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Editorial

Recent advances in energy demand research in China

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ABSTRACT

The continuously accelerating global energy demand leads to increased public concern about climate change. The international community expects China, the world's largest energy consumer, to play a leading role in the energy transition, especially since the United States has withdrawn from the Paris Agreement. This special issue on “Energy Demand in Emerging and Developing Economies: Measurement, Policy Interventions and Evaluation” improves international understanding of the patterns of energy demand in China by presenting recent experimental and empirical research following the Beijing Energy Conference in 2018. The main purpose of this introductory article is to present recent research advances by summarizing new findings and insights from this special issue, combined with recent literature. It shows that China's rising energy demand and energy transition practices have led to numerous policy interventions, which provides rich observational data on behavioral change and offers an “experimental window” with large opportunities for scholars. Beyond the traditional topics of residential and industrial energy demand and its drivers, an increasing number of studies focuses on energy policy evaluation or quantify the environmental and climate consequences of energy consumption. This new line of research, supported by policy-oriented model-based quantitative analyses, experimental approaches and econometric analyses using multi-source disaggregated data, offers new insights into various aspects of China's energy demand.

1. Introduction

Global energy demand is rapidly accelerating. Global energy consumption reached a record high of 13.9 Gigatons of oil equivalent (Gtoe) in 2018, with the fastest growth rate (2.9%) on record since 2010 (BP, 2019). The consequent increase in energy-related carbon emissions leads to widespread public concerns about the irreversible consequences of climate change (Timothy et al., 2019). China accounts for 25% of global energy demand (almost half of global energy demand along with the United States and India) and faces high expectations to take responsibility in the mitigation of global warming resulting from energy consumption. The United States announced its withdrawal from the 2015 Paris Agreement in 2017 (U.S. Department of State, 2019), leaving room for other actors and creating expectations, especially for China, India and other developing economies to lead the global energy transition. These countries, however, face serious energy issues in their own economic transitions, including energy access and energy supply shortages, carbon emissions and adverse health effects associated with fossil fuel use. In China, energy efficiency and energy demand responses in the residential, commercial and industrial sectors play a crucial role in these developments and require the attention of both academics and policy makers.

Despite substantial efforts made in the analysis of energy demand patterns in developing countries, the identification of determinants and the evaluation of intervention policies has received little academic attention due to both a shortage of local scholars and disaggregated source data. To bridge this gap, the Renmin University of China, University of Münster, Germany and Kyushu University, Japan, together with the China Economic Review journal, hosted the Beijing Energy Conference in September 2018. The conference theme was: “Energy Demand in Emerging and Developing Economies: Measurement, Policy Interventions and Evaluation”. The conference objective was to showcase recent experimental and empirical energy demand analyses, especially for China. This special issue highlights selected research published subsequent to the conference, specifically focusing on household energy demand, energy efficiency, policy evaluation and energy-related environmental and climate change impacts.

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2. Household energy demand in China

2.1. Urbanization and household energy use in China

Global urbanization has greatly supported economic growth and social development, accompanied by an increasing demand for energy (Poumanyvong & Kaneko, 2010). China has similarly experienced rapid urbanization during the past four decades and is projected to have around one billion urban residents by 2030, accounting for 70% of the national population (World Bank & Development Research Center, 2014). This urbanization has greatly increased pressure on ecological and environmental systems (Cui & Shi, 2012), though some scholars argue that resource productivity may actually benefit from urbanization due to production agglomeration and economies of scale (Glaeser & Kahn, 2010).

Xie, Yan, Zhang, and Wei (2020) investigated the role of urbanization in determining the residential energy consumption patterns using the Chinese Residential Energy Consumption Survey (CRECS) data from 2012 in this special issue. Their comparison between urban and rural households revealed that the direct effects of increased urbanization (infrastructure, institutions) lowered energy consumption while the indirect effects (household characteristics) increased energy consumption. Urbanization increases residential energy consumption and alters the energy mix toward more modern energy sources (electricity and gas).

2.2. Income and energy demand for China

Economic theory predicts that household income is the dominant variable for energy demand and income elasticity is positive, but less than one in most empirical studies (Löschel & Managi, 2019). The interaction between this income effect and energy consumption is not always linear and may differ among various groups. Wolfram, Shelef, and Gertler (2012) observed an S-curve when analyzing household income-electricity consumption data in Mexico. Auffhammer and Wolfram (2014) confirmed the existence of this S-curve in China, using aggregated provincial data. Inspired by these studies, two new papers using household-level data are included in this special issue.

