Analysis on the Rebound Effect of Cold Chain Logistics Energy

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Abstract. Cold chain logistics is a low temperature supply chain system that combines the refrigeration industry and logistics. Refrigerated transportation, cold storage, cold chain connection points and other auxiliary activities will cause a certain amount of energy consumption, and related technologies, management, equipment and facilities, Cold storage layout, etc. are all factors that affect energy consumption. Based on this research background, the research on the energy rebound effect of cold chain logistics is based on three aspects: definition, mechanism and empirical test. Based on the endogenous economic growth model, labour-enhancing technological progress and material cold chain logistics are introduced. Based on the assumption of long-term changes in capital, by constructing an invariable substitution elastic function, a theoretical model of the energy rebound effect of cold chain logistics is established, and the calculation formula for the energy rebound effect of cold chain logistics in the long and short term is obtained.

Keywords: Cold chain logistics, energy consumption, rebound effect.

1. Introduction
In recent years, the development of a low-carbon economy has become a consensus. With the rapid development of food cold chain logistics in my country, the energy consumption and environmental issues brought about by it have become the focus of attention. Building a resource-saving and environment-friendly society is my country's current development strategy. The scarcity of resources, environmental pollution and the lag of new energy technologies require all industries to actively seek measures to reduce energy consumption. As a combination of high-energy-consuming industrial logistics and refrigeration, cold chain logistics has more practical significance in the study of its energy consumption [1, 2]. At present, there are few research results on the utilization of cold chain energy. Some scholars analysed the energy consumption status of my country's logistics industry and proposed energy-saving countermeasures. Some scholars analysed the energy consumption and environmental pollution of refrigerated transportation, and put forward suggestions on the application of energy saving and emission reduction in refrigerated transportation in my country. Some scholars have put forward measures and methods for energy saving in cold storage by studying the power consumption of refrigeration systems in the cold storage industry. Some scholars have evaluated and analysed the energy consumption of the existing urban transportation system and the planned urban transportation system plan. These studies mainly focus on macro-industry fields such as transportation energy consumption,
road system energy consumption, and logistics industry energy consumption. Some focus on local energy-saving issues such as refrigerated trucks and agricultural cold storage. At present, my country's energy conservation level is steadily improving, the proportion of clean energy is increasing, and my country's energy consumption structure is gradually adjusted. A reasonable consumption structure enables energy to be used effectively to the greatest extent, promotes the upgrading of industrial structure, and thus contributes to sustained and stable economic growth. Have a positive impact. Since the introduction of the concept of rebound effect allows us to realize that there is a complex relationship between energy efficiency and total energy consumption, we have proved that my country does have a rebound effect, in order to better describe energy efficiency. After analysing the factors affecting the rebound effect, the model is established and the data obtained is used to obtain the specific value of the rebound effect, and the impact of the rebound effect on the process of reducing energy consumption by improving energy use efficiency is further analysed.

2. Estimation method of energy rebound effect

2.1. Rebound effect

Saunders, Wei and Terry defined the energy saving caused by the improvement of energy use efficiency as the elasticity of energy use efficiency. They expressed the rebound effect (R) as follows:

$$ R = 1 + \eta^F_{\tau^F} $$

Among them $\eta^F_{\tau^F} = d \ln F / d \ln \tau^F$. The model indicates that if energy use efficiency increases by 1 unit, energy use will increase by $R$ units. If $R=0$, and no rebound effect; if $0<R<1$, there is a rebound effect; and when $R>1$, it is a reverse rebound effect or a reverse effect [2]. According to (1) the rebound effect can be decomposed as follows:

$$ \eta^F_{\tau^F} = \frac{\tau}{F} \frac{\partial F}{\partial \tau} = \frac{\tau}{(F/Y)} \frac{\partial (F/Y)}{\partial \tau} + \frac{\tau}{Y} \frac{\partial Y}{\partial \tau} $$

The first part of the right end of the formula is the energy intensity effect. At this time, if the energy utilization rate is increased, the energy consumption per unit product can be reduced, that is, the energy intensity can be reduced. With the progress of energy-saving technology and the improvement of energy utilization rate, the output level of unit energy consumption will be increased. Therefore, the energy intensity effect at this time is negative, and the energy output efficiency is bound to be positive. Based on our deepened energy conservation conditions, under normal circumstances, the energy intensity effect is negative and its absolute value should be greater than the output effect [3]. This indicates that the improvement of energy efficiency will mainly be reflected in the reduction of energy consumption per unit of output, and the promotion of unit output level is relatively small.

