The Rebound effect in the Chinese context

Introduction

The rebound effect refers to the increase in demand for energy services offsetting the energy savings resulting from the improvements of energy efficiency. Studies on the rebound effect have begun since the 1970s when adjustments in energy consumption and influence energy price on energy demand were observed (Bohi and Zimmerman, 1984). Since then, many research efforts have been focused on describing the phenomenon of rebound effects by developing econometric models and identifying important variables. The correlation between the rising energy efficiency of energy services and increased energy consumption is confirmed by many empirical studies at both micro and macro levels (Madlener and Alcott, 2009, Dimitropoulos, 2007, Sorrell and Dimitropoulos, 2008). However, the nature and magnitude of the rebound effect remains undetermined. Moreover, definitions of the rebound effect are often stretched and extended to adapt to various assumptions in empirical estimates of the effect and limitations of data collection (Sorrell and Dimitropoulos, 2008). For this reason, to continue the effort and to build on research in this genre, we must first reflect and define several central concepts of the rebound effect.

Energy versus energy services

The distinction between energy and energy services is crucial. It helps to identify key elements in consumers' decisions regarding the use of energy, which directly affect energy demand. Studies using energy as the proxy of energy services omit other factors affecting energy demand (Howarth, 1997). Energy is only one of multiple inputs (e.g., labor, capital, energy commodities, and energy systems) of the production of energy services (e.g., refrigeration, thermal comfort, and motive power). The process produces energy services that have both functional and sensory attributes (Greening et al., 2000, Sorrell and Dimitropoulos, 2008). For example, vehicles can provide mobility and speed as well as comfort and an image of status. Thus, the evaluation of energy services is unavoidably involved rational and value trade-offs and the degree of desirability. The latter also indicates a state of *satiation* can cease the use of an energy service. More importantly, consumers' time is often one of the inputs in the process (e.g., driving and cooking). Therefore, three types of trade-offs are involved in consumers' decision-making of energy use (Sorrell and Dimitropoulos, 2008):

1. Trade-offs between different production factors such as substituting labor for energy (Howarth, 1997). Among trade-offs of this type, an important yet understudied category is the trade-off between energy and consumers' time. It has long been observed by both sociologists and economists that time is tightly associated with wages and imbued with a monetary value (Thompson, 1967, Becker, 1965). Because energy efficiency improvements due to technological progress often have a time-saving nature (Binswanger, 2001), they tend to invoke consumers' awareness of time costs (i.e., the opportunity cost of time and the amount of time required to produce an energy service). This, in turn, could induce nontrivial rebound effects (Sorrell and Dimitropoulos, 2008). For example, consumers would choose faster modes of transportation that require more energy.

2. Trade-offs between different energy services such as substituting personal transportation for public transportation or driving out dining instead of cooking at home.
3. Trade-offs between functional attributes and sensory attributes of an energy services such as substituting cost-savings of gas resulting from an energy-efficient car for a larger car.

Figure 1 summarizes the discussion in this section.

