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Threshold characteristic of energy efficiency on substitution between energy and non-energy factors

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ABSTRACT

The elasticity of substitution between energy and non-energy is a key parameter in quantifying distributional impacts of energy and environmental policies. However, the empirical results of energy substitution are contradictory. The source of discrepancies in the results remains controversial, which provides ample motivation for further interpretation. The present paper is to identify the discrepancies of energy and non-energy substitution from the perspective of energy efficiency. The case study is based on the elasticities between energy and non-energy of China's 36 industrial sectors during the period 1994–2008. The results show that there is overwhelming evidence of a threshold effect which separates the substitution of energy and non-energy, on the basis of energy efficiency. The findings imply that when the same energy-saving capital is invested to the industries, the energy intensive sectors are of more energy-saving potential.

1. Introduction

The elasticity of substitution between energy and non-energy is a key parameter in quantifying distributional impacts of energy and environmental policies. From the theoretical point, energy substitution is crucial for a host of economic issues, including capital taxes, fuel taxes, carbon taxes, investment subsidies, depletion allowances, and trading carbon greenhouse gas emission allowances (Frondel, 2011; Thompson, 2006). Kuper and Soest (2003) pointed out that the effectiveness of energy policy instruments crucially depended on the values of the substitution elasticities. In the earlier research, Hogan and Manne (1977) found that if the elasticity of substitution between energy and non-energy was 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 in energy supply. Alternatively, when it fell into 0.1–0.2, the economy of the country would be seriously susceptible if the country was in shortage of fuels and electricity. Much more, Jacoby et al. (2006) observed that, in the MIT EPPA model, the elasticity of substitution between energy and non-energy would affect the costs of "Kyoto forever" for the United States, because it has a direct effect on the cost of reducing industrial CO_2 emission (Arnberg and Bjørner, 2007). For instance, Okagawa and Ban (2008) estimated the substitution elasticities for CGE model and found that the conventional parameters could overestimate the necessary carbon price by 44%. Likewise, Beckman and Hertel (2009) found that the old energy substitution parameters in the original GTAP-E specification were too large, which led to the understatement of the costs meeting a given emission reduction target. Jaccard and Bataille (2000) noted that the magnitude of the energy rebound effect depended on the technical and economic ease, with which energy and other inputs to production and consumption can be substituted when the effective cost of using energy does in fact decrease.

However, the direction and magnitude of the substitution between energy and other inputs are historically a source of debate. Researchers have devoted considerable efforts to reconciling the conflicting results. The classic data in Berndt and Wood (1975) are frequently cited to estimate the elasticity of substitution between energy and non-energy factors. They found that energy and capital are strong complements, while others consider that they are substitutes (Griffin and Gregory, 1976; Thompson and Taylor, 1995). Also employing the data in Berndt and Wood (1975), Frondel (2004) obtained that there can be significant differences among the various elasticities of substitution, and argued that for energy policies, cross-price elasticities might be more appropriate than Allen partial elasticity of substitution (AES) and Morishima's elasticities of substitution (MES).

Apostolakis (1990) explained that the difference is time-series reflecting short-term relationships, while cross-section analyses capture long-term effects. He pointed out that the elasticities of substitution between capital and labor from the previous studies were reported Allen partial elasticities of substitution, which led to the apparent

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dichotomy between cross-sectional and time-series studies. But the dichotomy did not occur during their calculation of the Morishima elasticities. Therefore, it seems the divergent results stem from the inappropriate measure of the substitution.

Focusing on cross-price elasticity, Frondel and Schmidt (2002) argued that the magnitudes of elasticity estimates of two factors derived from static approaches were mainly driven by the cost shares of these factors. When the cost shares of both capital and energy are relatively large, the cross-price elasticity between energy and capital is likely to be substantially positive. To further explore the causes of the divergences of substitution, 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. The data aggregation may matter the elasticity estimates and aggregate data would lead to relatively large estimates. From the previous studies, we can conclude that by now the explanations for the discrepancy can't come to an agreement.

According to Solow (1987)'s argument, aggregate manufacturing outputs consist of many products that have different energy intensities which would lead to intractable aggregation biases. The possibility of capital and labor for energy intensive industries is much larger than those for less energy intensive industries (Kim and Labys, 1988; Okagawa and Ban, 2008). It seems that many types of energy efficiency improvement may be understood as the 'substitution' of capital for energy inputs (UKERC, 2007). A higher energy efficiency may lead to a change in the factor input mix (energy, capital, labor, materials) in production due to substitution or complementary relationship (van den Bergh Jeroen, 2011). It reflects that the sectors with various substitutions may be explained by different energy efficiency performances. Till now, few researches have been conducted on the relationship between energy efficiency and substitution (Huang et al., 2006). Thus, this paper builds upon the previous contributions and extends on them to throw new light on the possible explanation of the divergence of energy substitution from the view of energy efficiency. In other words, we try to detect if there is a statistically significant threshold level of energy efficiency above which energy efficiency affects elasticities differently than at lower energy efficiency?

