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Changes of energy consumption with economic development when an economy becomes more productive

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ABSTRACT

People often observe that energy consumption increases with economic growth such as in China. We developed a model based on heterogeneous productivity to analyze the macro-economic problem of the change of energy consumption with economic development when an economy becomes more productive. When an economy becomes more productive, it has greater output and inputs more resources, and the important factor energy also increases. This increase is the first means by which energy consumption increases with the growth of productivity. The second mechanism is that energy is also an end product; therefore, its consumption largely depends on income (output). Hence, growth in productivity also directly increases energy consumption in people's lives because they have more income. From the perspective of economic development, the change of energy consumption with economic development has an exceptional case. Energy consumption will be reduced when an economy does not pay attention to the pursuit of increased output purely with larger productivity if adequate necessities of life have already been attained. We also provided several policy recommendations to reduce energy consumption when an economy has experienced a growth of productivity based on our theoretical analysis with China as evidence.

1. Introduction

It is not surprise to hear from people claiming that there is connection between energy consumption and economic development, which is intuitively reasonable. Academic evidence about the relationship between energy consumption and economic development has been widely studied around the world. In the many analyses of development and energy consumption, the topic of pollution emission often arises. Soytas and Sari (2009) investigated the long run Granger causality relationship concerning economic growth, carbon dioxide emissions and energy consumption in Turkey. Some other researchers also studied the nexus in different locations, such Odhiambo (2009) in Tanzania, Apergis and Payne (2009) in six Central American countries, Tugcu et al. (2012) in the G7 countries, Wolde-Rufael (2012) for nuclear energy consumption in Taiwan (China), and Yildirim et al. (2012) in the USA, etc. Shuai et al. (2017), however, identified different key impact factors (KIF) across 125 countries using the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model and time-series analysis.

In the case of China, Chinese economic development lags behind the Western developed countries because of many historical factors, such as foreign invasion and domestic war before 1949. After the People's Republic of China was established (1 Oct, 1949), Chinese people experienced a stable internal environment and a relatively peaceful international environment to develop the economy. Unfortunately, China's economic performance over decades suffered in comparison to its East Asian neighbors at the end of the Cultural Revolution (Perkins, 1988). To achieve a degree economic development that the people hope to reach, Chinese leaders have made tremendous effort to develop the economy and society, starting with the *Reform and Open-up Policy* in 1978. In this process of economic construction, the degree of economic growth became an important indicator to measure political achievements in state governance. The overall development in the last three decades or more and the success of China's economic growth are very impressive. The economic growth of China is often called the Chinese growth miracle (Prasad, 2009). However, during the Chinese

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economic development process, some negative things gradually drew the attention of researchers and policy-makers, and one of them is that energy consumption rapidly increases with economic growth. China has become the economic powerhouse of the world and its largest energy consumer, Brockway et al. (2015) analyzed China's past and future energy demand and found an important insight. People may believe that economic growth basically causes huge energy consumption when they use the evidence of China.

The process of China's rapid economic growth can be roughly derived from information on the website of *National Bureau of Statistics* (NBS) of *the People's Republic of China*, although Holz (2014) indicated that Chinese official statistics have a reputation of unreliability and Liu et al. (2015) also criticized the uncertainty range of China's official emission estimates. Numerous relatively old studies discussed the relationship between energy consumption and growth from Chinese evidence, and the details could see the literature review of Tang and Peng (2017). Recently, there are also some new papers published in this field. Ma et al. (2017a, b, c, 2018) did substantial work mainly on empirical side. In the paper Ma et al. (2017a), they extended a model to calculate and compare with National building energy savings (NBES) data and confirmed that China's building energy efficiency policies brought positive results. In other two 2017 papers wrote by Ma et al., they also used STIRPAT model to study the driving force of carbon emission in China during 2000–2015, and showed various factors affecting the reduction of carbon emissions in China.

To our knowledge, on the theoretical side this study would be innovative and pioneering. In regard to the co-existence of economic growth and increased energy consumption, people intuitively think that growth is the essential reason for greater energy consumption, especially if they studied this topic using empirical evidence from China. However, in the process of Chinese economic growth, many other social factors played an important role. First, reform of the economic system produces economic efficiency for productivity. Second, an increasingly educated Chinese population led to an increase in skilled laborers. Third, China devotes many resources to R&D for technology development and the accumulation of scientific knowledge, which is reported in the *Science and Technology Fund Investment Statistics Bulletin of China* (NBS of the PRC, 2018a) every year. In other words, Chinese economy became more productive during the process of rapid economic growth. Hence, the increase in energy consumption with economic growth may have also come from the growth of productivity.