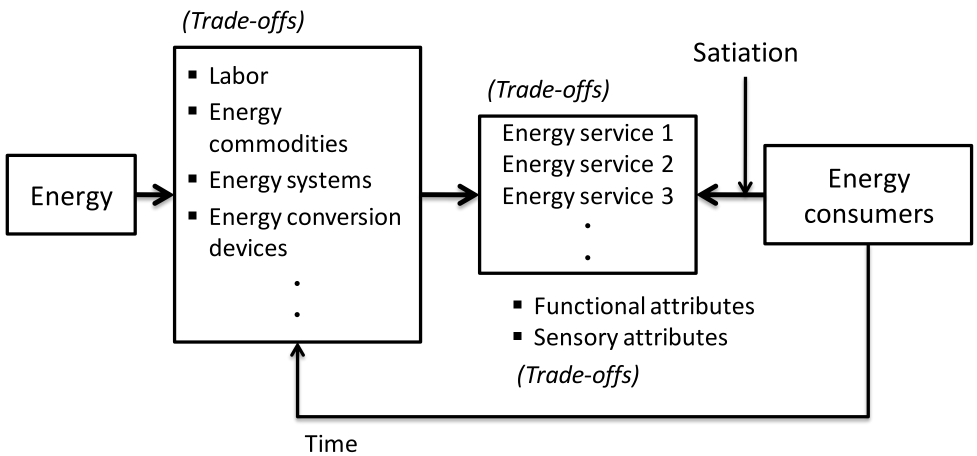

Figure 1 Trade-offs and factors of the production process of energy services

Efficiency and engineering savings

In the field of study, energy efficiency is often defined as the ratio of energy inputs to service outputs (Binswanger, 2001) and its improvements are due to technological progress rather than institutional or organizational change (Alcott, 2005). Based on the definition, *the expected consumption savings* are calculated as the consumption *before* the technological improvement multiplying the percentage difference between the energy input per unit *before* the improvement and that *after* the improvement (i.e., engineering savings). In essence, the use of engineering savings as the theoretical base for calculating the rebound effect gives rise to difficulties and ambiguities in the explanation of results. Various variables in the production process and exogenous factors affecting the process (e.g., policies and tax) could potentially contribute to the resulted difference of consumption. Because of this, seeking accurate estimation of the rebound effect is less meaningful once the significance of the effect is established. Additionally, correlations cannot be equated to cassations. Thus, more attentions should be shifted to examining why the rebound effect occurs.

Mechanisms

There are different categorizations of mechanisms underlying the rebound effect (Madlener and Alcott, 2009), depending on the purpose of studies. In general, these mechanisms are closely related to the aforementioned trade-offs.

General price effects: the most general hypothesis suggests that the price of energy services lowered by the energy efficiency improvement increase demand for energy services. Under this broad concept, many researchers view the *price elasticity of demand* as a main variable in modeling the rebound effect while ignore the price elasticity of *supply* by assuming the real price of energy is constant (Alcott, 2005). However, this assumption may no longer be justified when energy prices fluctuate due to the uncertain energy supply. Especially, recent studies using general equilibrium models show the importance of the market of energy supply in the rebound effect (Wei, 2010).

The general price effect can be decomposed into income effects and substitution effects since they describe responses to the lowered price of energy service and increased purchasing power. Both of them operate at micro level.

- *Income effects*: the reduced price of energy services contribute to the increase of consumers' income and purchasing power. However, income effects alone are insufficient to precisely explain the rebound effect. The propensity to purchase an energy service requires both the ability and willingness of consumer to pay for the energy service. Income effects denote the ability to purchase but not the willingness. For example, if demand for an energy service falls, a rise of income will not lead to more consumption of the service (i.e., depending on the *direction* of income effect) (Binswanger, 2001). In other words, income effects bring forth the question, how consumers respond to their increased income, which is an issue of consumer preference. Two unique situations should be brought up here:
    - *Time versus leisure:* as mentioned above, the time cost is an important factor affecting consumers' choice of energy use. Another situation is when consumers choose leisure instead of consumption, the rebound effect would be significantly reduced (Madlener and Alcott, 2009).
- *Substitution effects*: consumers use the energy services whose price drops due to improved efficiency to substitute for other energy services. The effect describes one of consumers' responses to a lowered cost of using an energy service. Thus it is important to recognize that the alternative services will be substituted only when the substitution is perceived by consumers as available and feasible. The substitutability is often assumed in econometric models (Binswanger, 2001).

Categorization of mechanisms based on the locale where they take place is useful in defining research scope and levels of analysis.

Direct effects: consumers demand for more of the *same* energy services of which energy efficiency is improved. The type of effect can be measured in a single energy service domain. Greening et al (2000) consider income effects and substitution effects as subcategories of direct effects, which is not precise. The classification ignores the fact that consumers can use the income gains in purchasing different energy services depending on their preference and needs. However, two different behavior assumptions they propose are theoretically useful in differentiating different outcomes of the rebound effects:

- *Cost minimizing behaviors* respond to the reduced price of an energy service with the substitution for other goods or services and, in turn, lead to demand for more energy (rebound effects). But this is likely to cause energy savings from the substituted energy service, which aggregates in the macro level as a moderated rebound.