2.2. Short-term rebound effect

In the short term, assuming that the amount of cold chain logistics capital is fixed and only the amount of energy used can change, the short-term rebound effect based on the theory of endogenous economic growth is:

$$ R_{short} = 1 + \eta^F_{\tau} = \frac{1 - (\gamma + 1)\rho}{1 - (\gamma + 1)\rho - s^F (1 - \rho)} $$

Elasticity of output to energy use: $s^F = \frac{FY}{Y^2F}$. In the long run, cold chain logistics capital supply (K) and energy consumption (F) can be freely changed. Therefore, according to the definition of rebound effect, the equation for long-term rebound effect can be obtained as:

$$ R_{long} = 1 + \eta^F_{\tau} = \frac{1}{1 - (1 - \rho)s^K} + \frac{(1 - \rho) \rho (1 + \gamma) s^F s^K}{[1 - (1 - \rho)s^K] \{\beta s^F + [1 - (\gamma + 1)\rho]s^K \}} $$
3. Estimation of the rebound effect of cold chain logistics energy

3.1. Setting of variables and selection of samples

3.1.1. Output data (Y). This article uses the cold-chain logistics economy at constant prices as the basic indicator to measure economic growth, converted at constant prices in 1952, in units of 100 million yuan [4].

3.1.2. Cold chain cold chain logistics capital investment data (K). Gold-smith pioneered the perpetual inventory method in 1952. The calculation method of the cold chain logistics capital stock in this article draws on this method. The formula is as follows:

\[ K_t = (1 - \phi_t)K_{t-1} + I_t \]  

Among them: \( K_t \) is the cold chain logistics capital stock of the current period, \( K_{t-1} \) is the cold chain logistics capital stock of the previous period, \( \Phi_t \) is the depreciation rate, and \( I_t \) is the investment amount of the current year. This article uses the number of employees in my country at the end of each year as the labour input data, and the unit is 10,000. This article selects the total energy consumption over the years as energy consumption data. The specific values are shown in Table 1 below:

| Years | Cold chain logistics economy (100 million yuan) \( Y \) | Fixed cold chain logistics capital stock (100 million yuan) \( K \) | Labour (10,000 people) \( L \) | Energy (10,000 tons of standard coal) \( F \) |
|-------|---------------------------------|---------------------------------|----------------|---------------------------------|
| 2007  | 84668.98                        | 74195                           | 72085          | 145531                          |
| 2008  | 93405.77                        | 81413.15                       | 73025          | 150406                          |
| 2009  | 101658.5                        | 120755.6                       | 73740          | 159431                          |
| 2010  | 112151.1                        | 168979.7                       | 74432          | 183792                          |
| 2011  | 130937.9                        | 225703.7                       | 75200          | 213456                          |
| 2012  | 149242.7                        | 295217.8                       | 75825          | 235997                          |
| 2013  | 170463.9                        | 379094.7                       | 76400          | 258676                          |
| 2014  | 205123.4                        | 478659                         | 76990          | 280508                          |
| 2015  | 224815.3                        | 591697.3                       | 77480          | 291448                          |
| 2016  | 245498.3                        | 744409.2                       | 77995          | 306647                          |
| 2017  | 271030.1                        | 925257.4                       | 76105          | 324939                          |
| 2018  | 296235.9                        | 1108021                        | 76420          | 348002                          |
| 2019  | 319046.1                        | 1314753                        | 76704          | 361732                          |

3.2. Model setting

3.2.1. Model assumptions. Taking into account the clarity and simplicity of the analysis and ensuring the validity of the model, the model established in this article is mainly based on Sauders' analysis of eight types of production and cost functions and made specific assumptions and made simple modifications [5].