In household energy demand analysis, electricity is usually the most popular and dominant energy type (Du, Guo, & Wei, 2017), but empirical studies of alternative energy types, such as coal, are available (Zhao & Luo, 2018). Using data from the China Urban Household Survey (CUHS) across 9 provinces from 1992 to 2009, Hu, Ho, and Cao (2019) present a household energy demand system that allows for an estimation of income, price and cross-price elasticity for electricity, coal, LPG, gas, district heating, gasoline and transportation. These estimations may, e.g., provide benchmark parameters for Computable General Equilibrium (CGE) models.

Li, Fei, Zhang, and Qin (2019), examined the effects of income inequality on appliance ownership. They aggregated cross-sectional household data from the China Health and Nutrition Survey (CHNS) to the community level and generated data covering 9 provinces for 9 survey years between 1989 and 2011. They regress two community level inequality indeces against appliances' penetration rate, with other variables controlled. Their results show the negative effect of income inequality on appliance ownership and identify different income thresholds for the adoption of various appliances. Li, Wei, and Yu (2020) investigated the impact of appliance ownership on electricity consumption, focusing specifically on income thresholds.[1] They revealed significant heterogeneity of income thresholds for appliance ownership across household and appliance types. They also show that significant bias could be introduced in estimating appliance ownership and electricity consumption if this threshold heterogeneity were ignored.

The increased availability of more granular data for China's household energy consumption has enabled more detailed analyses, ranging from demand analysis to inequality measurement (Wu, Zheng, & Wei, 2017). It is evident that consumer behavior changes as China urbanizes, and this is reflected in energy choices and consumption patterns.

3. Energy efficiency

3.1. Global patterns and market factors

Market-oriented reforms deployed in many developing countries usually attract foreign investment and advance production technologies and management practices. These developments favor energy savings in host countries. Conversely, these reforms also reduce constraints and increase incentives to increase the demand for products and resources resulting in rebound effects, i.e. the gap between actual and expected saving or the behavioral adjustment in response to an energy efficiency improvement, in terms of energy or greenhouse gas emissions. These rebound effects have been empirically examined in various household-level settings (Greene, Kahn, & Gibson, 1999; Ouyang, Long, & Hokao, 2010). Colmenares Montero, Löschel, and Madlener (2018) give an overview on how energy system and economy wide models include and quantify rebound effects, but studies of the presence and extent of the effect at the macro level are rare.

Li, Liu, and Du (2019) explored the mechanism and impact of the marketization of energy efficiency using a partially linear functional-coefficient model applied to Chinese provincial data from 2003 to 2013. Their result confirms the existence of this rebound

[1] This approach differs from Auffhammer and Wolfram (2014) which use a single income threshold for all households. Here, household income thresholds for appliance ownership are explicitly modeled to allow for any percentile of income threshold distribution. Using the constructed cohorts-based pseudo-panel that transformed with the household data from the CUHS, they reveal great heterogeneity of income thresholds for home appliance ownership across household and appliance types.

effect, accounting for an estimated 20% offset in expected energy savings from reform-induced efficiency improvements. This effect varies significantly between regions. The more developed east of China has a higher rebound effect of 33%.

3.2. The impact of China's energy efficiency interventions

Numerous energy efficiency programs have been implemented in China as strategies to meet the conflicting objectives of growing energy demand and energy savings. These measures have achieved remarkable success. In 1990, China's primary energy intensity (energy consumption per GDP) was 179% higher than the world average. By 2015, this gap had reduced to 30%. According to the annual report of the American Council for an Energy-Efficient Economy (ACEEE), China ranks 8th among the largest energy-consuming countries in terms of overall energy efficiency, measured by indicators including buildings, industry, transportation and national effort (Castro-Alvarez, Vaidyanathan, Bastian, & King, 2018).

The most prominent firm-based measure and direct regulation in China was the Top 1000 Firms Energy Conservations Program (T1000P) launched in the 11th Five Year Plan (FYP, 2006–2010) (Price et al., 2011). It targeted the largest energy end-users and integrated goal achievement with the promotion of regulated firms and local governments. The actual impact of these interventions, which are implemented in a mandatory command-and-control manner, on firm performance in the shorter term has not been determined. Two papers in this special issue attempt to quantify these regulatory effects.

Filippini, Geissmann, Karplus, and Zhang (2020), evaluate the impact of T1000P on the performance of China's iron and steel firms, using company data from the Chinese Annual Industrial Surveys in 2003 and 2008. Their results suggest that T1000P improved these companies' total-factor productivity by 3.1% (equivalent to an economic benefit of 148.7 million Yuan per year), attributed mainly to technical changes and economies of scale. Understanding technical change is important in policy response as its impact can be both positive and negative.

