Using Laspeyres decomposition method to evaluate the factors affecting freight transport energy consumption in China

Tian-Xiang Lv¹, Xu Wu²*
¹Beijing Jiaotong University, No.3 Shangyuancun Haidian District, Beijing, China.
²Beijing Jiaotong University, No.3 Shangyuancun Haidian District, Beijing, China.
Email: wuxu@bjtu.edu.cn

Abstract. As an energy-intensive and high-emission industry, transportation accounts for a large proportion of total energy consumption. Moreover, the energy consumption in freight transport has increased rapidly. ASIF identity was used to obtain the factors affecting energy consumption in freight transport. In this study, we use laspeyres decomposition method to obtain the impact and contribution rate of each variable. The results show that transport turnover is the most significant driving factor. Transport structure also has a positive effect while transport intensity is on the opposite. The government should further optimize the organization and efficiency of freight transport activities. From the perspective of each transport mode, railway transport has the greatest contribution to reduce freight energy consumption while road transport is the most significant driving factor. The government should further increase the proportion of railway transport. There exists positive relationship between the energy intensity and its impact on freight energy consumption in each mode. The impact of the energy intensity in road transport is the most significant.

1. Introduction
As an energy-intensive and high-emission industry, the transport sector has become the largest and fastest growing oil consuming sector due to active transport activities[1]. The National Bureau of Statistics data indicate that China’s passenger volume turnover has an average annual growth of 20.7% and the cargo volume turnover has more than tripled from 1995 to 2015.

With the rapid development of transportation, the absolute amount of energy consumption in freight transport increases obviously. According to the International Energy Agency (IEA), by 2035, the energy consumption of the world's transportation sector will increase by 43% and China will account for more than one-third of the energy consumption[2].

As estimated by DRC[3], energy consumption in freight transport has increased from 79 megaton of coal equivalent (mtce) in 2005 to 142 mtce in 2010, with an annual growth rate of 12%. The rapid increase of energy consumption in freight transport will result in serious energy security problems and environmental pressures in China. Energy outlook 2018 released by BP shows that oil import dependence will rise from 63% in 2016 to 72% in 2040. Gas dependence will rise from 34% to 43% in 2040[4]. Identifying the mechanism of the influence of each factor is the primary procedure in policy formulation. Therefore, it is very important to investigate the driving factors of energy consumption in freight transport.

Decomposition analysis is one of the most effective and widely applied tools for investigating the mechanisms influencing energy consumption[5] which consists of the index composition analysis (IDA) and structural decomposition analysis (SDA). Both analyses use the multiplication principle (Kaya
identity etc.) to obtain the various influencing factors\cite{6}. Wood\cite{7} used SDA to analyze the influencing factors of greenhouse gas emissions in Australia. The structural decomposition method is a quantitative economic model based on an input-output table and requires a large and complex dataset. Therefore, the IDA method is used preferentially. Achour et al.\cite{8} used the logarithmic mean divisia index (LMDI) decomposition method to decompose transport energy consumption in Tunisia into five factors: transport intensity, transport structure, per capita gross domestic product (GDP), and population. Mark et al.\cite{9} used Laspeyres Index decomposition method (LI) to analyze the influencing factors of Irish passenger transportation energy consumption. The results showed that transport activity measured by passenger-km was the main driver of the increase in fuel use, although intensity also contributed significantly.

The main advantage of the Laspeyres index method is the use of the familiar concept of percentage changes facilitating comprehension and exploitation of results in comparative assessments\cite{10}. Therefore we use this method to decompose the factors accounting for energy consumption in freight transport.

2. Decomposition model

2.1. Indicator selection

The starting point of this decomposition is the activity, modal share, energy intensity, carbon intensity (ASIF) equation, developed to understand and decompose components that multiply to yield a given output or input\cite{11}. It is the energy consumption not CO₂ emissions that is analyzed in this paper. Therefore the item ‘F’ which is the carbon emission coefficient of different energies is taken away. Therefore the model to explain energy consumption in freight transport is obtained.

\[
E' = \sum_k A' \times S_k' \times I_k'
\]  

Where \(E\) represents total freight transport energy consumption. \(A\) represents total freight transport turnover which is measured by tonne-km, \(S_k\) indicates transport structure which is the share of the \(k\)th transport mode with regard to the freight transport turnover, \(I_k\) indicates freight energy intensity which is measured by the energy consumption in unit freight transport turnover of the \(k\)th transport mode. \(k\) indicates specific transport mode including railway, road, waterway, aviation and pipeline. The subscript \(t\) represents the year.

