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## Letter of Recommendation for Yichen (Christy) Zhou

Dear Recruiting Committee,

It is a pleasure to write this letter in support of Christy Zhou's application for a position at your institution. I first came to know Christy in my capacity as her instructor for a Ph.D.-level course on *Environmental Taxation and Regulation* at the University of Maryland (AREC) in the spring of 2014. Since then I have served as a member of her dissertation committee. From the beginning, Christy has impressed me as one of the most proactive, independent, and motivated students I have worked with. Her job market paper makes an important contribution to an active area of research regularly featured in top general interest journals, and I believe that she will be a successful researcher for three main reasons. First, Christy is deeply motivated to understand endogenous technological change – an important topic for environmental economics and beyond. Second, she has a clear understanding of the big, open questions in the field. Third, she possesses the technical skills and the tenacity to successfully execute challenging work that addresses such big questions.

### *I. Literature Context for Christy's Contribution*

What drives technological change? Understanding this issue is fundamental for fields ranging from macroeconomics to industrial organization. In environmental and energy economics, this question has become particularly relevant as economists and policy makers seek to understand how price and policy changes affect technology. For example, it has been shown that technological change is critical for climate policy design (e.g., Aghion, Acemoglu, Bursztyn, Hemous, 2012, *American Economic Review (AER)*). However, the topic remains “a major open question” due to our limited empirical understanding of the determinants of technological change (Nordhaus, 2011).

Christy's job market paper bridges three major strands of the literature addressing this question in the important context of automotive technology:

First, a number of studies have estimated structural models of automobile demand and supply in order to assess how policy and price changes will affect the fuel economy of the vehicle fleet (e.g., Bento, Goulder, Jacobsen, and van Haefen, 2009, *AER*; Jacobsen, 2013, *AEJ: Policy, etc.*). However, these models often take automobile characteristics (weight, horsepower, etc.) as given, and focus on automakers' choices of pricing or pricing and fuel economy.

Second, and on the other hand, some recent work has quantified precisely the tradeoffs between fuel economy, weight, and engine power faced by automakers. For example, Knittel (2012, *AER*) empirically estimates the efficiency technology frontier and how it has shifted over time. However, this work focuses mainly on quantifying technological change, taking its origins as given.

Third, another set of papers focuses directly on the response of innovation to input prices and policies. These studies have demonstrated the importance of fuel prices and policies for, e.g., efficiency-related patenting (e.g., Popp, 2002, *AER*; Aghion, Dechezlepretre, Hemous, Martin, and Van Reenen, 2015, *Journal of Political Economy*). However, the realized efficiency gains from patents invite further study, particularly in the context of a model of (automobile) demand and supply with endogenous vehicle attributes. And this is where Christy's paper comes in.

## *II. Christy's Job Market Paper*

In her job market paper, Christy estimates a structural model of new automobile demand and supply. Automakers maximize profits by first choosing vehicle performance attributes (e.g., horsepower), adoption of fuel-efficiency improving technologies (e.g., turbocharger), and investment in knowledge capital (patenting). Automakers then set prices in Bertrand competition. Importantly, Christy's framework thus integrates three key elements of the literature in a single, consistent framework: (1) a full model of vehicle demand and supply as functions of vehicle attributes and prices, (2) an estimation of the fuel efficiency technology frontier facing automakers, and (3) novel evidence on how patenting and technology adoption enter both the fuel efficiency frontier and vehicle production costs. In order to estimate the model, Christy assembled a detailed data set of the new U.S. automobile market in 1986-2006 that includes (i) vehicle characteristics and technology adoption data from the U.S. EPA, (ii) knowledge capital data from the OECD Triadic Patent Family Database, and (iii) U.S. vehicle prices and sales. Once estimated, Christy further uses her model to conduct counterfactual simulations on the effects of gasoline tax increases, R&D subsidies, and a change in market structure (specifically a GM-Chrysler merger).

