Estimation of rebound effect in China's industrial sector: a multi-subsector analysis

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1. Introduction

The goals of China's energy policy have been: "giving priority to conservation, relying on domestic resources, encouraging diverse development, protecting the environment, promoting scientific and technological innovation, deepening reform, expanding international cooperation, and improving the people's livelihood."(China's Energy Policy 2012) Some more specific measures for the industrial and transport sectors can be summarised in the following five aspects: 1. optimization of the industrial structure, 2. strengthening energy conservation in industry, 3. promoting building energy conservation, 4, pushing forward energy conservation in transportation, 5. promoting energy conservation among all citizens. "The energy utilization efficiency of new projects in the heavy and chemical industries, such as non-ferrous metals, building materials and petrochemicals, is up to the world's advanced level." These policy goals call for a study of energy rebound in China.

In a simplified term, energy rebound effect refers to additional energy consumption due to a reduction in the unit cost of energy usually brought about by an elevated level of energy efficiency. The rebound effect has been studied at the economy level as well as sectors of the economy. A recent study by Shao et al (2014) attempted to measure China's economy-wide rebound effect following the logic that an energy efficiency improvement results in improved productivity (at least that of energy) which should accelerate economic growth which, in turn, calls for an increase in energy consumption. The rebound effect is determined by technological progress rate conditional on energy intensity and economic growth, which suggests that there will not be any rebound effect if there is a lack of technological progress, or the rebound effect is bound to arise regardless of the nature of technological progress.

Saunders (1992) shows that when the real price of energy remains constant energy efficiency gains will lead to an increase in energy consumption in the Cobb-Douglas production function case and also in the nested CES production function case using the Manne and Richels' nesting scheme if the energy elasticity of substitution is greater than unity. Wei (2007, 2010) uses a general equilibrium analysis to demonstrate that an increase in energy production efficiency will lead to an increase in energy consumption. All of these studies present a macroeconomic and theoretical justification for the possible existence of the rebound effect, that is, productivity growth that results in improvement in energy efficiency will lead to higher energy consumption, provided energy prices remain constant.

Those theoretical developments provide a paradigm for empirical studies using aggregated statistics either at a national or sector level. However, the Hogan and Jorgenson (1991) study, while emphasising the importance of technological trend, demonstrates that productivity growth at a sector level can be more thoroughly modelled when disaggregate data are available in the sense that both the direct and indirect effects of technological progress on technical biases can be taken into account.

It is clear that the rebound effect is otherwise completely observable had the technological progress rate been available. Thus, how to measure the rebound effect boils down to how to measure technological progress rate. Like the Shao study, the present paper takes on the productivity and endogeneity arguments coined by Sorrell (2009) for the work in Brookes

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(2000) to measure rebound effect. Unlike Shao et al, the present paper incorporates inter-subsector relationships into the estimation of the industrial sector's productivity.

The paper is organised as the follows. Section 2 provides a literature review on the energy rebound effect. Section 3 provides some descriptive statistics to show a macro-environment where energy rebound is likely to happen in light of Brooke's argument. Section 4 elaborates the modelling framework for estimating sector and subsector productivity growth rates and rebound calculations. Section 5 describes the data and presents empirical results with concluding remarks contain in Section 6.

2 Literature Review

Jevons in1865 put forward a view that energy-efficiency improvements will increase rather than decrease energy consumption. "…But such an improvement of the engine, when effected, will only accelerate anew the consumption of coal. Every branch of manufacture will receive a fresh impulse—hand labour will be still further replaced by mechanical labour, and greatly extended works will be undertaken by aid of the cheap air-power, which were not commercially possible by the use of the costly steam-power" (Jevons,1865, VII.21). This view is known as 'Jevons Paradox', which has spurred a great deal of research in the area whose subject matter is called rebound effect since it would have profound implications for sustainability if it is true. Jevons' idea had been neglected until recently. The two modern pioneers to advance Jevon's position are Khazzoom (1980) who appealed microeconomics reasoning for the existence of rebound effect, and Brookes (1990) who presented a macroeconomic argumentation for it. Saunders (1992) commented that while Khazzoom based his position on consumer responses to price changes and focused on the household electric appliance sector, Brookes provided "a well-articulated qualitative thesis" from a more macroeconomic perspective.

Given the well-established microeconomic theory on consumer and producer behaviours, to attach a microeconomic interpretation to rebound effect seems more natural and straightforward than to provide it with a grounding in macroeconomic theory. The significance of the contribution of Saunders (1992) is a macroeconomic theory for the possibility of rebound effect. Saunders (1992) started from the neoclassical growth theory which provides a convenient vehicle to incorporate production factors and their efficiencies under two scenarios of production technology, namely, Cobb-Douglas and nested Constant Elasticity of Substitution (CES). The final results of the theoretic derivations indicate that under the Cobb-Douglas production technology energy efficiency gains will lead to more energy consumption, that is, a rebound effect. Under the CES production technology, the magnitude of energy elasticity of substitution matters; an elasticity that exceeds unity will result in more energy use, whereas less energy will be used if it is smaller than unity (a narrower Khazzoom statement).

Greening et al (2000) provided a four-part typology of the rebound effect which encompasses both the microeconomic and macroeconomic views of the rebound effect. These four categories of market responses to changes in fuel efficiency are: (1) direct rebound effects, (2) secondary fuel use effects, (3) market clearing price and quantity adjustments (especially in fuel markets) or economy-wide effects, and (4) transformational effects. The direct rebound effects are mainly those occurred at a micro level, such as, a consumer's or a producer's response to changes in energy efficiency. The secondary fuel use effects are basically an income effect resulted from savings on energy expenditure. The economy-wide effect is the result of the aggregation of the direct and secondary effects. The transformational effect refers to changes in technology also have the potential to change consumers' preferences, alter social institutions, and rearrange the organization of production. Clearly, this is not restricted to energy related technology.

Below are a brief review of the rebound effect literature.

