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Elasticities of substitution between energy and non-energy inputs in China power sector

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ABSTRACT

Energy substitution is considered as a key process to determine the economic outcome of decisions related to energy and environment policies. The sign and magnitude of energy substitution have been widely debated, and the results are divergent. This paper applies the translog cost function specification to estimate factor share equations based on the energy and non-energy inputs, whose coefficients are used to observe the energy degree of substitutability with the other traditional inputs for power industry in China. The results suggest that energy is the least price sensitive among three production factors. The four types of input elasticities (cross-price, Morishima's, Allen and McFadden's shadow elasticity of substitution) show that there are substantial substitution possibilities between energy and capital, while energy and labor have weak substitution. The findings imply that for power industry in China, to reduce energy consumption, more capital should be invested. With respect to labor, though, it appears less energy-saving potential.

1. Introduction

Currently, great attentions have been paid to the energy economic area, with the increasing energy consumption mainly originated from industrialization, the limited supply of renewable energy and the awareness of the environment issues (greenhouse emission). Facing the issues, macroeconomic modeling has been increasingly built, whose results heavily depend on the endogenous parameters, such as energy elasticities of substitution (Apostolakis, 1990; Frondel and Schmidt, 2002; Koetse et al., 2008; Thompson and Taylor, 1995 for a survey). The elasticities are related to a host of economic considerations, including capital taxes, fuel taxes, carbon taxes, investment subsidies, depletion allowances, trading carbon greenhouse gas emission allowances, etc. (Frondel, 2011; Thompson, 2006).

In the earlier research, Hogan and Manne (1977) found that if the elasticities of substitution between energy and non-energy were in the range of 0.3–0.5, economic growth in the United States to the year 2010 would be only slightly impeded by even dramatic constraints on growth of energy supply. Alternatively, when it falls into 0.1–0.2, the economy of the country would be seriously susceptible if the country is in shortage of fuels and electricity. Moreover, Jacoby et al. (2006) observed that, in the MIT EPPA model, mostly the elasticity of substitution between energy and non-energy would affect the costs of "Kyoto forever" for the U.S. economy. This is due to the fact that it has a direct effect on the cost of reducing industrial CO_2 emission (Arnberg and Bjørner, 2007). Therefore, the issue of energy substitution is crucial for both theoretical dimension of model application and practical understanding of the macroenergy or related environment policies.

However, despite the fact that, a large number of empirical researches have targeted on various regions and sectors, the direction and magnitude of the substitution between energy and the other traditional production factors get little consensus. Apostolakis (1990) explained the difference, as time-series that reflect short-term relationships while cross-section analyses capture long-term effects. Thompson and Taylor (1995) pointed out that the elasticity of substitution between capital and labor from the previous studies reported Allen partial elasticities of substitution, which would lead to the apparent dichotomy between cross-sectional and time-series studies. However, when they calculated the Morishima elasticities, no dichotomy was found. Frondel and Schmidt (2002) argued that the magnitudes of cross-price elasticity estimates of two factors, derived from static approaches, were mainly driven by the cost shares of these factors. To explain the divergences of substitution from multiple perspectives, Koetse et al. (2008) presented a meta-analysis to investigate the heterogeneity in empirical estimates of capital–energy cross-price and Morishima elasticities. They found that the heterogeneity can be explained by the differences in model specification, data characteristics, regions and time periods. However,

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till now, the source of discrepancies in the results remains controversial. Thus, the need for further empirical clarification on the relation between energy and other inputs appears pertinent. In particular, it's vital for researcher to focus on energy economic issues of China, which took 20.3% of global energy consumption in 2010 that make it the largest energy consumer in the world.[1] And with China's rapid process of industrialization and urbanization, the remarkable demand growth of energy shows no sign of abating.

The empirical literatures on energy substitution about China are thin and primarily in Chinese (Fan et al., 2007; Lu and Shao, 2008; Lu and Zhou, 2008; Ma et al., 2009; Zheng and Liu, 2004). Nevertheless, as Ma et al.'s (2010) opinions, most of the studies suffer from short span data or model misspecification. Ma et al. (2009) pointed out that over the period of 1995–2004, for China as a whole, energy and capital were substitutable with an estimated partial elasticity of substitution of 0.8, and energy was also a substitute for labor with an estimated partial elasticity of 0.61. A latest research for relevance to the issue of energy substitution in China is from Smyth et al. (2011). They focus on China's steel sector and find that capital and energy and energy and labor are substitutes, and suggest that the removing of price ceilings can reduce energy use. To our knowledge, till now there is no published study that has examined energy substitution in power sector, though, a number of specific studies to power sector have been carried out (e.g. Andrews-Speed and Dow, 2000; Zhao and Ortolano, 2010; Zhu et al., 2005).

The power sector, in which coal was the dominant input production factor, contributed to 25.78% of total coal use in 1990, which is up to 48.15% by 2008 (CNBSa, 2009). At the current growth rates, China's power sector alone is expected to account for 16% of global energy demand growth in 2020.[2] Therefore, estimating factor substitution for power sector to identify the interplay between energy and other inputs is typical and prominent. It can explain the relationship between energy and capital and between energy and labor, and provide the reliable applications in energy economics in China. And with the substitution obtained, we can answer the question whether energy saving can be achieved by increasing investment and labor employment.

