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Estimating direct and indirect rebound effects by supply-driven input-output model: A case study of Taiwan's industry

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ABSTRACT

Most existing literature focuses on the direct rebound effect on the demand side for consumers. This study analyses direct and indirect rebound effects in Taiwan's industry from the perspective of producers. However, most studies on the producers' viewpoint may overlook inter-industry linkages. This study applies a supply-driven input-output model to quantify the magnitude of rebound effects by explicitly considering inter-industry linkages.

Empirical results showed that total rebound effects for most Taiwan's sectors were less than 10% in 2011. A comparison among the sectors yields that sectors with lower energy efficiency had higher direct rebound effects, while sectors with higher forward linkages generated higher indirect rebound effects. Taking the Mining sector (S3) as an example, which is an upstream supplier and has high forward linkages; it showed high indirect rebound effects that are derived from the accumulation of additional energy consumption by its downstream producers.

The findings also showed that in almost all sectors, indirect rebound effects were higher than direct rebound effects. In other words, if indirect rebound effects are neglected, the total rebound effects will be underestimated. Hence, the energy-saving potential may be overestimated.

1. Introduction

1.1. Background

The consideration of energy savings generally concerns only improved energy efficiency by reducing energy intensity.[1] Thus, it ignores the effects of shifts in stimulated consumer behaviours and additional energy consumptions, the so-called rebound effects. If the rebound effect is not taken into account, the expected energy savings resulting from enhanced energy efficiency may be overestimated. Consequently, energy conservation policies derived from such an approach might not be able to achieve expected effectiveness. Therefore, in the past three decades, an increasing number of researchers have paid close attention to the rebound effect [1] and defined it in terms of three dimensions [2–7], explained as follows:

(1) Direct rebound effects: Assuming *ceteris paribus*,[2] improved energy efficiency reduces energy consumption, and lowers energy input costs. This will increase output, which in turn increases energy consumption and offsets energy savings arising from improved energy efficiency within the same sector. For instance, energy efficiency improvements in the steel making will lower the cost of steels and might lead to increased steel production. This will induce additional energy consumptions [2].
(2) Indirect rebound effects: Improved energy efficiency causes variations in the primary input for the sector experiencing improvements; and thus changes the input mix and output sales for other sectors. Thus, the decline in energy cost from

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[1] In this study, energy efficiency improvement is by reducing energy intensity. To avoid prolixity, hereafter refer to "improved energy efficiency." The definition of energy intensity is the ratio of energy input divided by monetary output [8]. Energy efficiency is defined as an inverse indicator of energy intensity. Therefore, energy efficiencies measure a specific output and process efficiency for various sectors in an I-O model.

[2] Here, *ceteris paribus* means same other variables, which would encompass any factors from other sectors or the overall economic system, except for the energy efficiency of a given sector.

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improved energy efficiency results in the spare energy consumption being input into other products and services. For instance, energy efficiency improvements in the steel making will lower the cost of cars and might lead to increased car usage. The increased car demand and additional production will induce additional energy consumptions in car makers [2].

(3) Economy-wide rebound effects: Improved energy efficiency drives the productivity of the overall economy and stimulates additional energy demand. In turn, this promotes economic growth and an increase in energy consumption.

The rebound effect has mainly been analysed from the perspective of the demand side for households, a given sector, or the overall economic system. However, sectors of an economy have interdependent characteristics and inter-industry linkages.[3] Only focusing on an individual sector may lead to relationships with other sectors being neglected, and consequently underestimate total rebound effects. This study focused on direct and indirect rebound effects from the perspective of producers. A supply-driven input-output (I-O) model is employed to estimate rebound effects from improved energy efficiency in own-sector (i.e., direct rebound effects) and other sectors (i.e., indirect rebound effects). Using Taiwan's industry as a case study, we adopted Taiwan's I-O Table [9] and Energy Balance Sheet [10], both of which show data for 2011. Furthermore, we aggregated the original 166 sectors to create a hybrid table comprising 33 non-energy sectors and 6 energy ones.

1.2. Aim

The aims of this study are as follows:

(1) Apply a supply-driven I-O model to analyse the magnitude of total, direct, and indirect rebound effects arising from improved energy efficiency for a sector, based on production-side changes.
(2) Investigate the relationship between energy efficiency and direct rebound effects.
(3) Evaluate the relationship between inter-industry linkages and indirect rebound effects.