The remainder of the paper is structured as follows. We begin by reviewing the relevant literatures concerning the explanations of the divergent substitution elasticities. The forms of substitution elasticities and production functions are introduced in Section 2, while data are addressed in Section 3. Section 4 deals with estimation procedures and the empirical results are obtained. The final section concludes.

2. Elasticities of substitution and the models

2.1. A production function model

The general production functions are Cobb–Douglas, constant elasticity production functions, generalized Leontief production functions and translog function. According to the statistics from Frondel and Schmidt (2002), in 1996–2001 more than 100 literatures utilized, or at least mentioned the translog cost function approach, which was developed by Christensen et al. (1973). The regularity priorities of a translog model are non-negativity, monotonicity, and concavity. It is flexible in calculating elasticity of substitution without imposing prior restrictions on the values of elasticities. When introducing interaction terms, it can be expanded to include various inputs involving energy and non-energy, estimated in a symmetric system of derived factor share equations. A detailed discussion of the characteristics and specification of the translog cost function can be found in Thompson (2006). The logged input price and logged output are applied in translog cost function which takes fully into account Hicks-neutral technical change. Here we specify the following KLE (m = 3).

$$\begin{aligned}\ln C = {} & \beta_0 + \sum_{i=1}^{m} \beta_i \ln P_{it} + 0.5 \sum_{i=1}^{m} \sum_{j=1}^{m} \beta_{ij} \ln P_{it} \ln P_{jt} + \beta_t T + 0.5 \beta_{tt} T^2 \\ & + \sum_{i=1}^{m} \beta_{it} T \ln P_{it} + \beta_{iY} \ln Y_t + 0.5 \beta_{YY} (\ln Y_t)^2 + \sum_{i=1}^{m} \beta_{iY} \ln P_{it} \ln Y_t \\ & + \beta_{Yt} T \ln Y_t, \end{aligned} \tag{1}$$

where the equilibrium total cost (C) is

$$C = P_K K + P_L L + P_E E. \tag{2}$$

In Eq. (1), ln indicates the natural logarithm, P_{it} (P_{jt}) is the price of input factor i (j) at time t, i and j are indices for the three inputs (capital, labor and energy), t is a time variable to capture technical change, Y represents the output. The parameter β_0 is a constant and the other parameters of βs are to be estimated.

Linear homogeneity input price, an inherent feature of any cost function requires the following regularity conditions on the parameters:

$$\sum_{i=1}^{m} \beta_i = 1 \text{ and } \sum_{i=1}^{m} \beta_{ij} = 0. \tag{3}$$

Applying the Shephard's lemma, a linear expression of expenditure shares of each factor i can be derived from the cost function,

$$S_i = \beta_i + \sum_{j=1}^{m} \beta_{ij} \ln P_j + \beta_{it} T + \beta_{iY} \ln Y. \tag{4}$$

Generally, β_i and β_{ij} are appointed as distribution parameter and as substitution parameter respectively (Christensen et al., 1973). The former measures how the cost shares change in response to input price by the effect of factor substitution. And substitution parameter is to reflect the price elasticity of substitution between any two inputs. Here, β_{ij} equals β_{ji}. β_{it} measures the technology bias or nonneutral technological change and β_{iY} is returns to scale parameter.

To estimate Eq. (4), we give the additive disturbance term μ_i. They sum to zero at each observation, and the disturbance covariance matrix is singular. The system in Eq. (4) implies three equations with one for each of the three inputs and the three cost shares sum to unity at each observation. In other words, when the price homogeneity is imposed, the system is reduced to two equations. In the case when we drop the labor share equation and the system comes with two estimable equations:

$$\begin{cases} S_K = \beta_K + \beta_{KK}(\ln P_K - \ln P_L) + \beta_{KE}(\ln P_E - \ln P_L) + \beta_{KT} T + \beta_{KY} \ln Y + \mu_K \\ S_E = \beta_E + \beta_{EK}(\ln P_K - \ln P_L) + \beta_{EE}(\ln P_E - \ln P_L) + \beta_{ET} T + \beta_{EY} \ln Y + \mu_E \end{cases}. \tag{5}$$

When calculating system (5), we use maximum likelihood method to ensure that the results are the same no matter which share equation is dropped. The parameters of labor share equation can be derived by the symmetry condition of Eq. (3).

2.2. Elasticities of substitution

The two-variable elasticities of substitution were originally introduced by Hicks (1932) for the analysis of only two production factors. Hicks and Allen (1934) thought that the elasticity of substitution was a measure of the curvature of the isoquant. It expresses the variation in the factor proportion due to the relative change in the marginal rate of technical substitution while output is held constant. In other words, it represents how factor income shares change as the ratio of the factors