Microeconomic evidence for rebound effect

The rebound effect has a convenient microeconomic interpretation as illustrated Figs. 1 and 2 (Berkhout et al, 2000). In the producer's case, the producer uses energy, E_1, and capital, K_1, shown by A, to produce output Y. Suppose that energy becomes cheaper due to energy efficiency improvement, E_2 ($<E_1$) is needed to produce the same level of output. The new energy and capital combination is now shown at B to produce $Y^*(=Y)$. However, the cheaper energy would make the producer move to C for cost minimisation, which essentially is to substitute an amount of (E_3-E_2) energy for an amount of (K_1-K_2) capital, therefore, the rebound effect is given as E_3-E_2.. Depending on the market situation and price elasticity, the cheaper energy could make the producer to increase production output which then calls for more energy and capital; hence a rebound effect of the size E_4-E_3.

The above definition of rebound effect implies that measuring rebound effect amounts to measuring energy users' propensity to consume energy services when there is a change in energy efficiency. Sorrell et al (2009) have produced a survey of empirical studies on measuring direct rebound effect by energy service category, such as, personal automotive transportation, household cooling and heating, clothes washing, lighting. Most of the surveyed articles use econometric methods to estimate either the elasticity of energy service with respect to energy efficiency or a variation of it depending on the aggregation level of data. As Sorrell and Dimitropoulos (2007) pointed out, these different studies use different definitions of the direct rebound effect because of data limitation. Some studies do not mention the rebound effect at all, since their primary focus lies elsewhere. These studies nevertheless provide estimates of price elasticity of energy service demand, which may be used as proxy measures of the direct rebound effect if consumers respond to a price reduction similarly to an energy efficiency improvement.

The most frequently studied context in which rebound effect is evaluated is personal automotive transportation and household heating, with very few studies of other energy services. The majority of studies have been conducted in the United States, with the evidence for direct rebound effects in developing countries being particularly weak. The study of Small and van Dender (2005) is concerned with evaluation of rebound effect in personal automotive transportation in the US using aggregated state level data. The aggregation meant that the measure of energy efficiency of vehicles cannot be that specified by the manufacturer, that is, gallons of gasoline per 100 miles. The authors measured energy efficiency with the ratio of total miles travelled to total amount fuel consumed at the state level. The rebound effect is calculated as the elasticity of energy service with respect to its price, where the energy service is the total vehicle miles travelled per adult and the price is the yearly real price of gasoline divided by energy efficiency. Clearly, there is a departure from the very definition of rebound effect, which is necessary because of the aggregate level of the data. The advantage of using aggregate data, such as the state level, is that one is able to obtain a time series of reasonable long periods for the variables of interest so that it is possible to estimate both short-run and long-run parameters. In fact, energy efficiency improvement normally takes place when new energy efficient equipment is deployed to replace the old one. Thus, it is more appropriate to regard rebound effect as a long-run phenomenon. With econometric time series models the analyst can not only estimate short- and long-run rebound effect but also the effect of other factors on the rebound. As the authors have shown, the short-run rebound effect in US personal automotive transportation over the period 1966-2001 is found to be 4.5% and the long-run 22.2%. Both types of rebound effect are likely to diminish as income rises since a higher income is generally compensating for price increases.

Although the work of Hausman (1979) is not a study to reveal rebound effect in US households that purchase and utilise air conditioners, Hausman estimated the elasticity of energy service with respect to energy efficiency, which can be conveniently interpreted as an estimate of rebound effect. The energy service which is defined as total degree-hours of utilisation per year is generally unobservable. Hausman discussed functional forms for the utility function that allow the total degree-hours to be approximated by kilo watt hours per year which are observable for each household. The model that is relevant to rebound effect studies expresses yearly kilo watt hours as a function of energy efficiency such that its estimates allow construction of the energy efficiency elasticity of total degree-hours. This elasticity is estimated to be 26.5%.

Macroeconomic evidence for rebound effect

At the macroeconomic level, evaluation of the economy-wide rebound effect which represents the sum of direct and indirect effects relies on aggregate production functions or their dual equivalent cost functions. The production/cost function characterises the production technology and typically has three inputs, namely, for the production function, output (Y), capital (K), labour (L) and energy (E), $Y = f(K, L, E)$, where E can be written as energy efficiency, ε, times fuel, F, $E = \varepsilon F$. Rebound effect is then defined as the partial derivative of the output with respective to ε, , i.e., $\partial lnY/\partial ln\varepsilon$.

Saunders (1992) used a three-factor production function, $Y = f(K, L, E)$, to examine what would happen to energy consumption if energy efficiency improves, as a result of an energy-augmenting technical progress (a larger ε), while the real energy price remains unchanged. When the f is Cobb-Douglas, energy consumption will rise when technical progress is energy-augmenting. In fact, the same conclusion holds even if technical progress is either capital- or labour-augmenting or neutral. Thus, Saunders concludes that if one were to accept a Cobb-Douglas production function, then rebound effect will be implied by growth theory. For a more general case, Saunders considered the CES production function with the Manne-Richels nesting, that is, capital and labour are combined in a Cobb-Douglas fashion, which is then combined with energy additively under a CES fashion. The results are the same as the Cobb-Douglas case except for when the energy elasticity of substitution is less than unity. This exception can be dismissed under the conditions that the energy cost share in the economy is very small and the price elasticity of energy is elastic (<-1), a condition based on which Khazzoom drew his conclusions.

Saunders (2000) offered a few key insights extracted from theoretical macroeconomic considerations of the rebound issue. He offered eleven insights that were to be found by thoughtful application of top-down theoretical macroeconomic models of the neoclassical growth theories. The insights were very well elaborated and could provide policy-makers substantial advantages in understanding the issues without any modelling exercise. They also helped researchers furnish testable hypotheses amenable for empirical testing.

Sorrell (2009) made several qualitative statements regarding empirical evidence for the rebound effect presented up to the time of his writing. His general conclusion is that although the evidence presented was not conclusive due to some empirical and theoretical weaknesses, "it does suggest that economy-wide rebound effects are larger than is conventionally assumed and that energy plays a more important role in driving productivity improvements and economic growth than is conventionally assumed". He also pointed out that rebound effect will tend to be higher for energy intensive industries, energy producers, core technologies, and developing countries; with the term core technologies, he referred to "win-win" and/or general purpose technologies. The logic is that core technologies as described are used more extensively in the economy than for example, dedicated technologies, therefore, once they become more energy efficient, many sectors in the economy will experience energy efficiency gains.