- *Output maximizing behaviors* respond to the reduced price of an energy service with more production and, in turn, contribute to *economic growth* (or an expansion of a market size) and demand for more energy (rebound effects).

The two assumptions are one of a few considerations regarding consumer preference, which demonstrate that different behavioral preferences lead to different rebound outcomes.

Indirect effects: consumers demand for different goods or energy services.

Economy-wide effects describe the aggregation of the rebound effect at macroeconomic level. Reduced costs of energy services (or energy/fuel, as some scholars suggested) (Hertwich, 2005) may lead to price and quantity adjustments throughout the economy or multiple sectors (Sorrell and Dimitropoulos, 2008).

Direct and indirect effects are often measured at microeconomic level (e.g., household, firms, an energy service) while economic-wide effects are measured at macroeconomic level (e.g., nations and world).

Rebound effect in the Chinese context

Since the open and reform in the 1970s, the Chinese government has been acutely aware of the severe energy constraints facing China. Many measures are used to control the energy use. For example, electricity rationing[1] and energy efficiency standards for the household use of energy are implemented. In addition, the Chinese government lists the goal of reducing 20% of the energy consumption per GDP in the eleventh five-year plan (2006-2010). But the household energy consumption (Ouyang et al., 2010) as well as the demand for energy continue to increase. Figure 2 shows the trend of China's rising energy consumption and economic growth (GDP). The increasing demand for energy is commonly attributed to China's rapid economic growth. Only recently, a few scholars have begun to pay attention to the rebound effect in the Chinese context.

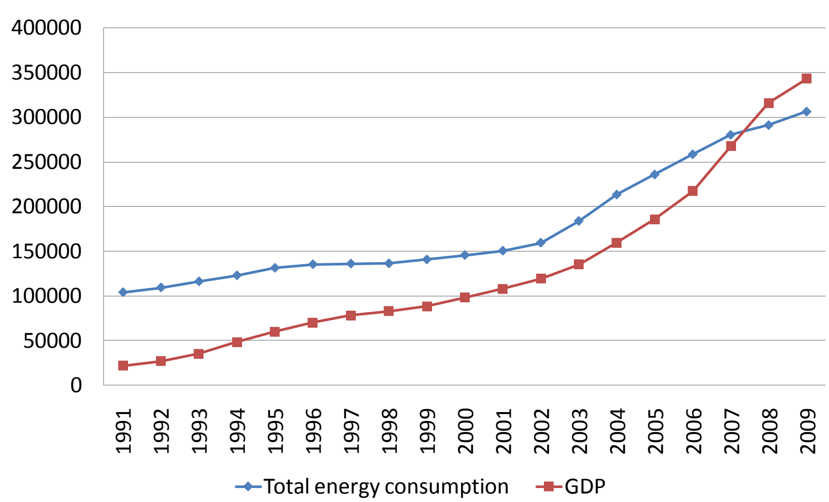

Figure 2 China's total energy consumption and economic growth (1991-2009)

[1] Ministry of Water Conservations and Electricity (1982), "Notice of the State Council on Ratifying and Forwarding Interim Measures for Electricity Rationing."

Chinese literature on rebound effect

All of the six studies published in Chinese journals use econometric models in estimating the rebound effect at macro-level. Table 1 summarizes these studies and results. Generally, these studies confirmed a high level of rebound effects in the context of China and it is decreasing over time. They also show significant regional differences of the rebound effect. The difference between the development of the Chinese studies and Western studies on the rebound effect is threefold.

