Applied Energy 190 (2017) 1081–1089

Contents lists available at ScienceDirect

Applied Energy

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

Energy biased technology change: Focused on Chinese energy-intensive industries

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HIGHLIGHTS

- We build an empirical model to enable us to determine the bias in more than two input.
- The biased technical change is derived from elasticity of substitution in nested CES production functions.
- (KE)L nesting structure is optimal for eight out of the eleven energy intensive industries in China.
- The policy recommendation is to specifically target these six energy biased industries.

ARTICLE INFO

Article history:
Received 29 June 2016
Received in revised form 19 October 2016
Accepted 1 November 2016
Available online 21 January 2017

Keywords:
Energy biased technology
Energy-intensive industries
Elasticity of substitution

ABSTRACT

Technical change bias has predominately been measured through two-factor models. Resulting from the rising importance of energy we devised a framework to estimate technical change bias for three input factors. The framework involves an estimation of elasticity and technical change parameters for a constant elasticity of substitution function with capital, labour and energy, which is derived from the elasticities and marginal output. We apply the framework to investigate eleven Chinese energy-intensive industries. The optimal nested structure for eight of the industries is for capital and energy to be combined first at the composite level and then with labour to form total output. Between 1990 and 2012, six of the industries were energy biased, three were towards capital, one towards labour and one mixed. The results show that recent Chinese energy intensity reduction programs are not sufficient to induce energy efficient development. The policy recommendations target specifically the energy biased industries to achieve desired energy savings in the future.

1. Introduction

Since Solow [1] argued that technological change (TC) was neutral, macroeconomists have traditionally assumed Hicks-neutrality. Nonetheless, most recent empirical studies reject the assumption of Hicks neutrality (see Betts [2], Bessen [3], Karanfil and Yeddir-Tamsamani [4] and so on). This implies a change in factor prices may encourage inventions directed at saving the expected expensive factor [5]. Hicks argued that TC is biased towards a factor if it increases the marginal product of that factor more than the other factor. Hence, TC would affect the factor distribution. Acemoglu [6] gave a number of examples to illustrate the potential importance of the biases. On the empirical side, bias of TC has generally been measured in two-factor models, using value-added functions. There is also an overall tendency that TC is capital-using and labour-saving (Sato [7], Binswanger [8], Acemoglu [9] and Verschelde et al. [10]). The widely cited theoretical literatures Acemoglu [11] suggested that when technical progress is asymptotically labour augmenting, it may become capital-biased in transition to induce factor-saving innovations. Consequently, the conventional neutrality forms may be rejected in favour of general factor augmentation [12].

Nonetheless, energy is now considered a vital factor of production resulting from the increasing environmental problems and issues of energy security [13]. Indeed, for energy efficiency modelling energy is an indispensable factor of production [14]. Consequently, examining the bias of TC of energy along with other inputs has become essential. This is especially important for developing countries like China, the trajectory from supporting economic

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http://dx.doi.org/10.1016/j.apenergy.2016.11.001
0306-2619/

growth by consuming energy to limiting energy consumption without sacrificing growth. The large-scale deployment of innovative technologies is a key determinant for reducing emissions in an effective and efficient manner [15]. Adetutu [16] treated energy efficiency as fuel-augmenting technological progress to estimate the elasticities between capital and energy, but without considering TC of other inputs. There are limited empirical studies on whether TC is energy biased or energy saving. Jin and Jorgenson [17] developed an econometric modelling with the rate and biases of TC by unobservable or latent variables. They highlight that prior to 1980, TC created labour and material saving and also capital and energy use. However, after 1980, progress resulted in energy use. Sato [18] investigated factor bias in the Japanese industrial sector from 1973 to 2008. The author determines that TC resulted in electricity and capital use but resulted in labour and non-electricity energy saving. Karanfil and Yeddir-Tamsamani [4] estimated a translog cost-share system investigating technical bias in the French economy. The authors argue that the results are mixed regarding whether energy bias exists. Indeed, theoretically whether TC resulted in energy bias depends on the elasticity of substitution between energy and non-energy inputs, which is not involved in the above research. As highlighted by research including Carraro et al. [19], Otto et al. [20], Smulders and de Nooij [21], when TC increases productivity of inputs complementary to energy, demand will increase. The reverse applies when inputs are substitutes to energy. The way TC affected the distribution through its effects on the elasticity of substitution.

Resulting from the need to consider energy as an input, we contribute by enhancing our framework to study the technical change of any number of factors at the sector level. The multi-factor generalisation is derived from elasticity of substitution and TC of the factors. To estimate elasticities covering energy with more than one other factor would require a nested Constant Elasticity of Substitution (CES) function [22]. The CES function is the most theoretically sound estimation technique [23]. Additionally, the CES function is more structured and has a smaller number of parameters to estimate than other functions, including the translog function [24]. Nonetheless, as pointed out by Hoff [25], current models incorporating three or more factors of production suffer from approximation errors. Consequently, to tackle this problem our theoretical framework enables us to determine elasticity of substitution for the three factor nested CES through a first order condition estimation. We then derive equations to determine TC bias between two factors of production and a total bias measure for three inputs.