Empirical studies in evaluating economy-wide rebound effect are much rarer than those on direct rebound effect. Barker et al (2007) examined the macroeconomic rebound effect for the UK economy in connection to UK's energy efficiency policies and programs for the period 2000-2010. Thus, the evaluation requires the specification of scenarios to reflect the set of UK energy efficiency policies and programmes for the domestic, business, commercial and public, and transport sectors of the economy for the period 2000–2010. The direct rebound effects out of those policies and programs were obtained from the literature and engineering studies. It is not an econometric study but a large-scale macroeconomic modelling simulation evaluation. The final results indicated a 26% macroeconomic rebound effect which is the sum of the direct rebound effects and the economy-wide rebound. Another study on macroeconomic rebound effect is that of Bentzen (2004) that estimated the rebound effect in US manufacturing sector. The rebound effect is estimated as the elasticity of energy demand with respect to cuts in energy price, implying that energy users are assumed to respond to a drop in energy price similarly to an improvement in energy efficiency.

Recently, Shao et al (2014) studied China's economy-wide energy rebound effect over 1954-2010 using the productivity argument and the endogeneity argument implied in Brookes (2000) and explained explicitly in Sorrell (2009). The productivity argument afforded the authors to do away with energy price information and the endogeneity argument allowed them to build productivity in a three-factor decomposition of energy consumption with the three factors being, population, GDP per capita and energy use per unit of GDP. As Sorrell (2009) pointed out, the validity of such a decomposition depends on whether the three factors are independent of one another. Assuming independence, the authors re-expressed the decomposition in a two-factor decomposition, namely, output and energy intensity. Then, the increment in energy consumption from one period to the next is dichotomised into that brought about by productivity growth and that due to other causes. The only unobservable component in their new decomposition is productivity growth which Shao et al modelled using the state space model and is estimated by the Kalman filter algorithm. The use of the Kalman filter algorithm implies that technological progress is autonomous and exogenous. Given the fact that governments around the globe are proactive in energy and environmental policies and technological innovations for better use of fossil fuels and clean energy are strongly influenced by those policies, it is more appropriate to regard technological progress as an endogenous factor in studies of energy efficiency.

The present paper evaluates rebound effect in China's manufacturing sector, taking the approach that Shao et al took by following the productivity arguments. However, instead of estimating the productivity for the whole sector which could be done using a time series approach like Kalman filter, the research explores inter-subsectoral linkages to take into account subsectoral productivity spill over effects. The modelling framework is developed in the light of the work of Long and Plosser (1983). As a result, the subsectoral productivity is not only endogenously determined by subsectoral economic characteristics, but the productivity estimation has an economic structure built in it.

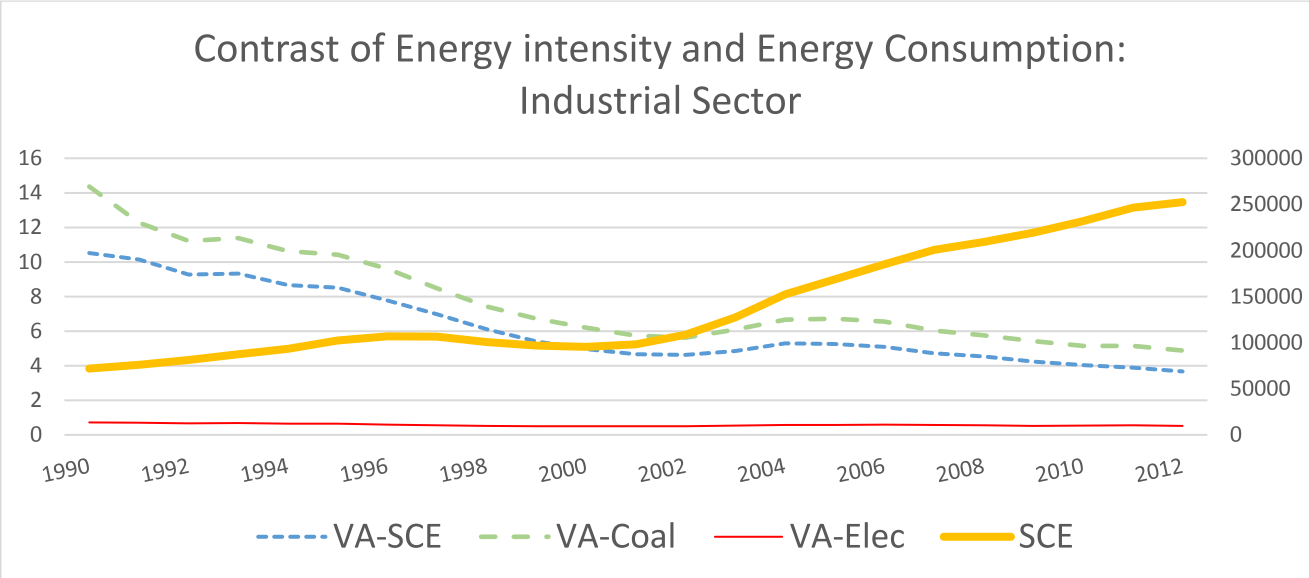
3. An examination of rebound environment in China's industrial sector

Brookes (2000) expresses the view that energy rebound effect is unavoidable when energy intensity is declining while total energy consumption is going up. This is because productivity growth, as evidenced by the decline of energy intensity, results in output growth that causes additional energy demand which outweighs energy saving brought about by energy efficiency improvement. The second is when deliberate action, for example, energy efficiency polices that results in increasing electrification, to raise energy efficiency will necessarily lead to total factor productivity growth (TFP), since a rising TFP generally requires the substitution of energy and machines for labour.

The industrial sector consumes about 70% of total energy consumption and, therefore, is the primary target of government energy conservation initiatives. The general goals of China's energy policy are to give priority to conservation and promoting scientific and technological innovation. For the industrial sector, the policy goals are to optimise the industrial structure and to strengthen energy conservation in the industry.

Policy directions for energy production include reinforcing energy technology R&D, encouragements of advanced and adaptive technologies, for example, high-efficiency and intensive coal mining. Policy directions for energy consumption include promoting energy equipment technology and enforcing technical standards for energy equipment.