Therefore the change of transport energy consumption in time \(t\) comparing with the consumption in the base year \(t=0\) can be calculated as follows:

\[
\Delta E = E' - E^0 = \sum_k A' \times S_k' \times I_k' - \sum_k A^0 \times S_k^0 \times I_k^0
\]

2.2. The value of the impacts

The Laspeyres index method follows the Laspeyres price and quantity indices in economics by isolating the impact of a variable through letting that specific variable change while holding the other variables at their respective base year values\cite{12}.

Moreover, the combined impacts of two or more variables on transport energy consumption are equally distributed to each variable. Thus, Equation (2) is transformed into the sum of separate and combined impacts shown in Equation (3).

\[
\Delta E = \Delta E_d + \Delta E_a + \Delta E_i
\]

According to the “jointly created and equally distributed” principle\cite{13}, the above three impacts can be calculated as follows:

\[
\Delta E_d = \sum_k \Delta A \times S_k^0 \times I_k^0 + \frac{1}{2} \sum_k \Delta A \times S_k' \times I_k^0 + \frac{1}{2} \sum_k \Delta A \times S_k^0 \times \Delta I_k + \frac{1}{3} \sum_k \Delta A \times \Delta S_k \times \Delta I_k
\]
$\Delta E_s = \sum_k \Delta E_{sk} = \sum_k \left( A_s^n \times \Delta S_k^n \times I_k^n + \frac{1}{2} A_s^o \times \Delta S_k^o \times I_k^o + \frac{1}{2} A_s^\odot \times \Delta S_k^\odot \times I_k^\odot + \frac{1}{3} A_s^\odot \times \Delta S_k^\odot \times I_k^\odot \right)$ (5)

$\Delta E_I = \sum_k \Delta E_{Ik} = \sum_k \left( A_I^n \times S_k^n \times I_k^0 + \frac{1}{2} A_I^o \times S_k^o \times I_k^0 + \frac{1}{2} A_I^\odot \times S_k^\odot \times I_k^0 + \frac{1}{3} A_I^\odot \times S_k^\odot \times I_k^0 \right)$ (6)

### 2.3. Contribution rate of each variable

The impact of each variable on the energy consumption in freight transport may be positive or negative which contributes to the appearance that the ratio of the specific impact to the total impacts may overtake 1. It is not conducive to identify the key factors affecting energy consumption. Therefore, this study replaces the sum of the original values with the sum of absolute values to obtain the contribution rate of each variable.

$$P_A = \frac{\Delta E_A}{|\Delta E_A| + |\Delta E_I| + |\Delta E_I|} \times 100\%$$ (7)

$$P_S = \frac{\Delta E_S}{|\Delta E_A| + |\Delta E_I| + |\Delta E_I|} \times 100\%$$ (8)

$$P_I = \frac{\Delta E_I}{|\Delta E_A| + |\Delta E_I| + |\Delta E_I|} \times 100\%$$ (9)

### 3. Results and discussion

#### 3.1. Cumulative contribution of each factor

The freight transport turnover, transport structure and energy consumption of each mode can be obtained or calculated from the China Statistical Yearbook and China Energy Statistics Yearbook. Freight energy intensity of each mode is calculated using the method of Kaya[14]. The ocean transport is removed from water transport because the energy consumption of this part is not caused by domestic transportation activities.

The cumulative contribution rate is obtained as the base year is 1995 and the current year is 2015. As shown in Figure 1, the rate of energy intensity of freight transport in 1995-2015 is negative while the rates of freight transport turnover and transport structure are positive. The results showed that the energy intensity of freight transportation inhibits the increase of energy consumption in freight transport while the transportation turnover and transportation structure have positive effects on the increase of energy consumption. The cumulative contribution rate of freight transport turnover is the largest, and its contribution rate on energy consumption is 65.84%, while the cumulative contribution rate of transportation structure and energy intensity is 11.88% and -22.28% respectively.

![Figure 1. Cumulative contribution rate of each factor](image-url)
3.2. The annual contribution of each factor

As shown in Figure 2, the annual contribution of freight transport turnover is mostly positive and the contribution rate is high, which indicates that the increase of freight transport turnover has a great contribution to the increase of the energy consumption in freight transport. The government should further optimize the organization and efficiency of freight transport activities and reduce unnecessary energy consumption.