This study develops a new theoretical model as an alternative option other than the traditional analytical tools like STIRPAT model to analyze the change of energy consumption with economic development when an economy becomes more productive. In terms of the structure of energy consumption, we could find various reasons for increased energy consumption as economic productivity increased. These findings could be used to provide some interesting policy implications about energy consumption, economic development and the growth of productivity. In the following sections, we firstly discuss the basic energy situation of China in Section 2, since China's energy consumption situation can provide insight for our general analysis. We present a theoretical analysis in Section 3 after introducing the basic framework, and then conclusions with policy implications in Section 4.

2. Basic facts regarding China's energy consumption

Energy, is a necessary factor for production, and plays an important role in economic growth when new cleaner technology is relatively unavailable, such as in China. Many factors have contributed to the rapid economic growth in China, such as sustained capital accumulation (Song et al., 2011), a demographic transition (Cai, 2010), and sophistication of exports (Jarreau and Poncet, 2012), but an increase in energy production and consumption during growth was notable. Some information about the energy situation in China can be revealed from the data in the *China Energy Statistical Yearbook* 2014 (Department of Energy Statistics of NBS, 2015). The publisher indicates that the yearbook contains very comprehensive data on many aspects of energy, and the principal data came from the *China Statistical Yearbook* (NBS of the PRC, 2018b) and annual statistical reports from NBS of China. This database is relatively authoritative and accurate about China's energy situation in general, and has been used in many important studies such as that by Guan et al. (2012). Per capita energy production and consumption in China during 1980–2013 year is depicted in Fig. 1(raw data in Table A1 in Appendix).

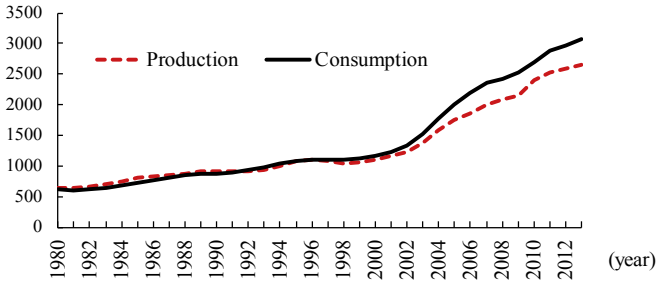

Fig. 1. Per capita energy production and consumption in China from 1980 to 2013 (kgce). **Source:** Authors searched the information from *Energy Production and Consumption Per Capita* in *China Energy Statistical Yearbook* 2014 (Department of Energy Statistics of NBS, 2015). **Note:** The unit "kgce" indicates "kg coal equivalent".

Fig. 1 shows that per capita energy production and consumption in China increased on the whole from 1980 to 2013. Hence, we think that China's economy and society increasingly relies on energy consumption when the economy experienced rapid growth during this period. More importantly, per capita energy consumption was greater than production after 1991 which indicates that energy production in China could not completely satisfy the demand for energy. The gap between production and consumption gradually widened, as shown in Fig. 1. The primary means of obtaining more energy to satisfy the demand was to purchase energy from the foreign energy market, i.e., to rely on energy imports. In our opinion, China must import much of its crude oil for economic development since its oil reserves are low compared to its economic scale. Additionally, China also imported a great deal of coal (Lin et al., 2012), although the Chinese coal reserves are very large.

Enormous energy consumption was affected by economic

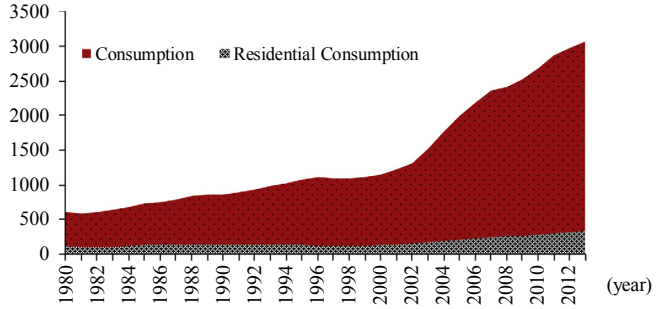

Fig. 2. Per capita residential energy consumption relative to total energy consumption in China from 1980 to 2013 (kgce). **Source:** Authors searched the information from *Energy Production and Consumption Per Capita* and *Residential Energy Consumption Per Capita* in *China Energy Statistical Yearbook* 2014 (Department of Energy Statistics of NBS, 2015), respectively. **Note:** See Fig. 1 note.