Figure 1

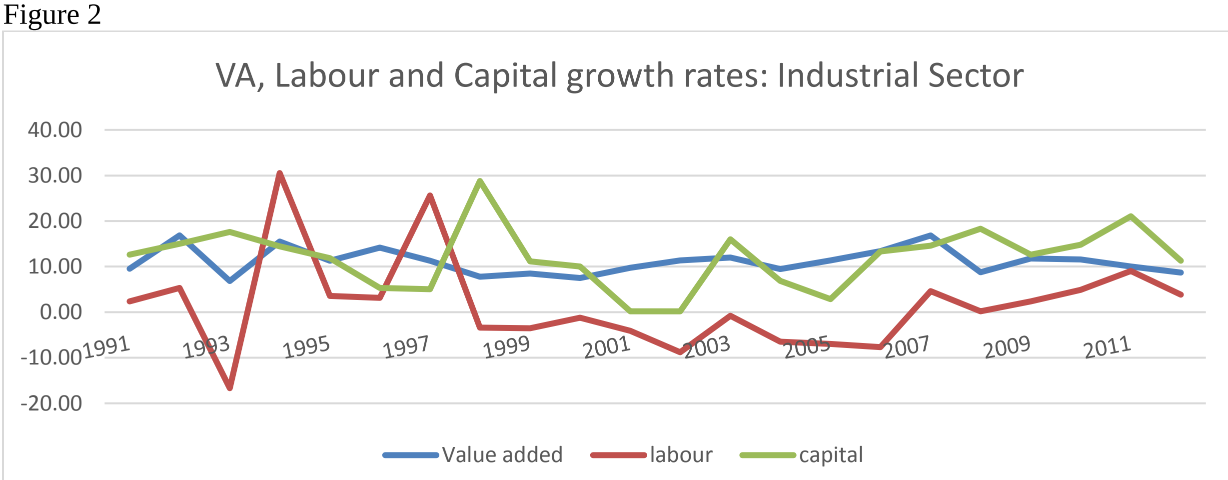


Notes: VA: value-added 100 million RMB in the 1990 prices. SCE: 10,000 (right axis) Ton; Coal: 10,000 Ton; Elec: 100 million kWh

Figure 1 shows the industrial sector's total energy consumption measured by tons of standard coal equivalent (SCE) and three measures of energy intensity, namely, the ratios of value-added (VA) to SCE, VA to coal and VA to electricity. It is evident that the SCE intensity and SCE consumption were moving in the opposite directions, with the former continuously declining and the latter continuously rising. What seems conspicuous is the relatively constant electricity intensity.

A correct measure of capital stock is essential to evaluate total factor productivity growth. Capital stock data for the industrial sector are available, researchers have resorted to own estimations. A well-documented procedure for estimation of capital stock is provided in Holz (2006) that has identified 5 reasons for re-estimating China's economy-wide capital stock. The capital stock data in the present paper are author's own estimation based on Holz's data and China's latest input-output tables starting from 1992 and ending 2012.

Figure 2



The most salient characteristic of Figure 2 is that capital for the industrial sector has since the end of last century persistently outgrown labour, which is in contrast to the preceding period of 10 years or so. The faster growth of capital, coupled with the electrification implied by Figure 1, is an indication of productivity growth.

4. Empirical Modelling

4.1. Modelling Productivity Growth

In view of Hogan and Jorgenson (1991)'s work, the present study estimates the rebound effect for China's industrial sector using disaggregate data for 11 subsectors. The Long and Plosser (1983) model was used to model the production function for subsector *i* in the industrial sector, namely,

$$Y_{i,t+1} = \lambda_{i,t+1} L_{i,t}^{b_i} \prod_j^{11} X_{ijt}^{a_{ij}} \tag{1}$$

where $Y_{i,t+1}$ is the value of output in subsector *i*; the values of inputs, X_{ijt} satisfies $\sum_{i,j} X_{ijt} = Y_t$, the value of total output of the industrial sector; the parameters b_i and a_{ij} are elasticities of output Y with respect to labour and factor j, respectively, and $\{\lambda_t\}$ follows a multiplicative random walk process, i.e., $\lambda_{i,t+1} = \lambda_{i,t} e^{v_{i,t+1}}$, with $v_{i,t+1}$ being a normally distributed random variable with zero mean and constant variance. Under constant returns to scale, they are also cost shares of labour and factor *j* in the total production cost of subsector *i*. Therefore, these parameters correspond to the elements in an input-output.

Although the LP model is intended to study business cycles, it incorporates sector/subsector relations in describing the time paths of their outputs and, therefore, their productivities . The model can be written in an AR(1) form,

$$y_{t+1} = Ay_t + k + \eta_{t+1} \tag{2}$$

where y is an 11 × 1 vector of logs of the Ys and η_{t+1} is productivity shock at t+1. *A* is a 11 × 11 matrix of input-output coefficients. Thus, the total factor productivity growth at time *t+1* is,

$$g_{t+1} = \eta_{t+1} - \eta_t = (y_{t+1} - Ay_t) - (y_t - Ay_{t-1}) \tag{3}$$

Since the *A* matrix is observable in the sense that it is published by the government (albeit five yearly), the convenience of equation (3) is that the total factor productivity growth can be calculated rather than estimated.

4.2 Calculation of rebound effects

Having estimated the productivity shocks over the period 1992-2006, the rebound effects by subsector can be calculated by using the very definition of energy rebound, namely, the difference between the potential saving and the actual saving. The method proposed by Shao et al (2014) is to compute the difference as a fraction of a counter factual additional energy consumption due to growth of output.

