Journal of Cleaner Production 202 (2018) 969–979

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Output elasticities and inter-factor substitution: Empirical evidence from the transportation sector of Shanghai

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ARTICLE INFO

Article history:
Received 10 March 2018
Received in revised form
6 June 2018
Accepted 18 August 2018
Available online 22 August 2018

Keywords:
Transportation sector
Trans-log production function
Elasticity of substitution
Shanghai

ABSTRACT

As a major consumer of fossil fuels, the transportation sector in Shanghai presents a wide range of problems, including air pollution, noise, and traffic congestion. This study aims to explore the energy substitution effect based on a trans-log production function to evaluate the contribution of each input factor to sectoral output, and reveal the substitution possibilities between capital, labor, and energy. To deal with a multicollinearity problem, we adopt ridge regression to obtain the coefficient of each variable under the appropriate penalty value. The bootstrap method is used for making statistical inferences, and the 95% confidence interval is obtained with 1000 bootstrap samples. The empirical results demonstrate the following. (1) The output elasticities of capital (0.13–0.15), labor (0.24–0.25), and energy (0.43–0.48) are positive and show an increasing trend over the study period. (2) The substitution elasticity between labor and energy is the highest among the input factors (around 1.0095), with a slight decreasing trend. (3) The substitution elasticity between energy and capital ranges from 1.0018 to 1.0021, and the substitution elasticity between capital and labor is infinitely close to 1.

1. Introduction

The transportation sector is playing an increasingly important role in the growth and development of countries, supporting not only the increasing mobility demands of passengers and freight but also commercial demands. However, transportation activities that are supported by energy usage are associated with growing levels of environmental degradation. The transportation sector was the second largest energy user in China in 2014, accounting for 8.53% of total final energy consumption (China Statistical Yearbook, 2001–2015). Energy consumption of the transportation sector has been on the rise and growing rapidly in recent years, climbing from 315 million tons of coal equivalent (MTCE) in 2012 to 370 MTCE in 2014. In particular, China's foreign oil dependence reached 67.4% in 2017, driven by rapid growth of the transportation sector. China became the world's largest net importer of total petroleum and other liquid fuels in 2013, which surpassed the U.S. in annual gross crude oil imports in 2017. Therefore, the oil security has become the key to energy security of China.

Shanghai, as an international metropolis integrating high-end services and high-end manufacturing, is the center of China's economy, transportation, science and technology, industry, finance, trade, exhibition, and shipping (Kresl, 2015). It is notable that the development of the transportation sector accelerated with the rapid industrialization and urbanization of Shanghai in past decades. Shanghai's volume of passenger traffic increased from 38 million in 1990 to 185 million in 2015 (accounting for about 1% of the national volume), of which the average annual increase amounted to 15.4%. Shanghai's airports ranked first in China in terms of passenger throughput, with around 99 million passengers in 2015, accounting for 10.8% of national airport throughput. Shanghai's transportation sector was dominated by railway (52% of total passenger traffic), followed by civil aviation (27%) and highways (20%).

From a small base of 2.2% of China's freight volume, Shanghai's freight traffic increased substantially from 228 million tons (MT) in 1990 to 912 MT in 2015 at an average annual growth rate of about 15%. Affected by the global financial crisis, the volume of freight traffic in Shanghai decreased slightly in 2008, but recovered after 2011, and has been maintained at around 900 MT since then. In particular, Shanghai's container throughput reached 36.537 million TEU (20-foot equivalent unit) in 2015, ranking first in the world again. Shanghai's cargo transport was mainly composed of water

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https://doi.org/10.1016/j.jclepro.2018.08.188
0959-6526/

Nomenclature

C–D	Cobb–Douglas
CES	constant elasticity of substitution
CNY	Chinese yuan
MTCE	million tons of coal equivalent
OLS	ordinary least square
MT	Million tons
SNA	System of national accounts
TEU	Twenty-foot equivalent unit

(50.0%) and road transport modes (48.2%).

As shown in Fig. 1, the final energy consumption of Shanghai's transportation sector was 21.4 MTCE in 2015, or 7.7 times that in 1990. Shanghai accounted for nearly 6% of China's transportation energy consumption in 2015. This rapid growth has caused Shanghai's proportion of total energy consumption to rise significantly. The share of energy consumed by transportation in Shanghai rose from 8.9% in 1990 to 18.5% in 2015. Shanghai's final energy consumption was about twice that of Beijing in 2015. With the promotion of a low-carbon transportation system, the final energy consumption of Shanghai's transportation sector remained stable from 2009 to 2015, with an average annual growth rate of 1.8%.