Christy's main results include the following. First, the demand system implies own-price and fuel efficiency elasticities in line with the literature. Second, estimates of the fuel efficiency frontier suggest that changes in the adoption of existing technologies (e.g., multi-valve) account for the majority (92%) of observed fuel efficiency improvements, with the remainder (8%) due to increases in knowledge capital. However, as Christy is careful to note, these results apply in the medium-run. In the long-run, one may expect knowledge capital to become more important as newly patented technologies mature and penetrate the market. Third, the model produces estimates for both the costs and potential efficiency gains associated with technology adoption. Similarly, the results imply cost estimates for increasing knowledge capital through R&D (e.g., \$516 million for an increase in patents of 10% in 2006 in partial equilibrium) as well as associated decreases in vehicle production costs (\$37 per vehicle in 2006, *ceteris paribus*) and the potential for further increases in revenues through corresponding improvements in fuel efficiency.

The estimated model enables Christy to conduct counterfactual simulations on the effects of gasoline taxes and R&D subsidies. Importantly, Christy's framework simultaneously accounts for four channels through which these policy and price changes may alter fleet fuel economy: (1) vehicle price and demand changes (i.e., fleet composition), (2) movements along the fuel efficiency frontier through changes in vehicle characteristics, (3) shifts of the fuel efficiency frontier through technology adoption, and (4) shifts of the fuel efficiency frontier through patent development. Christy's main contribution is both to add channels (3) and (4) and to consider them alongside channels (1) and (2) in a structural model of new vehicle demand and supply.

The core results of the counterfactual simulations are threefold. First, a \$1/gallon increase in gasoline taxes in 2006 increases fleet fuel economy by 0.47 miles per gallon, doubling the observed

annual improvement from 2003-2006. In contrast, abstracting from endogenous changes in vehicle attributes and technology (i.e., limiting the response to the tax to channel (1), vehicle prices and demand) would suggest fuel economy improvements of 0.85 miles per gallon. The impact channels added by Christy's framework thus have important implications for the policy outcome of interest. Second, an R&D subsidy reducing the marginal cost of knowledge capital development by 25% increases patenting and decreases average vehicle production costs, but only results in fuel economy improvements of 0.06 miles per gallon (in the medium-run). Third, a simulated merger of GM and Chrysler is predicted to decrease vehicle quality (performance as well as fuel-saving technology adoption) but also to increase patenting activity. This third finding relates to new work on both the impacts of market structure in a setting with endogenous product characteristics (e.g., Wollman, 2014) and on the relationship between market power and innovation (e.g., Aghion, Bloom, Blundell, Griffith, and Howitt, 2005, *Quarterly Journal of Economics*.)

### *III. Christy's Approach, Skills, and Traits*

Christy easily stands out as one of the most proactive and persistent graduate students I have had the pleasure of working with. She has been highly motivated to advance the literature on induced innovation and energy efficiency since before I met her. Looking back at early versions of her work from last year, both the pace and the magnitude of her progress are very impressive to me. Christy wanted to answer a big question that entailed many empirical and technical challenges, but she has been undeterred and eager to do and learn whatever it takes to get things right. Of course there are tradeoffs and abstractions she had to make in her model, but I believe that she made them thoughtfully, and will not shy away from advancing these aspects of her work in the future.

Christy has generally impressed me with how proactively and professionally she approaches research. She has taken the initiative to ask for everything ranging from an energy and environmental economics reading group to presentation opportunities. Christy always follows up, and does so promptly. Once I mentioned off-hand that a former student of mine had interned with an automobile manufacturer's R&D department. Christy emailed me within seconds to follow up and seek out the contact. In my experience, Christy brings this persistent approach to everything ranging from following up on papers and potential data sources to feedback on her work.

Overall, I thus believe that Christy will be a successful researcher. She brings to the table both personal traits and technical skills that will enable her to make important contributions to environmental and energy economics and beyond. Her expertise in industrial organization, structural modeling, and empirical estimation enable her to ask big questions on topics such as technological change and the impacts of environmental policies in settings that account for key firm and consumer responses, such as changes in product characteristics or market structure.

Lastly, on a personal level, Christy is delightful to work with. She is polite, positive, and professional. While I do not know her as a teacher, I would imagine that she will be dedicated and that students will respond very well to her.

If I can be of further help in your evaluation of Christy's candidacy, please do not hesitate to contact me at 203-506-9767, or at [lint\\_barrage@brown.edu](mailto:lint_barrage@brown.edu).

Sincerely,

Lint Barrage (Assistant Professor, Brown University, Department of Economics & IBES)