The transport structure has an inhibitory effect on the energy consumption in the period 2001-2005 because the proportion of railway transport has increased. After 2005, the proportion of railway transport decreased significantly. Moreover the freight transportation turnover of road transport has increased significantly and exceeded that of railway transport in 2014. As shown in Figure 3 and Figure 4, railway transport has the greatest contribution to reduce freight energy consumption while road transport is the most important driving factor of energy consumption in freight transport. Compared with railway transport, road transport is a high-consumption transportation mode\textsuperscript{15}. As the increase of its proportion, it will inevitably lead to an increase in transport energy consumption further. Therefore, the change of transportation structure has positively promoted the energy consumption in freight transport.

The annual contribution rate of energy intensity is continuously negative while its value has declined. Moreover, the effect of changes in energy intensity on energy consumption has decreased. As shown in figure 5 and figure 6, the freight transport intensity of each mode has declined which causes inhibitory effect on the freight transport energy consumption. The effect of road transport is
particularly obvious, indicating that reducing the energy intensity of road transportation is an effective method to reduce energy consumption. The government can further reduce the energy intensity of road transport to save energy and reduce emissions.

![Figure 5. The proportion of the annual impacts of transport intensity in each transport mode.](image)

![Figure 6. The energy intensity of each transport mode. (kgce/one hundred tons of km)](image)

4. Conclusions
In this paper, we identified the impacts of three factors on the energy consumption in freight transport using Laspeyres index decomposition method. From the perspective of cumulative impact, transport turnover is the most significant driving factor. Transport structure also has a positive effect while transport intensity is on the opposite. The government should further optimize the organization and efficiency of freight transport activities. From the perspective of each transport mode, railway transport has the greatest contribution to reduce freight energy consumption while road transport is the most significant driving factor. The government should further increase the proportion of railway transport. In addition, there exists positive relationship between the energy intensity and its impact on freight energy consumption in each mode. The impact of the energy intensity in road transport is the most significant. The government should further reduce the energy intensity of road transport.

Acknowledgments
This study was supported by the National Natural Science Foundation of China (61503022).

References
[1] Xu, B., Lin, B.Q. (2015) Carbon dioxide emissions reduction in China's transport sector: A dynamic VAR (vector autoregression) approach. Energy, 83:486-495.
[2] Zhou G., Chung W. (2013) Zhang X. A study of carbon dioxide emissions performance of China's transport sector. Energy, 50, 1:302-314.
[3] Development Research Center. (2013) Research on China's Medium and Long Term Energy Development Strategy. China Development Press, Beijing.
[4] BP, (2018) Country insight – China. https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/country-and-regional-insights/china-insights.html.
[5] Diakoulaki D., Mandaraka M. (2007) Decomposition analysis for assessing the progress in decoupling industrial growth from CO2 emissions in the EU manufacturing sector. Energy Economics, 29, 4:636-664.
[6] Nie H., Kemp R., Vivanco D.F. (2016) Structural decomposition analysis of energy-related CO2 emissions in China from 1997 to 2010. Energy Efficiency, 9, 6:1-17.
[7] Wood R. (2009) Structural decomposition analysis of Australia's greenhouse gas emissions. Energy Policy, 37, 11:4943-4948.

[8] Achour H., Belloumi M. (2016) Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method. Transport Policy, 52:64-71.

[9] Jennings M., ó Gallachóir, Brian P., Schipper L. (2013) Irish passenger transport: Data refinements, international comparisons, and decomposition analysis. Energy Policy, 56:151-164.

[10] Ang, B.W. (2004) Decomposition analysis for policymaking in energy: which is the preferred method. Energy Policy, 32, 9:1131–1139.

[11] Schipper, L., Marie, C., Gorham, R. (2000) Flexing the Link between Urban Transport and CO₂ Emissions. http://www.iea.org/textbase/nppdf/free/2000/flex2000.pdf.

[12] Ang B. W., Zhang F. Q. (2000) A survey of index decomposition analysis in energy and environmental studies. Energy, 25,12:1149-1176.

[13] Shenggang R., Zhen H. (2012) Effects of decoupling of carbon dioxide emission by Chinese nonferrous metals industry. Energy Policy, 43, 2:407-414.

[14] Kaya Y. (1990) Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. Paris: Response Strategies Working Group, Paris.

[15] Chen, F., Zhu, D., Kun, X. (2009) Research on Urban Low-carbon Traffic Model,Current Situation and Strategy: An Empirical Analysis of Shanghai. Urban Planning Forum, 22, 6:39-46.