This remainder of the paper is organized as follows. We begin in Section 2 with the description of energy and electricity consumption in China. Section 3 introduces the econometric model and the forms of substitution elasticities, while data are addressed in Section 4. Section 5 deals with estimation procedures and presents the empirical results. The final section concludes.

2. Energy and electricity consumption in China

China's prominent economic growth has been largely supported by its energy consumption. In 2008, China has been the second largest energy consumer in the world, only 167 Mtoe (million tons of oil equivalent) less than the USA (IEA, 2011). At the first ten years of this century, the average annual growth rate of energy consumption is 8.2% compared to 4.03% in the 1990s (CNBSb, 2009). Some projections suggest that there will be a higher growth rate of energy consumption for China in the future. As we all know, the energy intensity in China has experienced prominent decline in the last two decades. Nevertheless, its energy efficiency is still much lower than OECD countries. For example, in 2008 the energy intensity (energy consumption per unit of gross domestic production) was 0.81 (toe/thousand 2000 USD) in China, comparing with 0.19 in the USA and 0.10 in Japan (IEA, 2011). Consequently, improving energy efficiency has become an urgent issue for China. In practice, the Chinese government has launched a series of vigorous program to reduce energy intensity. Over the Eleventh Five Year (2006–2010), it successfully attained the goal of 20% drop on energy intensity. For the Twelfth Five Year (2011–2015), energy intensity and CO_2 emission are set to decrease by 16% and 17% respectively.

According to Chinese government's statistics, China's aggregate primary energy consumption was 57.144 million tons of standard coal equivalent (SCE) in 1978, 3.4% of which was power (hydropower, nuclear power and wind power). In 2009, it climbed to 306.647 million tons of SCE and the ratio of power consumption grew to 7.8% (CNBSb, 1999, 2010). As the last measurement shows, the fuel structure has undergone significant changes. The electricity, a secondary energy source, has increased much faster than primary energy sources such as coal and oil. During 1985–2009, the average growth rate of electricity consumption is 8.25%, versus 5.74% for coal and 6.23% for petroleum, see Fig. 1 (CNBSa various years). The reasons for the phenomenon are complex (Yang et al., 2010). The essential influencing factor comes from the surging demands which are mainly driven by industrialization, urbanization and population growth, each of them operated as a driver in different ways (Steenhof and Fulton, 2007). Another reason may be attributed to the fact that the retail electricity prices in China are designed by the government that cannot completely reflect the cost and lack a formal, transparent pricing mechanism (IEA, 2006).

Taking 2008 as sample, 74.32% of total electricity was consumed by industrial sector, followed by household sector with 11.37%. Production and Supply of Electric Power and Heat Power, Smelting and Pressing of Ferrous Metals, and Manufacture of Raw Chemical Materials and Chemical Products were the three largest industrial sectors in terms of electricity demand. Nevertheless, taking population into consideration, electricity consumption per capita in China is still far behind than that in other developed countries. For instance, in 2008 electricity consumption per capita in China was 2453 (kWh/capita), which was much lower than 13,647 (kWh/capita) in the USA and 8072 (kWh/capita) in Japan (IEA, 2011). Therefore, it is expected that the consumption of electricity will keep on increasing with the fast growth of China's economy and the improvement of people's living standards.

To satisfy the accelerating electricity demand, China's power industry has experienced a remarkable development, with generating capacity growth at a sustained rate of 10.09% during 1991–2008 (CNBSb, various years). And now China has been the world's second largest electricity producer, just next to the United States. In China, coal and hydro are the two largest components in the country's electricity generation fuel mix, 80.48% thermal power and 16.88% in 2008 water power, while the remaining 2.64% is nuclear power. Yet, the capacity expansion of the power sector is still lagging behind the demand for the whole country, which would lead to large supply shortages. The local government has to curtail electricity in industry supplies to fight for the power shortage especially during the hot summer, typically in the year of 2003 with the growth rate of electricity demand getting to the peak of 16.53%. Another major aim of cutting power in some regions is to achieve the energy saving and carbon reduction allocated by the central government (Yang et al., 2010). As referred by Kahrl et al. (2011), China's electricity system currently lacks the flexibility in planning, operations, and pricing to respond to conflicting pressures from demand growth, rising costs, and environmental mandates. Thus, prospective reform of power sector to increase supply and promote incentives for efficiency improvement is essential.

3. Methodology

3.1. A production function model

The choice of function form may affect the estimated elasticities. The typical method to obtain the energy substitution is a static translog cost function specification developed by Christensen et al. (1973). From 1996 to 2001, more than 100 literatures utilized or at least mentioned

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[1] Data source: BP statistical review of world energy, June 2011. There are statistic discrepancies from different organizations.

[2] Data source: Global Climate Change, China/U.S. energy efficiency alliance, http://chinauseealliance.org/why-support-us/global-climate-change/2012-3-12.