Hypothesis 1: Economic output depends on the input of three elements: energy, labour, and cold chain logistics capital; Hypothesis 2: There is no energy production sector in the economy (energy supply is exogenous from the economy); Hypothesis 3: Technology endogenous, economy The improvement of technology level is manifested in two aspects: one is labour-enhanced technology, and the other is energy-enhanced technology; Hypothesis 4: The cold chain logistics capital price is fixed, and the labour supply rate is the same and fixed as the population growth rate; Five: Energy supply is exogenous, and energy prices are fixed; Hypothesis Six: Each market is a perfectly competitive market.
3.2.2. Production function. (K) Cold chain logistics capital, (L) labour, (E) energy are the three elements necessary for product production. The production function adopts a fixed replacement elastic production function (CES production function), as shown below:

\[ Y = \left[ a[K^\alpha (AL)^{1-\alpha}]^\rho + b(E)^\rho \right]^{1/\rho} \]  \hspace{1cm} (6)

Among them: Y is output, A is technology, E is the amount of energy service provided, \( \rho = \frac{\sigma - 1}{\sigma} \), \( \sigma \) are the amount of energy service provided (E) and the replacement elasticity of the combination of cold chain logistics capital labour \((K^\alpha (AL)^{1-\alpha})\). The relationship between energy consumption (F) and energy service provision (E) is, \( E = \tau F \); thus, formula (1) is rewritten as:

\[ Y = \left[ a[K^\alpha (AL)^{1-\alpha}]^\rho + b(\tau F)^\rho \right]^{1/\rho} \]  \hspace{1cm} (7)

In the classical economic growth model, technology is regarded as an endogenous variable, because the most important source of technological change is learned from observation and practice. According to the endogenous growth model of technology, the formula is as follows:

\[ A = BK^\phi \]  \hspace{1cm} (8)

At the same time, it is assumed in this article that the accumulation level of cold chain logistics capital in society and the amount of energy used determine the improvement of energy use efficiency. The formula is as follows:

\[ \tau = CK^\beta F^\gamma \]  \hspace{1cm} (9)

Based on the labour-enhanced technology, energy-enhanced technology, and the setting of the production function, this article derives the production function as:

\[ Y = \left[ \left( a[BK^{\alpha + \phi(1-\alpha)}L^{1-\alpha}] + b(CK^\beta F^{\gamma + 1}) \right)^\rho \right]^{1/\rho} \]  \hspace{1cm} (10)

The first-order condition for the output of equation (9) on energy consumption is as follows:

\[ Y = \left[ \frac{P_F}{c(\gamma + 1)} b^{-\rho} (CK^\beta)^{-\rho} \right]^{\frac{1}{1-\rho}} F \left( 1 + \rho \right) \]  \hspace{1cm} (11)

Logarithmically transform it:

\[ \log\left( \frac{Y_t}{Y_{t-1}} \right) = -\rho \beta \log\left( \frac{K_t}{K_{t-1}} \right) + \frac{1 - (\gamma + 1)\rho}{1 - \rho} \log\left( \frac{F_t}{F_{t-1}} \right) + C \]  \hspace{1cm} (12)

Formula (11) is the estimation equation of this article

3.3. Model estimation and result analysis

This article uses the maximum likelihood estimation method, mainly by estimating the formula (3), determining some parameters, and then calculating the rebound effect, and obtaining the result. The Eviews 6.0 software is used in the calculation process [6]. Eviews can quickly find out from the data Calculate the relationship and use the obtained relationship to predict the future value of the data. (1)

First use Eviews6.0 software to perform ADF test on the three variables \( \log\left( \frac{Y_t}{Y_{t-1}} \right), \log\left( \frac{K_t}{K_{t-1}} \right), \log\left( \frac{F_t}{F_{t-1}} \right) \) and all variables reject the hypothesis of unit roots at the 5% significance level, as shown in Table 2. The parameter estimation results are shown in Table 3.
Table 2. ADF test of each variable

| Variable       | Model testing form (CPT) | T test value |
|----------------|--------------------------|--------------|
| \( \frac{Y_i}{Y_{i-1}} \) | COO                      | -2.98*       |
| \( \frac{K_i}{K_{i-1}} \) | COO                      | -2.97*       |
| \( \frac{F_i}{F_{i-1}} \) | COO                      | -2.63*       |