1. Most Western studies focus on micro-level rebound effects such as household heating or firm lighting, while Chinese literature focuses on macro-level effects (Ouyang et al., 2010). In addition, while most Western studies focus on energy efficiency improvements due to technological progress, the Chinese studies do not differentiate technologically-induced efficiency improvements from improvements resulting from other changes. Instead, they suggest efficiency improvements caused by industrial-structural and institutional changes should be taken into account. The organizational and institutional emphasis can be understood from China's context of reform and development. Since the 1970s, China has re-organized its government agencies, privatized a large number of state-owned enterprises, cultivated numerous private firms and formed allies with many foreign firms. This national-wide, large-scale organizational reform results in salient efficiency improvements. However, the unique history also imposes difficulties to disentangle the rebound effects resulting from technological progress and that from organizational and institutional changes. As a result, these macro-level, Chinese studies are unable to provide clear interpretations of the modeling results and unambiguous policy suggestions.
2. Few of the Chinese studies test price elasticity. This is likely due to the fact that the price of energy and energy services in China is institutionally controlled rather than determined by the market force. In the sector of energy, multiple levels of energy prices are implemented to ensure the basic living conditions of low-income citizens. In particular, the price policy is shifting from central control in a planned economy to dual-track pricing in transition to a market economy.
3. More salient regional differences are observed by the Chinese scholars. In the period of transformation and development, infrastructure for energy production and supply is distributed unevenly on China's immense land. In addition, different pace and policy focus of development have contributed to distinct income disparity. These factors are likely to cause different degrees of rebound effects.

Table 1 Summary of Chinese literature on the rebound effect

Author/year	Data	Method	Rebound effect (%)	Trend
Zhou and Lin (2007)	National wide 1978-2004	Direct measuring Only considering technological effect	30-80 1979-2004:40.91 (1979-1989:78.81) (1979-2001:66.46) (1990-2001:55.13)	descending

Wang and Zhou (2008)	National wide 1981-2004	Direct measuring Including technological effect and structural effect	1981-2004:62.8 (1981-1985:100.9) (1986-1990:75.6) (1991-1995:43.4) (1996-2001:38.7)	descending
Liu and Liu (2008)	Provincial panel 1985-2005	Direct measuring Neoclassical production function	53.68 Significant difference between east, central and west region	descending
Liang et al. (2009)	Social accounting matrix (SAM) base on 2002	CGE	Rebound effect exists, but sectoral specific	
Yang et al. (2010)	Zhejiang Province 1990-2008	Multiple periods model of IPAT function	9 years: backfire effect 2 years: complete rebound effect 5 years: partial rebound effect 2 years: zero rebound effect	fluctuating
Zha and zhou (2010)	SAM based on 2002	CGE	Coal：32.17 Oil：33.06 Electricity：32.28	N/A
Chen (2011)	Hubei Province 1980-2007	Direct measuring	123.7 (1981-1989: 301.6) (1990-1999:56.2) (2000-2007:53.7)	descending

A critique on the existing literature

From the fundamental definition of the rebound effect and its central concepts, it becomes clear that rebound effects encompass both behavioral and systems responses to cost reductions of energy services and technological progress (Hertwich, 2005, Binswanger, 2001). In other words, the preferences and behaviors of energy service consumers are critical factors determining the magnitude and nature of the rebound effect. Since consumer preference and behaviors are deeply shaped by social values, norms, and realities, the rebound effect is not only an economic phenomenon but a social phenomenon.

In addition, while the correlation between energy efficiency improvements and increased energy consumption is confirmed, causal linkages between energy efficiency improvements and consumers' responses to the improvements remain understudied. To address potential causal linkages, three directions in research design might deserve attentions. First, the relations and interactions among multiple variables in the production process of energy services (see Figure 1) should be tested in different research designs. Second, different types of consumers (e.g., governmental agencies, firms, households) tend to have different preferences and behaviors. Thus, comparing the behavior of different consumer types could shed light on the effect of consumer preference and its consequent rebound. Third, a more holistic picture of the ways through which rebound effects affect energy consumption and sustainable development requires an understanding of interaction between main factors operating at macroeconomic and microeconomic level. For example, Chinese scholars argue that while technological improvements lead to rising energy efficiency, national policies (e.g., subsidies, preferential tax, and grand) and industrial structure (e.g., a development favoring energy-intensive industries) have important influences on consumers' behaviors. Some Western scholars propose that individuals' value and needs critically influence their choices; for instance, demand saturation and the value of time and status expressed with energy services matter (Madlener and Alcott, 2009, Greening et al., 2000).