The paper is structured into six sections. The next section reviews relevant literature. Section 3 interprets the methodology. Section 4 looks at data collection and processing. Section 5 presents the results. The final section provides our conclusion and discussion.

2. Literature review

The concept of rebound effects can be traced back to Stanley Jevons' 1865 book, The Coal Question. Jevons pointed out that although the use of the coal-fired steam engine had greatly improved production efficiency, its widespread use had led to increased coal consumption [11]. In the 1980s, Brookes [12] and Khazzoom [13], both pioneers in the field of the rebound effect, separately proposed similar views with regard to the macroeconomic level and microeconomic level, respectively. Further, Gavankar and Geyer [5] classified direct rebound effects belong to microeconomic level [14], while indirect and economy-wide rebounds belong to macroeconomic level [15,16].

With regard to researches of direct rebound effects on the consumer's perspective, its theoretical mechanism was first studied by Khazzoom [13]. Many works [2,3,5] study in this field. Some researchers [17–19] investigate vehicle travels, others investigate individual energy sectors such as heating and lighting [20] and air conditioning [3]. For instance in personal automotive traveling, Hymel and Small [17], and Staplenton et al. [18] studied the direct rebound effects in the US and the UK between the 1960s and 2010s. The former found that the direct rebound effects ranged from 10% to 27%, while the latter obtained a range of 4.7%–30%.

In terms of theoretical mechanisms of producers' direct rebound effects, Brookes [21], Saunders [22,23], and Sorrell [24,25] attributed these to the output effect and substitution effect. Among those, Saunders [22,23] followed the Neoclassical theory and used the Cobb–Douglas production function to derive the Khazzoom–Brooks Postulate, albeit under a number of assumptions, such as the value of elasticity of substitution. Lin and Li [26] conducted an empirical analysis of China's heavy industry. Based on the KLEM[4] production framework and asymmetric price responses, they obtained a figure of 74.3%. Bentzen [27] applied a dynamic OLS[5] method to estimate direct rebound effects for US manufacturers in 1949–1999, and estimated these to be approximately 24%.

With regard to indirect and economy-wide rebound effects, various methods have been attempted. For instance, top-down theoretical macroeconomic models of neoclassical growth [16], Cambridge multisectoral dynamic model (MDM-E3) [28], computable general equilibrium (CGE) [29–31], and energy-input–output (E-I-O) [32]. To study economic-wide effects, such measures as economy-energy-environment (E3) [33] have been used. As for theoretical mechanisms of indirect rebound effects from the producers' perspective, Herring and Sorrell [2], as well as Gavankar and Geyer [5], introduced the embodied energy.[6] As for the empirical study, in 2015, Broberg et al. [34] utilised a general equilibrium view to analyse economy-wide rebound effects in Swedish industry.

In existing researches, the magnitude of the rebound effects varies considerably. Some researchers [5,17,28,35] have discussed this issue, attributing the large variation to the different methods used and lack of consistency regarding the empirical approaches to be taken. Regardless of the directness or indirectness of rebound effects, the existing literature has mainly analysed from the consumer's perspective. Researches related to indirect rebound effects on the production side are scarce. Therefore, this study uses a supply-driven I-O model to analyse production changes, arising from improvements in energy efficiency, and to estimate the magnitude of the direct and indirect rebound effects. The supply-driven I-O model is elaborated in the following section.

3. Methodology

3.1. Supply-driven I-O model

The I-O table depicts the status of product circulation and distribution between various sectors within the economic system. Ghosh [36,37] introduced the supply-driven model in 1958 and

[3] In an input-output table having n sectors, we have a $n \times n$ square table. Vertical analysis of sector k shows the relevance of sector k and its supplying sectors. On the other hand, a horizontal analysis of sector k shows the relevance of sector k and its distributed sectors. Such cross relevance is referred to as inter-industry linkages.

[4] KLEM is an abbreviation for capital (K), labour (L), energy (E), and materials (M).

[5] OLS is short for ordinary least squares. This is a common method for estimating the unknown parameters in a regression model.

[6] Embodied energy is the total energy amount consumed to produce any goods or services in an entire product life-cycle. Hence, it covers energy used to manufacture equipment for improving energy efficiency or for manufacturing intermediate products for other sectors.