison, WI
Project Assistant,
Professor Kenneth Hendricks (Fall 2015-present)

Universidad de los Andes, School of Business and Economics (Chile)
Research Professor, 2010-2013

TEACHING EXPERIENCE

University of Wisconsin–Madison, Economics Department, Madison, WI
Teaching Assistant
Econ 410, Undergraduate Introductory Econometrics, Professor Joachim Freyberger, Fall 2014
Econ 710, PhD Econometrics, Professor Bruce Hansen, Spring 2015

Universidad de los Andes, School of Business and Economics (Chile)
Lecturer
Optimization (1st semester, 2011; 1st semester, 2012; 2nd semester, 2012)
Pricing Strategy (1st semester, 2011; 2nd semester, 2011; 1st semester, 2012; 2nd semester, 2012)

Guest Lecturer
Industry Analysis, "The Chilean Electricity Industry," (2nd semester, 2010; 2nd semester, 2011; 2nd semester, 2012)

Pontificia Universidad Católica de Chile, School of Engineering (Chile)
Teaching assistant
Power Systems Planning, Professor Cristián Muñoz, 2010
Electrical Machines, Professor Juan Dixon, 2007
Electronics, Professor Marcelo Guarini, 2007
Optimization, Professor Felipe Palomino, 2006-2007
Signal Analysis, Professor Aldo Cipriano, 2006

Pontificia Universidad Católica de Chile, Mathematics Department (Chile)
Math Laboratory Assistant
Calculus, 2005-2006
Differential Equations, 2006

HONORS AND AWARDS

Graduate School Fellowship, University of Wisconsin-Madison, 2013-2014. Two-year fellowship.

Top score in the degree exam, School of Engineering, Pontificia Universidad Católica de Chile, 2009.

Congeniality Award, Electrical Engineering Department, Pontificia Universidad Católica de Chile, 2009.

RESEARCH GRANTS

Research Fund FAI, Universidad de los Andes, 2012, "The Intertemporal Response of Electricity Generators to a Carbon Tax." Provided with funds for bibliography and travel.

PUBLICATIONS

Papers in edited volumes
Galetovic A., Hernández, C., Muñoz, C. and L.M. Neira, (2014), "Microeconomic Reforms, Productivity and Policies: An Exploration into Chile's Electricity Sector," Growth Oportunities for Chile, Santiago: CEP.

Research papers under review
Galetovic A., Hernández, C., Muñoz, C. and L.M. Neira, (2013), "Are Renewable Portfolio Standards Effective to Reduce CO2 Emissions?" *Review and resubmit in Energy Economics*

Reports
Galetovic A. and Hernández, C., (2012), "The Differential Cost of Generation Alternatives in the Central Interconnected System," prepared for the Chilean Chamber of Construction, mimeo.

PRESENTATIONS

"Are Renewable Portfolio Standards Effective to Reduce CO2 Emissions?" at International Energy Workshop, International Energy Agency, Paris, France, June 2013.

Seminar: "The Dynamic Response of Chilean Electricity Generators to Alternative Environmental Policies," at Instituto Milenio Sistemas Complejos de Ingeniería, Santiago, Chile, March 2011.

SERVICE ACTIVITIES

Vice-chair, IEEE student branch at Pontificia Universidad Católica de Chile, 2008-2009.

Volunteer at the IEEE Teaching in Service Program, Montevideo, Uruguay, 2009.

Volunteer at the Micro-loan program at Un Techo Para Chile, 2005.

COMPUTER SKILLS

Programming languages: C, C++, C#, Java, AMPL, OPL, Visual Basic.

Scientific software: Matlab, Stata, Maple, Mathematica, Sage Math.

THE UNIVERSITY of WISCONSIN MADISON

To Whom It May Concern:

This is a letter of recommendation for Cristian Andres Hernandez who is applying for a doctoral fellowship with the NBER energy program. Let me just from the outset that Cristian is one of the top students in our entire PhD program and I believe will stand a very good chance for a competitive academic placement when he enters the job market in a few years. He has chosen to specialize in industrial organization but has an interest in pursuing research on market power in the energy industry. He has particular interest in the effects of market structure on government policy directed towards environmental and efficiency objectives in the industry – I will describe the projects he intends to pursue as part of his fellowship further below. He has a background before coming to the PhD program working in an agency in Chile where he gained intimae knowledge of the electricity market in Chile both technologically and economically. I am fully encouraging him to pursue projects related to detailed data he has collected for the Chilean electricity sector and believe some very interesting ideas will come out of his research in this area.

Let me just start with a word about the accomplishments Cristian already has under his belt in our program. I view Cristian as an expert in computational economics and he has helped our entire group (Ken Hendricks, Alan Sorensen, and myself) get to the frontier in this area for our own projects. He has shown great insight at understanding the interplay between computation, econometrics, and applied problems in industrial organization. His field paper written in the second year was a beautifully conceived idea of using the MPEC (mathematical programming subject to equilibrium constraints) paradigm for estimating structural models in economics to a classic first price auction environment where this connection had not yet been made at all. It was far from obvious how to establish he link as the MPEC machinery had thus far been used in the literature as an alternative to nested fixed point problems, and auction estimation has typically not taken a nested fixed point form. Neverhtless Cristian showed how MPEC can naturally be used to express the empirical criterion function in auctions thus avoiding a great deal of the computational complexity as well as considerably simplifying the econometric properties of the resulting estimator. This whole line of thought could easily evolve into a full-blown thesis unto itself that would already make him one of the more novel thesis ideas that have been developed among our students. Instead Cristian will likely finish the paper and it should chance a very good chance at publication in an outlet such as RAND or Journal of Econometrics.

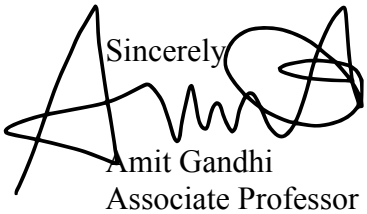
Instead for his thesis works Cristian wishes to move into energy/environmental problems. In particular he has focused on electricity industry in his home country of Chile, and is interested in the the historical experience that hydroelectric generation did not escalate after the privatization of the market in the 80's in the way the government had planned. Cristian seeks to examine the role that initial allocation of property rights

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played in this outcome, where water rights are a critical input to the production process. He aims to build a dynamic oligopoly model of investment decision among the three major players in the industry to understand the magnitude of the mechanism that property rights played in the slow growth of hydroelectricity as a renewable energy source.

I fully believe that Cristian has the utmost skill and ability to produce a very strong paper on this topic. He has access to data, knowledge of the models and tools, and ambition/creativity to pull it all off. I think he will help diversify the energy economics literature in IO by aiming to understand a developing country and how the industrial organization of those markets impacts emission goals of the world as a whole. I believe he will greatly benefit from the guidance and support that backing from the NBER energy program would provide him and plead as hard as a I can to the powers that be in the program that Cristian is a very good bet for your funding dollars!!

Sincerely



Amit Gandhi
Associate Professor of Economics.

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