Link Foundation Fellowship Report

Development and Adoption of Plug-in Electric Vehicles in China: Markets, Policy, and Innovation

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1. Introduction

Over the past fifteen years since joining the World Trade Organization, China has rapidly grown to become the largest passenger car market in the world, with annual sales growing from less than 1 million in 2001 to over 21 million in 2015 (OICA, 2015). With approximately 20% of the world's population, China has just 80 vehicles per thousand people compared to the U.S. which holds less than 5% of the world's population but has 770 vehicles per thousand people (National Bureau of Statistics of China, 2014; The World Bank, 2014; Worldometers, 2015), suggesting this growth may continue for quite some time. Such rapid expansion in vehicle production and demand in China has been associated with rapidly increasing demand for oil (vehicles consume approximately half of all crude oil used in China (Ma et al., 2012), as well as increases in air pollution. It is estimated that 7% of China's greenhouse gas emissions came from automobiles in 2008 (U.S. EIA, 2014), and over half of all volatile organic compound, carbon monoxide, and nitrogen dioxide now come from passenger vehicles in China (Lang et al., 2013).

In response to these harmful impacts from passenger cars, the Chinese government has aggressively promoted the development and adoption of plug-in electric vehicles (PEVs), which can use grid electricity for fuel (State Council, 2012). PEVs have become strategically attractive as a way of reducing oil consumption and pollution from passenger cars while providing Chinese automakers an opportunity to obtain a position of leadership in an emerging technology in the global automotive industry. China's State Council has linked this vision to its economic development plans, which emphasize industrial upgrading to higher technologies and higher value added roles in global production chains (Howell et al., 2014; State Council, 2012).

Given this context, this project comprises the last two of my three-paper Ph.D. thesis, which assesses how characteristics of China's domestic environment, including consumer preferences, national and local institutions, market characteristics, and policies, are associated with the development and adoption of PEVs in China.

2. Results

The first study in my thesis compares consumer preferences for PEVs in China and the U.S. by estimating discrete choice models using a conjoint survey I designed and fielded in each country in 2012. Results suggest that Chinese respondents are more receptive to today's full electric

vehicles than American respondents, regardless of subsidies, implying the potential for earlier PEV adoption in China given adequate supply (Helveston et al., 2015). Despite these promising results, one potential weakness in the study is that the results are based on survey data, and consumers may make choices differently in the real market. With this known limitation, one of the two studies I pursued as a Link Foundation Fellow was to explore new methods for overcoming this potential weakness. The other study I conducted explores relationships between Chinese institutions (such as formal regulations and how they are implemented) and trends in PEV innovation among automakers in China.

The first study focuses on the "pooling" modeling technique where modelers pool together survey and market sales data into one model in an effort to mitigate the relative weaknesses and benefit from the relative strengths of each type of data. Surprisingly, despite over two decades of research on the method, little research has empirically examined the validity of this method in terms of improving parameter *bias*. In this study, I use a synthetic data experiment to test the performance of models that pool survey and market sales data in recovering true market preference parameters under conditions that modelers are likely to face. Specifically, I explore the benefits of pooling when there are endogenous parameters in market data (a commonly cited source of parameter bias in market choice data) and when survey data suffers from "hypothetical bias" (i.e. when consumers respond to questions differently on surveys than in real market settings). In addition to finding a number of cases where pooling market and survey data does *not* mitigate each data sources' respective weaknesses, I also show that the most frequently used statistical test (the likelihood ratio, or LR test) used to determine whether pooling is statistically justifiable is unreliable when the number of markets in the market data is small or when the market data suffers from endogeneity. The LR test also has rejection rates that are far above the nominal level for typical size data sets; that is, the LR test will often reject pooling when it should be accepted. Based on these results, I provide new guidelines for understanding under what conditions pooling data sources may or may not be advisable for accurately estimating true market preference parameters, including consideration of the context and conditions under which the data were generated as well as the relative balance of information between data sources.