Alongside the transportation sector's contribution to Shanghai's industrialization and urbanization, many serious problems have resulted, such as environmental pollution and ecological destruction. In 2015, Shanghai's transportation sector accounted for 37% of total carbon dioxide (CO_2) emissions of Shanghai (Xie et al., 2016) and produced 66,000 tons of sulfur dioxide and 219,000 tons of nitrogen oxide (NOx), according to the coefficient based on the World Input–Output database.

The energy consumption structure in Panel A of Fig. 2 shows that the final energy consumption of Shanghai's transportation sector was dominated by oil products (including fuel oil, gasoline, kerosene, and diesel), accounting for more than 96.4%. Electricity accounted for only about 2.5% and the proportion of other energy was relatively low (1.1%). By comparison, the energy structure of Beijing (Panel B, Fig. 2), another super metropolis in China, was more diversified. Oil consumption accounted for about 91.4% of the total energy consumption of Beijing's transportation sector (5 percentage points lower than that of Shanghai); natural gas accounted for 2.5% (2.0 percentage points higher) and electricity accounted for 5.2% (2.7 percentage points higher). Therefore, Shanghai could better manage emissions of its atmospheric pollution by learning from Beijing's energy structure pattern.

The increase of household transportation expenditure has been garnering increased national attention in the last decade. In 2015, the number of motor vehicles in Shanghai reached 3.344 million, of which 2.074 million were private cars. In other words, every second family owned a private car. Moreover, emissions from private cars in Shanghai were 2.6 MTCE, or 0.33 MTCE more than the average in 2014 found by Li and Qian (2008). Considering Shanghai's license plate limit policy in which only people who win an auction have the right to register a local license plate at the vehicle administration office, the actual number of private cars in Shanghai might be higher than the official statistics. Furthermore, there is substantial room for growth in the number of private cars in Shanghai based on a comparison with developed countries; for example, in the US, every family has about 1.97 cars.

Considering that the transportation sector plays a crucial role in the atmospheric environment, some scholars have proposed the concept of "energy substitution," which can be achieved by reconfiguring input factors, including mutual substitution among various energy sources and among various input factors, and in most cases, involves replacing non-renewable energy with renewable energy. Meanwhile, energy substitution is not limited to the internal evolution of factors—it can be achieved through replacement between factors with faster speed (Ouyang et al., 2018). Taking the transportation sector as an example, energy consumption can be saved by increasing capital and labor inputs while cutting energy investment. The most representative substitution is to increase capital spending to promote advances in energy-efficient technologies for both freight and passenger transport, increase rates of vehicle scrappage, and improve the state of the infrastructure. However, a few scholars have argued that the substitution relationship between energy and non-energy factors is uncertain (Field and Grebenstein, 1980; Hazilla and Kopp, 1984; Chichilnisky and Heal, 1993). Thus, it is necessary to identify

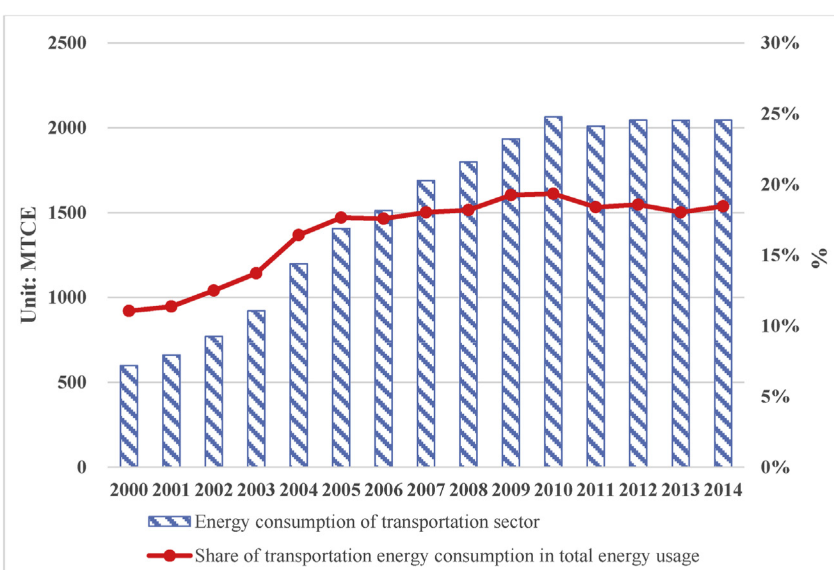

Fig. 1. Energy consumption of transportation sector in Shanghai (2000–2014).