More specifically, denote the growth of real output and energy intensity at period *t+1* as ΔY_{t+1} and ξ_{t+1}, then the counter factual additional energy consumption purely due to output growth will be, $\Delta Y_{t+1} \xi_t$. When there is technical progress that leads to productivity growth at the rate g_{t+1}, the resulting output growth is deemed to be $g_{t+1} \Delta Y_{t+1}$, and hence the additional energy consumption due to technical progress is:

$$\Delta E_{g,t+1} = g_{t+1} \Delta Y_{t+1} \xi_t. \tag{4}$$

$\Delta E_{g,t+1}$ will be considered the shortfall of potential energy saving resulting that is brought about by improvement in energy efficiency, and, hence, is deemed to be the magnitude of energy rebound for period *t+1* if $\Delta\xi_{t+1} < 0$. An interpretation of (4) when $\Delta\xi_{t+1} > 0$ is that it is the additional energy consumption resulting from productivity growth that failed to lift energy efficiency or energy productivity. To express the rebound in percentage we have,

$RE_{t+1} = (100\ \Delta E_{g,t+1}\ /\ Y_{t+1} * |\Delta\xi_{t+1}|)\%$ (5)

4.3 Composition effects on rebound

Equations (4) and (5) are applicable for aggregated data (in our case, data for the whole of industrial sector). When disaggregate data are available, which is the case for the present study, sub-sector composition effects on rebound can also be analysed in the sense of equations (4) and (5). Denote by g^a_{t+1} productivity growth rate calculated from aggregated data, then equation (4) for the aggregated data set $g^a_{t+1} * \Delta Y_{t+1}\ \xi_t$ which can be written as

$$\Delta E^a_{g,t+1} = (g^a_{t+1}, \dots, g^a_{t+1})\ (\Delta Y_{1,t+1}, \dots, \Delta Y_{N,t+1})'\xi_t \quad (6)$$

where $\Delta Y_{t+1} = \Delta Y_{1,t+1} + \cdots + \Delta Y_{N,t+1}$

Equation (6) is then comparable to equation (4) for the disaggregate data which is as follows,

$$\Delta E^d_{g,t+1} = (g^d_{1,t+1}, \dots, g^d_{N,t+1})\ (\Delta Y_{1,t+1}, \dots, \Delta Y_{N,t+1})'\xi_t \quad (7)$$

The difference between equation (6) and equation (7) is in the first bracket. Equation (7) recognises the differentials in total factor productivity growth between subsectors while equation (6) does not. Thus, a comparison of equation (6) and equation (7) allows for evaluation of the composition effect on the rebound. More specifically, denote the average of the subsector productivity growth rate by $g^{\bar{d}}_{t+1}$, then the composition effect is measured by

$$\Delta E^a_{g,t+1} - \Delta E^{\bar{d}}_{g,t+1} \quad (8)$$

where $\Delta E^{\bar{d}}_{g,t+1}$ is equal to the right hand side of equation (7) with $g^d_{i,t+1}$ replaced by $g^{\bar{d}}_{t+1}$.

5. Data and rebound estimates

5.1 Data

This study disaggregates China's industrial sector into 13 subsectors whose shares of the total energy consumption and the total output are summarised in Table 1 for the period 1990-2006. The subsectors collectively have accounted for about 70 of the total energy consumption measured in standard coal equivalent (SCE) for each of the years over the period. Their collective output share ranged from 50 per cent to 80 per cent the total output of the economy over the period. The data sources for the present study were provided by All China Market Research (2007) and two departments of China's National Bureau of Statistics, namely, Departments of Comprehensive Statistics (1999) and National Accounts (2007).

Table 1
Shares of total energy consumption and total output by subsectors: 1990-2006[a] (per cent)

Subsector	Energy			Output		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1. Energy Production	11.2	19.7	15.7	5.3	11.5	6.9

2. Mining	1.1	1.8	1.4	0.5	0.9	0.8
3. Food and Tobacco	1.9	3.5	2.9	3.6	6.1	5.5
4. Textile	2.3	3.6	3.0	3.8	7.6	6.3
5. Timber, Paper and Printing	1.9	2.4	2.1	1.8	2.8	2.3
6. Chemical Industrial Products	12.2	17.0	13.4	5.4	8.3	6.9
7. Non-metallic Mineral Products	7.2	11.8	9.6	2.2	5.2	3.8
8. Metal Products	14.8	21.9	16.6	5.8	20.4	10.2
9. Machinery	0.8	3.0	1.5	1.7	4.9	3.0
10. Transportation equipment	0.9	1.2	1.1	1.8	4.9	3.0
11. Electronics and Instruments	0.8	1.3	1.1	1.5	7.3	3.3
12. Other manufacturing	0.5	1.2	1.0	0.3	0.8	0.4
13. Construction	1.0	2.0	1.0	0.3	0.9	0.6

a: Energy consumption is measured in standard coal equivalent (10,000tons). Total output is measured as the gross value of output in the 1990 prices (1,000 RMB).

5.2. Rebound estimates

In addition to the energy consumption and output data, the present study uses 4 recent input-output tables that correspond to 1992, 1997, 2002 and 2007. Those input-output tables provide the A matrix described in the previous section. Since the A matrix is time invariant according to the LP model, the analysis is conducted for each of four tables which demonstrate the sector and subsector configurations over the 20 year period. Figures 3-6 presents energy rebound percentages under the 4 different configurations and contrasts the results from using disaggregate data to those from using aggregate data. It is clear that rebound estimates vary significantly when the level of aggregation changes; the estimates based on disaggregate data have taken subsector relationships into account and therefore should be regarded as more accurate than the estimates on the aggregate data.