In addition to this study, the Link Foundation Fellowship enabled me to make a research field trip to China during the summer to 2015 before my last year as a Ph.D. student to study

innovation in China's PEV sector. A major regulation that has greatly affect the automotive market structure in China is the Joint Venture system, which requires all foreign (non-Chinese) firms to form joint venture firms with Chinese partner firms in order to manufacture and sell vehicles in China. The regulation has been in place since the 1980s and was largely a measure to facilitate technology transfer from foreign to domestic Chinese firms. Today, large international joint venture firms comprise approximately 75% of automotive sales in China, leaving independent domestic Chinese firms (those with no historic partnerships with international joint venture firms) with minority market shares. However, in the PEV market, the independent domestic Chinese firms are actually undertaking a surprising diversity of innovation, and today they lead the PEV market comprising approximately 95% of PEV sales in China.

I apply inductive, grounded theory building techniques to help explain this diversity of innovation in China's PEV firms. Triangulating annual vehicle make and model sales data from 2003-2014, archival data from Chinese news and academic outlets, and 37 qualitative interviews across industry, government, and academic stakeholders, I demonstrate the existence of at least three distinct innovation directions ("up", "down", and "sideways") ranging from vehicle technology to organizational and business strategies. My findings suggest that while national institutions such as the joint venture system may be inadvertently discouraging innovation and diffusion of PEV technologies from both the domestic and foreign arms of international joint venture automotive firms, regional institutions such as local protectionism may be serving as incubators for a variety of innovations within independent domestic firms in their early development stages. The size and diversity of China's domestic market may be large enough to support this variety of innovations. That said, as these domestic firms begin to grow beyond their protected regional markets, China's institutions may need to evolve to support national standardization of policies and plug-in infrastructure.

3. Significance and impact

The first of the two Link Foundation Fellowship studies I conducted provides an important overview and critique of the state of the art in pooling survey and market sales data together in choice modeling. Such models are frequently used to inform policy decisions about new or emerging products or product features, and getting the model parameters "right" is critically important for making accurately informed policy decisions. This study provides an important

step in correcting some previous assumptions embedded in these models that could lead to erroneous conclusions and provides new guidelines upon which future studies on combining two data sources in one model can build.

The second study builds new theory about the impact a nation's institutions can have on innovation and industry development and has important implications for policy makers and strategic management. In particular, the interaction between national and local institutions in China could have important implications for the future growth and expansion of PEV firms in China. For example, strong local protectionism has provided many domestic Chinese PEV firms in effect "incubators" for new innovations, including support such as free or low rent for offices and production facilities. However, local protectionism has also led to challenges for firms to expand beyond their local region, and the lack of effective nation-wide charging standards compounds this challenge for domestic Chinese PEV firms. The result of these new, innovative business models and products might provide different development pathways for the global PEV sector. Table 1 summarizes the contributions from these two studies sponsored by the Link Foundation Fellowship.

Table 1: Summary of contributions from Link Foundation Fellowship-sponsored studies

Topic	Approach	Contribution
Combining Survey & Market Sales Data in Demand Models	Methodological / Simulation	• In the presence of endogeneity, the frequently-used likelihood ratio test is non-informative, and pooling market and survey data could either improve or worsen parameter estimates. • Given that endogeneity is a known problem in automotive sales (market) data, we cannot be certain if a pooled market-survey model will improve estimates from previous studies that employ only market or survey data. Future work is needed to improve upon these methodological challenges, such as finding ways to identify endogeneities in market data while exploiting the rich variation from survey data.
Innovation & Institutions in Chinese PEV Firms	Mixed / Qualitative	• Independent Chinese firms are advancing China's emerging PEV sector by innovating in a wide variety of directions. • The diversity of innovation directions may be shaped by historical co-evolution of national institutions, local institutions, and the size and heterogeneity of China's domestic market.