Table 3. Parameter estimation results

| Coefficient       | Estimated value | Standard deviation | T statistics |
|-------------------|-----------------|--------------------|--------------|
| \( \frac{\gamma}{1-\rho} \) | -0.51148        | 0.137687           | -3.71479     |
| \( \frac{1-(\gamma+1)\rho}{1-\rho} \) | 1.154382        | 0.3711683          | 3.105824     |
| C                 | 0.067376        | 0.009205           | 7.319152     |

From the estimation results, the short-term and long-term rebound effects can be simplified as follows:

\[
\rho_{\text{short}} = \frac{1-(\gamma+1)\rho}{1-(\gamma+1)\rho - s_x(1-\rho)} \left( 1 + 1.96 s_x \right)
\]

\[
R_{\text{long}} = \frac{1}{1-(1-\rho)s_x} \left[ \frac{(1-\rho)\rho(1+\gamma)s_x^2}{1-(1-\rho)s_x} \right]\left[ \frac{1}{0.067s_x + 0.51s_k} \right]
\]

Output energy elasticity, output cold chain logistics capital elasticity and short-term rebound effect can be calculated, as shown in Table 4.

Table 4. 2012-2020 short-term rebound effect value

| Years | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Short-term Rebound effect | 33.07 | 28.43 | 26.43 | 19.03 | 17.94 | 23.09 | 23.37 | 28.44 | 21.31 |

Since the value of \( \rho \) cannot be directly estimated, the long-term rebound effect values under different values of \( \rho \) given in this article are shown in Table 5:

Table 5. Long-term rebound effect values under different \( \rho \) values

| \( \rho \) / time period | 2000-2004 | 2005-2009 | 2010-2014 | 2015-2019 |
|--------------------------|-----------|-----------|-----------|-----------|
| -100                     | 2.216     | 4.974     | 1.855     | 2.629     |
| -10                      | 2.354     | 6.289     | 2.348     | 3.486     |
| -0.9                     | 3.312     | 26.467    | 46.797    | -30.067   |
| -0.7                     | 3.486     | 35.919    | -54.412   | -15.737   |
| -0.3                     | 4.077     | 251.198   | -8.418    | -7.186    |
| -0.1                     | 4.637     | -95.222   | -5.45     | -5.341    |
| 0.1                      | 5.672     | -36.752   | -3.818    | -4.085    |
| 0.3                      | 8.233     | -21.414   | -2.785    | -3.173    |
| 0.5                      | 25.184    | -14.342   | -2.073    | -2.482    |
| 0.7                      | -10.502   | -10.273   | -1.552    | -1.94     |
| 0.9                      | -2.776    | -7.628    | -1.154    | -1.504    |
| 10                       | 2.026     | 3.442     | 1.342     | 1.799     |
| 100                      | 2.183     | 4.689     | 1.755     | 2.463     |
For the above calculation results, the following explanation is required. First, the main difference between the short-term rebound effect and the long-term rebound effect is that the short-term rebound effect does not consider the impact of cold chain logistics capital changes on the energy rebound effect, while the long-term rebound effect considers the cold chain logistics capital changes. Therefore, this paper calculates the short-term rebound effect and the long-term rebound effect in different time periods for comparison. Secondly, since this article does not directly estimate the value of $\rho$, this article gives the long-term rebound effect value of different $\rho$ values and different time periods, as shown in Figure 1.

![Figure 1. Long-term rebound effect under different $\rho$ values](image)

4. Conclusion
Theoretical research shows that the short-term energy rebound effect is related to the elasticity of output to energy consumption, the substitution parameters of energy consumption and cold chain logistics capital labour union, and the elasticity of energy utilization efficiency to energy consumption $\rho$; The elasticity of energy consumption and material cold chain logistics capital stock, the substitution parameters of energy consumption and cold chain logistics capital labour union, the elasticity of energy utilization efficiency to energy consumption $\rho$, and the energy utilization efficiency to cold chain logistics capital flexibility is related.

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