In this paper we apply our technique to investigate the energy-intensive sectors of China. Ever since China's industrialisation started in the late 1970s, China has been one of the fastest growing economies in the world. It has maintained a 10 percent average annual growth rate of GDP over the past 30 years largely fueled by its energy consumption. Since 2008 China has been the second largest energy consumer in the world.[1] China's oil consumption accounted for 43% of the global oil consumption growth in 2014. Every year during this period the industry of China consumed approximately 70% of total energy. However, a significant 83% of the energy is consumed by only 10 sectors in 2012 [26]. This would imply that directed policy intervention targeting these energy-intensive industries is vital to limit the detrimental effects on the environment. Indeed, a major reason for the extensive growth of energy demand comes from heavily subsidized fuel costs by the central government. IEA [27] estimated that the rate of fossil-fuel subsidy as a percentage of the reference price was 11% in China, about CNY 30.02 billion (1998 price). This would lead to inefficient and over consumption of energy. It is no surprise that energy efficiency in China is much worse than the OECD countries. In 2012, the energy intensity was 0.64 (PPP) (toe/thousand 2000 USD) in China compared to 0.15 in USA and 0.10 in Japan [28]. However, as suggested TC can be energy saving or energy biased. Indeed, with the rising energy price over recent years, firms in China may have developed energy-saving technologies. And it is important to recognize that over the last two decades Chinese energy intensity has declined significantly. Hence, to enable effective policy to be developed, it is critical to determine for certain whether TC is energy biased for these energy-intensive industries, which is found to be used in the design of energy efficiency policy [29].

The rest of this paper is structured as follows. The next section outlines the empirical model that we have developed. This includes a discussion of the nested CES function and the derivation of the first order condition estimation of the TC and elasticity parameters. The third section outlines the data that is constructed. The fourth section presents the results with the final section concluding.

2. Methodology

2.1. CES production function

Neoclassical production functions indicate the maximum possible economic output (Y) obtainable from capital (K), labour (L) and energy (E) given the technology available at a particular time (t) [30].

$$Y_t = F(A_tK_t, B_tL_t, C_tE_t) \tag{1}$$

where Y is total output, and K, L and E are the inputs of capital, labour and energy respectively. A, B and C stand for capital, labour and energy augmenting technological progress, respectively. t is time. Given the availability of data, materials are not included in the production function.

As the CES at a single-level function has the same elasticity for all the factors, a nested CES is adopted to allow for elasticities to differ between factors. The three nested functions for capital, labour and energy (K, L, E) are (KL)E, (KE)L and (EL)K, which are specified below respectively. For example, (KL) E signifies K and L to be combined at the composite level and then with E to form total output.

$$Y_t = \{\beta[\alpha(A_tK_t)^{-\rho_1} + (1-\alpha)(B_tL_t)^{-\rho_1}]^{\frac{\rho}{\rho_1}} + (1-\beta)(C_tE_t)^{-\rho}\}^{-\frac{1}{\rho}} \tag{2}$$

$$Y_t = \{\beta[\alpha(A_tK_t)^{-\rho_1} + (1-\alpha)(C_tE_t)^{-\rho_1}]^{\frac{\rho}{\rho_1}} + (1-\beta)(B_tL_t)^{-\rho}\}^{-\frac{1}{\rho}} \tag{3}$$

$$Y_t = \{\beta[\alpha(C_tE_t)^{-\rho_1} + (1-\alpha)(B_tL_t)^{-\rho_1}]^{\frac{\rho}{\rho_1}} + (1-\beta)(A_tK_t)^{-\rho}\}^{-\frac{1}{\rho}} \tag{4}$$

where the distribution parameter is $\alpha \in (0,1)$ and $\beta \in (0,1)$ represents the contribution ratio of capital in output. $\rho \in (-1,\infty)$ and $\rho_1 \in (-1,\infty)$ are the substitution parameters.

From a meta-study, Koetse et al. [31] found that controlling for technological progress significantly changes the value of the measured elasticities. Restricting the analysis to Hicks-neutral technological change necessarily biases the estimates of the elasticity towards one. Here, the factor-augmenting TC are simulated by the "augmenting multipliers" as below[2]:

$$A_t = A_0\exp^{\gamma(t-t_0)}, \quad B_t = B_0\exp^{\mu(t-t_0)}, \quad C_t = C_0\exp^{\nu(t-t_0)} \tag{5}$$

[1] IEA (International Energy Agency). International Energy Agency. http://www.iea.org/statistics/statisticssearch/.2015-3-1.

[2] The form for TC is always specified to circumvent the problem of impossibility theorem [32].