Directions for further study

1. To improve and validate existing econometric models, cross-national comparisons of several relatively well-defined models are useful.
    a. Single service model is insufficient in capture a full range of the rebound effect induced by a technological improvement but it is useful in validate metric in the rebound effect model in cross-national comparisons. In particular, in developing countries where government grant is used as incentives to encourage the use of energy services with improved technologies, consumers do not bear the total cost of energy efficiency improvements.
    b. Both long- and short-term models should be compared. Models using short-term data can better locate key variables and assume others unchanged but long-term models are more likely to capture lagged consumption responses.
        i. Mixed design such as looking at communities experiencing building retrofit for energy efficiency improvement as intervention; then we can use two sets of cross-sectional or longitudinal in comparative analysis.
    c. Data comparability could be an issue. Data availability in China needs a preliminary survey; for instance, is there consumer expenditures survey data in China? How energy consumption is calculated in China? Is the consumption of private firms included?
    d. Income effects can be tested in China's regions with different income levels. Two areas of studies can be considered: household consumption and industrial structure (it is assumed that higher income leads to higher demand for energy-intensive services (Binswanger)).
    e. In the U.S., personal transportation constitutes about 60% of US transportation energy use (Greening et al., 2000); But public transportation remain a dominant transportation mode in China (include or exclude taxi?). Thus other modes of transportation (personal of public) might need examination in the Chinese context.
2. Other important variables should be included into the existing models.
    a. Price elasticity of the supply market; fuel price.
    b. Substitutability among multiple energy services.
    c. Time rebound. For example, testing the following hypotheses: passengers are assumed to prefer faster modes of transportation (measurement: the energy used per passenger km). Therefore, the overall effect of time-saving technological progress will be an increase in energy use (Binswanger).

   d. Capital cost; income saving propensity. For example: modeling long-run behaviors of energy consumption that include periods of low- and high-energy prices as well as capital cost could test price elasticity and the effect of capital costs.

3. More importantly, we need to supplement existing econometric models and place a greater emphasis on the behavior of energy consumers. In econometric models, consumers are assumed to make their energy consumption choices with full information regarding energy prices and savings. A recent survey of 505 participants in the USA shows that they do not (Attari et al., 2010). There is a difference between consumers' perceived energy savings and actual ones. And consumers make choices based on their perceptions. Moreover, how technological induced improvements in energy efficiency are perceived by individuals and translated in their behaviors is a function of social structures, values, and habits. This is why a cross-national comparison of a behavioral model is crucial for us to better capture the underlying mechanisms of the rebound effect and to assign causal linkages among important variables. To do this, insights drawing from fields of consumer behavior, social science, policy making, and industrial ecology are necessary. We propose several directions of research for further discussion and exploration:
   a. In China's context, it is likely to explore a temporary rebound effect coming from reluctant conformity to coercive policies in national economic development plans. This can be observed from the initial adoption of energy-saving practices followed by later abandonment or a low frequency of using energy-saving devices.
   b. Building a behavioral model focusing on production/consumption behaviors of major actors in the production process of a few relatively well-defined energy services enables us to integrate responses to energy efficiency improvements at multiple levels. This actor-centered model includes actors who play different roles and act at different levels (e.g., government, firm, household) in the process and seeks to understand the priority and perceptions behind their energy consumption choices.
      i. We might need to incorporate fundamental factors affecting energy consumers' demand for energy need in the model. Specifically:
         - physical needs (e.g., use energy services for basic living style),
         - psychological needs (e.g., use energy services for luxury living style or status signaling) (Madlener and Alcott, 2009),
         - attitudes toward a energy-saving technologies,
         - saving versus spending propensity (irrelevant to capital costs or bank interest),
         - and satiation.

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