Figure 3 Rebound effect: 1992 configuration

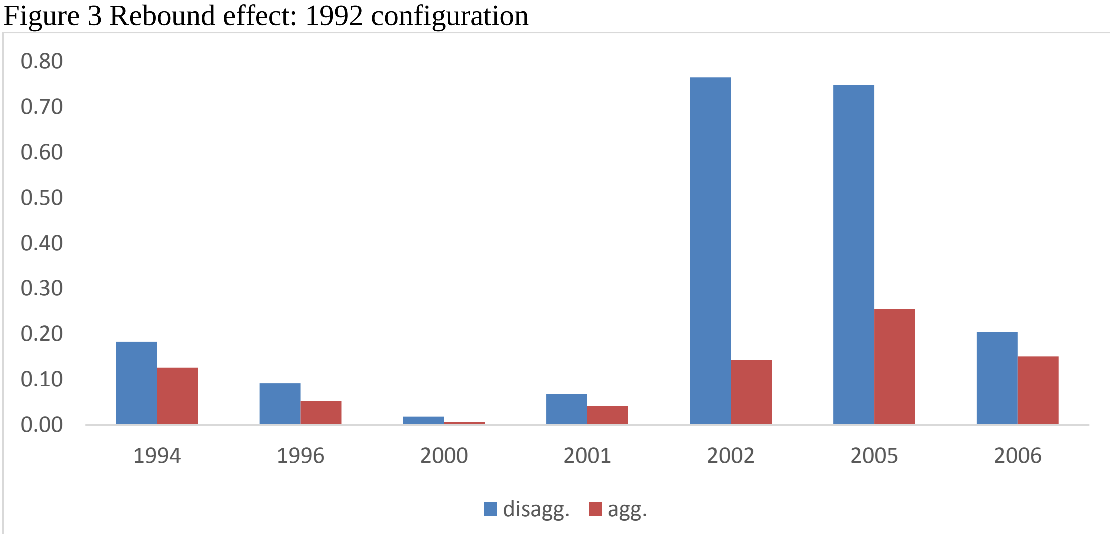


Figure 4 Rebound effect: 1997 configuration

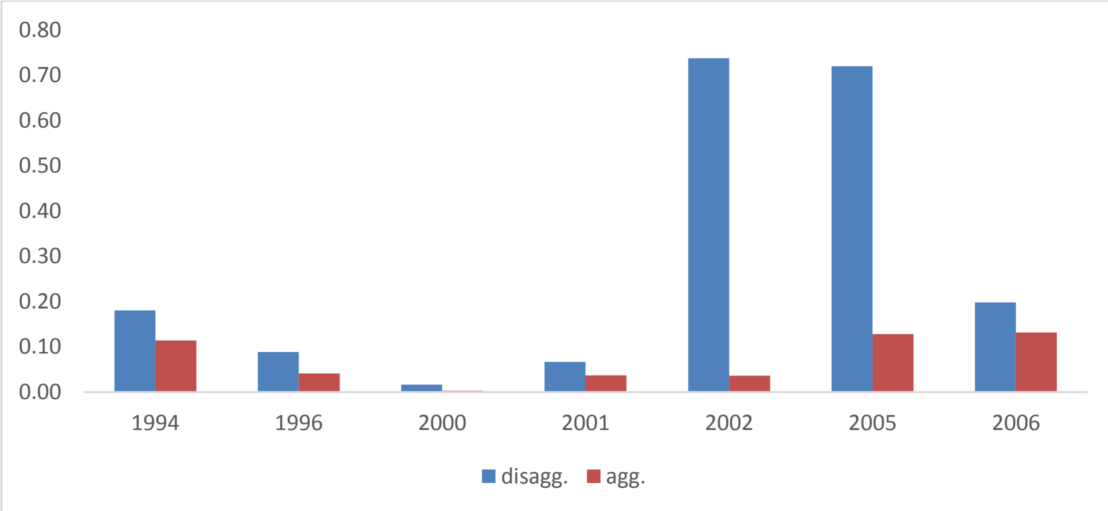


Figure 5 Rebound effect: 2002 configuration

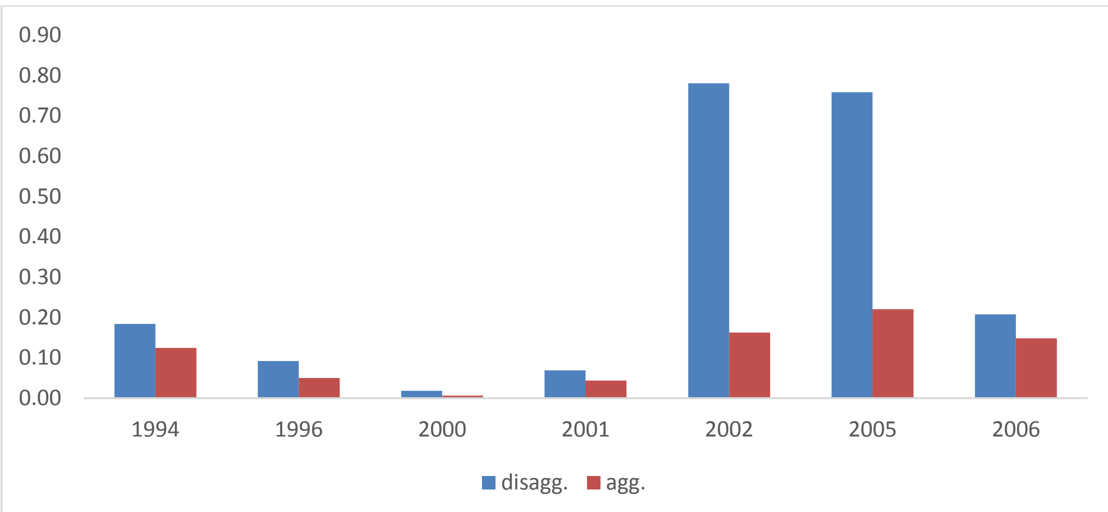


Figure 6 Rebound effect: 2007 configuration

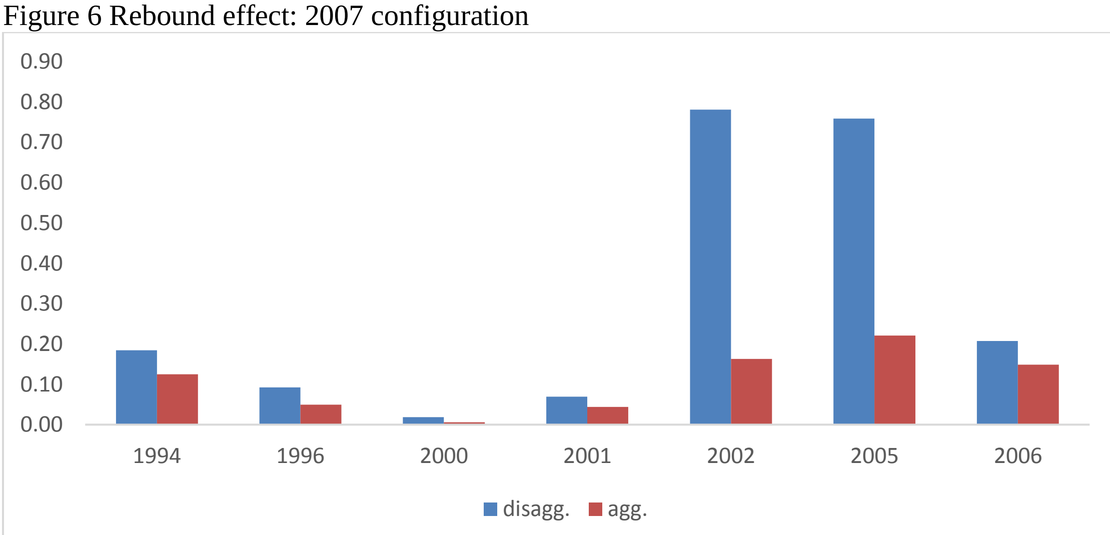


Figure 7. Rebound effect: 1992 configuration controlling for composition effects

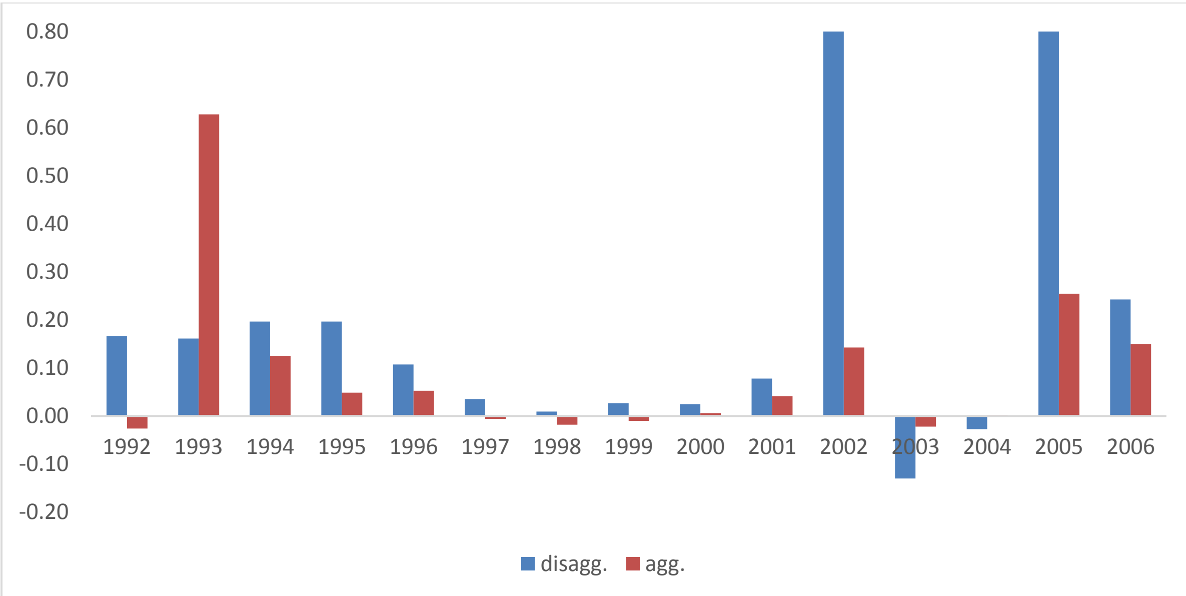


Figure 8. Rebound effect: 1997 configuration controlling for composition effects

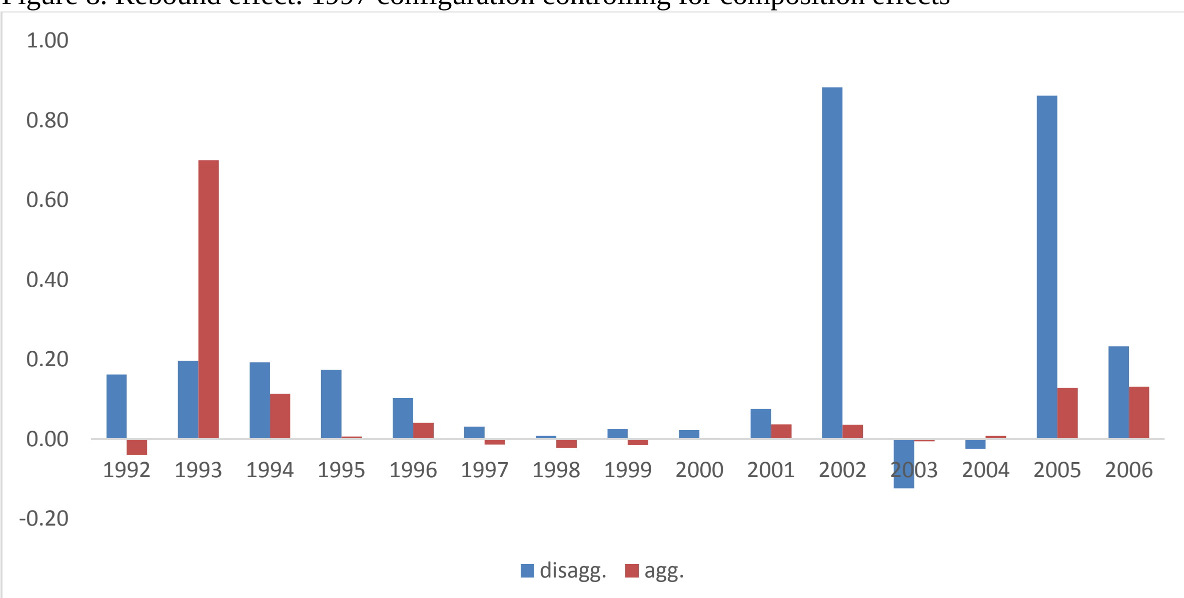


Figure 9. Rebound effect: 2002 configuration controlling for composition effects

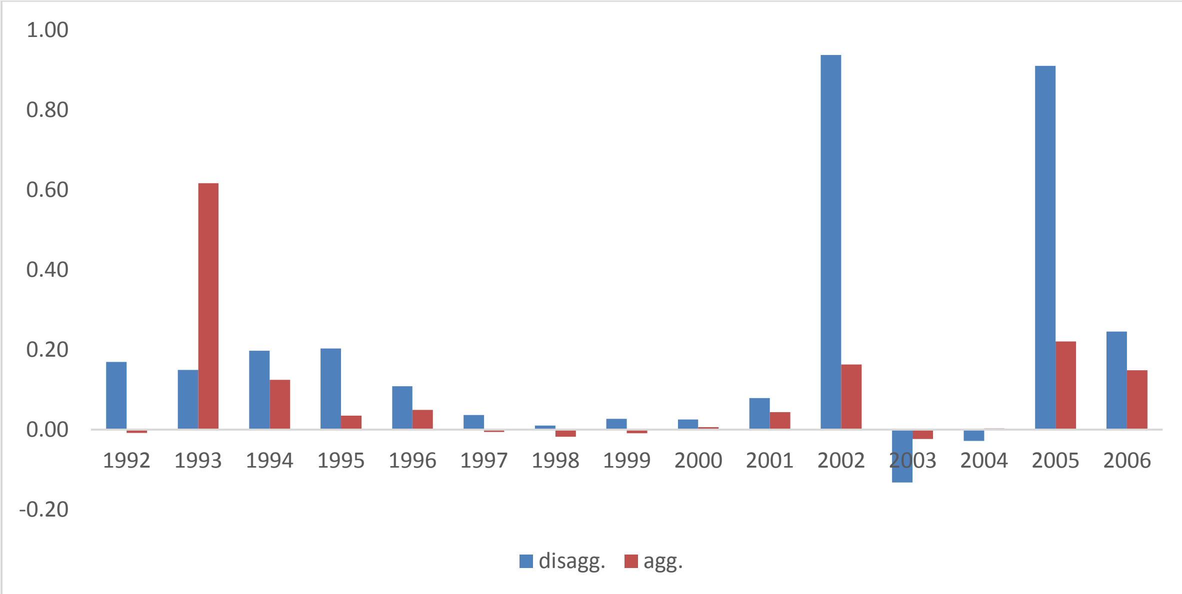
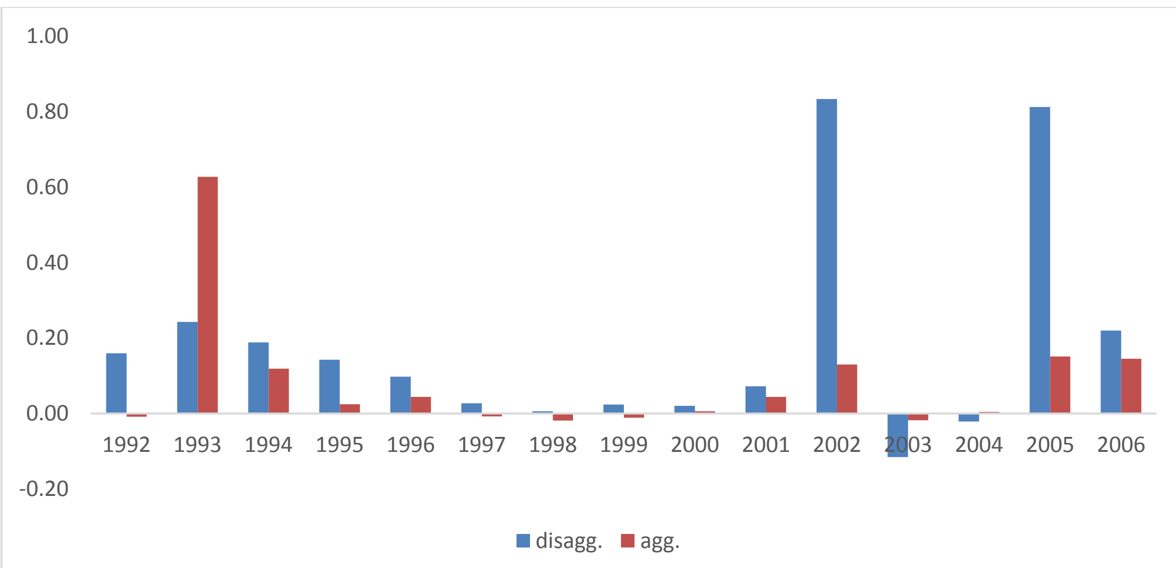


Figure 10. Rebound effect: 2007 configuration controlling for composition effects



The rebound estimates based on the disaggregate data may be subject to compositional effects which could compound the role of inter-subsector relationships in the estimation of rebound effects. As outline in the previous section, the compositional effects can be controlled for so that one can find the pure effects of inter-subsector relationships on energy rebound effects. Figures 7-10 show that the evidence shown on Figures 3-7 is almost unaltered, with the exception in 1993.