Chen, Chen, Jin, and Lu (2020) quantify the impact of the 11th FYP's energy regulation on firms, using a difference in difference (DID) approach with a matched dataset of company energy consumption and accounting data from 2003 to 2009. They defined (a) the provincially committed energy intensity target and (b) the text-frequency of “energy saving” or similar words in government reports as the two indicators of regulation stringency. Their results suggest that the 11th FYP's energy regulation has improved energy productivity, driven through R&D and the optimal re-allocation of energy among companies.

Despite different energy efficiency program's positive effect on firm performance, an “energy efficiency gap” still exists between optimal and realized energy efficiency (Allcott & Greenstone, 2012). Incomplete and imperfect information between regulators and firms has been identified as a barrier to the accurate assessment of energy savings potential and the improvement of energy efficiency. To examine the impact of information asymmetry on China's industrial energy intensity, Liu, Yao, and Wei (2019) applied a stochastic frontier model with provincial data from 2006 to 2015. Their results show that: (a) the information gap accounts for around 75% of the energy efficiency gap and (b) in 19 out of 30 provinces, the achieved industrial energy intensity is lower than that predicted for a perfect information scenario. These findings imply that information asymmetries complicate a precise target allocation scheme among provinces. Among environmental policy instruments, voluntary environmental management programs for firms are popular, however, the effectiveness of such programs is ambiguous at best based on the existing literature (Kube, von Graevenitz, Löschel, & Massier, 2019). Wei, Ni, and Du (2012) have suggested that market-oriented instruments may be the most cost effective to eliminate energy efficiency gaps.

4. Policy evaluation

4.1. Energy pricing mechanisms and their application in China

Behavioral instruments for consumers that have been deployed successfully in developed countries were also introduced to developing countries, but still lack empirical evaluation. An example is real-time pricing or time-of-use (TOU) pricing for electricity. Numerous studies have examined the effect of TOU pricing on consumers' demand without yielding consistent conclusions. While some studies show that residential electricity demand displays strong price elasticity (Krishnamurthy & Kriström, 2015), others suggest a lower elasticity or even inelastic demand (Lijesen, 2007).

China is often criticized for the lack of TOU pricing in the residential sector. Households pay a constant price, which might limit the flexibility of household energy demand. Zhou, Ma, Su, and Wu (2019) presented evidence for the impacts of TOU pricing in China by using high-frequency, firm-level electricity consumption data in industrial and commercial sectors in Shanghai in 2016. They show that TOU pricing had - except for small-scale firms - no effect in terms of shifting firms' electricity demand at both daily and hourly intervals. This finding seems contrary to a larger string of literature and may be attributable to the TOU pricing levels not being set high enough to compensate for the cost of production rescheduling and fuel switching.

4.2. Effects of trade conflicts

The recent global trade conflict and the accompanying uncertainty raised scholars' concerns about its social and environmental effects (Lin et al., 2019). The trade conflict between China and the United States prompted Xia, Kong, Ji, and Zhang (2019) to evaluate and simulate the consequence on the economy and energy demand. They adopted a global input-output model and found that both China and the United States would be losers in a trade conflict impeding a global recovery. However, the expected impact of the trade conflict on other industries/sectors and other countries varies.

5. Energy-related environmental impacts and climate change

5.1. China's energy demand and greenhouse gas emissions

Energy consumption is the major source of greenhouse gas (GHG) emissions and increased environmental pollution. Strong economic growth and accompanying energy consumption increases are a common dilemma in most developing countries. The government usually plays a key role in the development process. Government's practices and responses in balancing economic growth and environmental quality offer new perspectives to existing environment literature. This is especially true for China, the largest transitional economy that combines political centralization and fiscal decentralization. Deng, Wu, and Xu (2019) studied the linkages between political turnover and environmental performance. Using manually collected prefecture leader data that are merged with locally listed firm accounting and pollution data for the time 2007 to 2015, they found that firm pollution is positively related with the appointment of new officials, higher turnover frequency of officials and firm-official connection/collusion.

While previous studies usually assume a linear relationship between energy use and GHG emissions, more recent research has begun to explore the bidirectional causality nexus. This approach suggests that energy-induced climate change may lead to temperature variations which can change decision-makers' behavior and further stimulate the use of energy (Li, Yang, & Long, 2018). Using China's data from 1953 to 2017, Zhang, Xu, and Sharp (2019) conducted a causality test for energy and CO_2 and examined the determinants of energy consumption. Their analysis incorporates CO_2 as a driving factor and shows that economic growth dominates China's increased energy consumption. They also found evidence for the described two-way causality.