4. Where might this lead?

Based on the results of the research I conducted as a Link Foundation Fellow, the future of PEV development and adoption in China may depend at least as much on process and business model innovations as it will on advancements in technological innovation. PEVs today have important limitations that businesses and consumers are well aware of (such as expensive batteries and long charging times), but China has already begun making the switch from gasoline to electricity before waiting for battery technology to improve. Innovative Chinese firms are finding new ways to use existing technologies to introduce consumers to PEVs, such as new PEV car-sharing platforms. In addition, China's low vehicle ownership rate and the general willingness of Chinese consumers to consider PEVs over traditional gasoline-powered vehicles suggests a future where China may out-pace many other, more developed nations in PEV adoption. What a PEV future in China looks like, however, may be quite different from current trends in the U.S. Rather than highways full of Tesla PEVs, if current trends continue the majority of PEVs in China may be much smaller electric two-seaters that consumers rent rather than own and cost less per mile driven than owning a conventional vehicle, which could have enormous implications for reducing energy consumption from automobiles.

As a researcher, I aim to continue studying important topics related to policy and environmental sustainability. In the domain of sustainable technologies, value capture from important measurements such as reduced pollution are becoming an increasingly important intersection between business strategy and policy. My research objectives are to understand this intersection to inform policy and strategic management decisions that can aid in the development and adoption of technologies that have important impacts on environmental sustainability and reduced energy consumption, particularly in China. Two specific goals have been to 1) develop new and improve existing methods for empirically measuring consumer preferences to improve understanding of consumer adoption of new technologies, and 2) build new theory on the relationships between policy, strategic management, and innovation in the sustainable energy space. The research I conducted as a Link Foundation Fellow is an important first step towards achieving these goals as a scholar and provides a foundation upon which I intend to build a future career as a researcher.

5. Scholarly reports

Papers:

- Helveston, J.P., J.J. Michalek, and E.M. Feit "When Should We Pool Revealed and Stated Preference Data? Assessing Endogeneity and Context," Working paper, under review at *Transportation Research Part B: Methodological*.
- Helveston, J.P., Y. Wang, V. Karplus, and E. Fuchs "Up, Down, and Sideways: Innovation in China and the Case of Plug-in Electric Vehicles," Working paper, under review. Latest version available at SSRN: http://ssrn.com/abstract=2817052

Presentations:

- Symposium Chair & Organizer, "Innovation in China From an Individual, Firm, and National Perspective," Academy of Management Annual Meeting Proceedings, 08/2016, Submission 14779.
- "Up, Down, and Sideways: Innovation in China and the Case of Plug-in Electric Vehicles," Academy of Management Annual Meeting. August 09, 2016, Anaheim, CA.
- "Up, Down, and Sideways: Innovation in China and the Case of Plug-in Electric Vehicles," DRUID Annual Conference. June 13-15, 2016, Copenhagen, Denmark.
- "Up, Down, and Sideways: Innovation in China and the Case of Plug-in Electric Vehicles," Consortium For Cooperation And Competition. June 10-12, 2016, Milan, Italy.
- "Up, Down, and Sideways: Innovation in China and the Case of Plug-in Electric Vehicles," Industry Studies Association (ISA) Conference. May 24-26, 2016, Minneapolis, MN.

6. How did the fellowship make a difference?

One major impact the Link Foundation Fellowship had on the direction of my thesis work was that it enabled me to take a critical trip to China during the summer of 2015 before my last year as a PhD student. During the trip I spent 6 weeks conducting interviews with independent domestic Chinese automakers. This trip not only resulted in the bulk of data for the last chapter

of my thesis, but also provided insights that have motivated my current work as a Postdoctoral Fellow at the newly-established Institute for Sustainable Energy at Boston University. I plan to follow up on this study with more trips to China to conduct more interviews focusing in greater depth on emerging PEV car sharing business models and their implications for greater PEV adoption in China and around the world. The first of these research trips will be during the month of October, 2016.

In addition to enabling the pursuit of this specific research direction, the Link Foundation Fellowship also helped ground my broader research interests in sustainable energy. As an academic researcher, building a career trajectory and a clear research scope is a critical challenge that greatly impacts future research endeavors and funding opportunities. In applying for post-doctoral fellowships, the Link Foundation award was widely noticed as a signal of my commitment to pursuing research in sustainable energy, as my current position at Boston University reflects.

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