In summary, the rebound effect in China's industrial sector is evident, particularly during the early period of the present century with a magnitude of as high as 80%. The role of inter-subsector relationships cannot be ignored in increasing the rebound effects. Since a backfire is not the case, there is no alarm that existing energy efficiency programs and industry polices should be halted.

6. Conclusions

The goals of China's energy policy have been: "giving priority to conservation, relying on domestic resources, encouraging diverse development, protecting the environment, promoting scientific and technological innovation, deepening reform, expanding international cooperation, and improving the people's livelihood."(China's Energy Policy 2012). These policy goals foster an economic environment that lends itself to the Khazzoom-Brookes postulate coined by Saunders (1992). Similar to existing studies on the rebound effect, the present research saught to model the relationship between productivity growth and energy consumption, with the data for China's industrial sector for period 1992-2006. However, the present study recognised the advantage of disaggregated data in modelling productivity trends as illustrated by Hogan and Jorgenson (1991). The empirical results as summarised by the four graphs show that the rebound effect existed in China's industrial sector over the study period, with the maximum magnitude of 12 percent when only the aggregated data were used; this figure rose to nearly 80 percent when the disaggregated data were used.

Dupor (1999) investigated the difference between a single sector model and a multi-subsector model in terms of whether subsector specific productivity shocks amplify sector productivity shocks. Although he concluded that inter-sector linkages as characterised by the input-use matrix play no role in such a context. However, Horvath (1998) showed that Dupor's conclusion is valid only if the rows in the input-use matrix are full when the data are becoming more and more disaggregated, which is not true in our case. Therefore, to estimate and compare rebound results for both aggregated and disaggregated cases can be justified based on Horvath's results.

Because the subsector relationships were only captured 4 times in the form of an input-output table during the 25-year period, the rebound effect was calculated each year for 4 times, each corresponding to a different input-output table, using the LP model as a vehicle to compute productivity trends. It is clear that different subsector relationships, other things held constant, will lead to different magnitudes of rebound estimates and occurrences of the rebound effect. A policy implication for China's energy policy makers is that the country energy's policy need be designed together with relevant industry policy aiming at adjusting inter-industry/sector relationships.

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