5.2. Market mechanisms for curbing GHG emissions

Under purely rational economic behavior, every market participant has an incentive to “free-ride” and is not expected to voluntarily contribute to global public goods. In the case of climate change mitigation, that implies that no one would act voluntarily to prevent global warming: the marginal costs exceed by far the marginal benefits of climate mitigation for the individual actor. Free-riders on the other hand enjoy the benefits of CO_2 reductions without incurring any cost. Conte and Jacobsen (2016) provided practical evidence of potential deviations, i.e. consumers willing to pay a premium for carbon-free electricity, despite being of equal quality to other electricity. Löschel, Sturm, and Uehleke (2017) reported that people may contribute their own money for CO_2 abatement even though it might be considered a donation and the contributions increase as free-riding is reduced.

Individuals might act conditionally cooperative, i.e. individuals are more likely to cooperate if others will share the burden. Different research papers investigate whether and to what extent people adopt conditionally cooperative behavior. Results vary significantly between countries and cultures. However, cooperative behavior in China, the single largest CO_2 emitter, has not been studied.

Sturm, Pei, Wang, Löschel, and Zhao (2019) presented evidence for China with a laboratory experiment conducted in Beijing in 2017. They make use of China's pilot carbon emission trading schemes (Jotzo et al., 2018) and offer participants from Beijing the opportunity to buy certificates from the Beijing Emissions Trading Scheme. The certificates were retired yielding real CO_2 reductions in Beijing. This experiment shows that participants are more likely to engage in CO_2 reduction if other cooperate and do the same. Their findings confirm the existence of conditionally cooperative behavior in China.

Emissions trading is a market-based instrument and cost-effective in addressing the global warming challenge (Löschel, Lutz, & Managi, 2019; Rose & Stevens, 1993). Theoretically, ETS markets allow participants to trade at the lowest cost, assuming perfect competition. Real world markets, however, often show market imperfections on product markets (Böhringer, Löschel, & Welsch, 2008) and emission markets. Tanaka, Matsukawa, and Managi (2020) designed an experiment to examine whether market power by a few large traders hinders market performance. Their result shows that the bilateral oligopoly model fits well with real trading schemes in terms of equilibrium prices. In order to mitigate the inefficiency resulting from market power in emission markets, they suggest a uniform price auction instead of a double auction.

6. Conclusion

This special issue presents the latest advances in energy demand analyses with a focus on China. It includes experiments on energy and resource consumption behavior, environmental and climate consequences of energy demand, the evaluation of policy interventions, and policy insights on demand-side management. Three broad conclusions can be drawn from these studies:

First, disaggregated data is more widely applied in energy demand research. The increased availability of university-led household surveys, e.g. the China Family Panel Studies by Peking University or CRECS by Renmin University (Zheng et al., 2014; Zheng & Wei, 2019), and public access to official statistics such as the China Industrial Enterprise Database and the China Economic Census Data (Wei, Löschel, & Liu, 2015), has enabled scholars to analyze more disaggregated household and firm-level data. Some studies are now trying to use device-level data for more detailed analysis (Zhang, Sun, Fei, & Wei, 2020). These micro-level data can be combined with other data sources to adapt to new research questions and needs. Moreover, high-frequency “big” data and newly available experimental data for China, will allow new energy research ideas to be tested and will foster novel empirical approaches.

Second, policy-oriented research is gaining important and get highly prioritized. Most of the studies included in this special issue are derived from a strong policy background and aim to assess and quantify the impacts of certain policies on different scales ranging from individuals to cities, provinces, and nations. The increased availability of energy-related data allows for a more detailed analysis of regulatory initiatives and will lead to improved evidence-based advice on energy and climate policies in China.

Third, the findings show that insights from empirical work in developed countries might not simply transferred in a developing country context, but have to be developed with caution. For example, contrary to observations in other countries, Chinese firms display little or no sensitivity to price changes in a non-competitive market. However, the income-energy S-curve is empirically confirmed through the observation of lower-income rural household data in China. This explains the widely extant downward bias in various energy projections (Fischer, Herrnstadt, & Morgenstern, 2009), especially when considering developing countries. Like in many other countries, individuals in China cooperate in situations of social dilemmas. More research on China with new data and methods is needed as energy demand depends on the specific economic, social, technological and physical context.

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