Decoupling effects among energy use, economic growth and CO_2 emission from the transportation sector

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Abstract

The energy consumption and CO_2 emission from the transportation sector has played an important role in Taiwan. Currently the CO_2 released from Taiwan is 245 Mt, accounting for 1% of world emissions and ranking Taiwan as 22nd in the world. Although Taiwan is neither a member of the UNFCCC nor a non-Annex I country, the government has held two national energy conferences to establish priorities of sectors and measures to upgrade the energy efficiency and to reduce CO_2 emissions from major sectors. This study aims to assess the linkage and decoupling effects among energy use, economic driving force and CO_2 emissions from the transportation sector in order to better understand the development trends among transportation energy demand, GDP and CO_2 emissions. We use the decoupling indicator to examine the relative growth rate of environmental pressure (CO_2 emission) and economic driving force (GDP) from 1990 to 2004. Comparisons are also made with Japan and South Korea. Results indicate that the growth of transportation energy consumption in Japan was at a higher rate than its economic productivity during 1985-1995; however, there was a strong decoupling effect between 2000 and 2003. In South Korea, there was a strong demand in fuel consumption which yielded a higher growing rate than its economic growth. In Taiwan, the variation of energy use and economic productivity had similar patterns like South Korea; the index showed an expansive coupling effect during 1990-1995 and a weak decoupling after 1995. Comparing the growth rate of traffic CO_2 emission with respect to GDP, Japan increased steadily from 1990 to 1999 and then decreased for less CO_2 intensity. The linkage effect of CO_2 and GDP in Taiwan and South Korea demonstrated weak decoupling in the late 1990s and expansive coupling during 2000-2003.

Keywords: energy use, CO_2 emission, economic growth, decoupling effect, transportation sector, Taiwan, Japan, South Korea.

WIT Transactions on Ecology and the Environment, Vol 105, © 2007 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/ESUS070231

1 Introduction

The transportation system has played an important role in upgrading national economy as well as serving public mobility in Taiwan. Also, it causes enormous energy consumption and serious environmental problems. From 1981- 2004, the energy consumption of the transportation sector in Taiwan increased from 16.5% to 22.7%. In 2004, the energy consumption and CO_2 emission of the transportation sector were 15.7 million tonnes of oil equivalent and 42.5 million metric tons, accounting for 22.7% of total final energy consumption and 17.5% of CO_2 emission in Taiwan.

The CO_2 released from Taiwan during the past 10 years increased substantially, ranking Taiwan as 22nd (1% of world emissions). Although Taiwan is neither a member of the UNFCCC nor a non-Annex I country, the government of Taiwan has held 2 national energy conferences in order to respond to the Kyoto Protocol. This study aims to analyze the energy consumption and CO_2 emissions of the transportation sector in Taiwan. Furthermore, the decoupling effects of transport activity, such as GDP elasticity of transport energy demand and GDP elasticity of transport CO_2 emission, are examined to check the development patterns among transportation energy demand, GDP and CO_2 emissions in Japan and South Korea.

A number of studies have attempted to explore the relationship between GDP, transport energy consumption and CO_2 emission. For example, Dreher et al. [1] used neural networks to obtain the elasticity curve of energy-service demand with respect to current price level and the direction of price change in passenger traffic sector. They found that the influence of energy price on the passenger traffic volume was minimal. Stead [2] proposed several indicators of transport intensity and investigated the energy efficiency and economic performance of the transportation system from 1970-1995 in European Member States. He found that the performance of transport intensity in different EU countries had different paths. Mielnik and Goldemberg [3] analyzed the decoupling between energy and GDP in developing countries and found that energy intensity decreased steadily from the reformation of technology and the adjustment in economic structure. Gu et al. [4] established an environmental stress indicator to analyze the aggregate environmental pressure on the domestic environments of six countries (China, Germany, the Netherlands, Austria, Japan and the United States). From this study, they found an apparent decoupling effect in five industrial countries, except for China. Tapio [5] examined the difference between decoupling, coupling and negative decoupling and analyzed the growth pattern of GDP elasticity and transport elasticity in 15 EU countries between 1970 and 2001.

2 Methodology

According to a 2002 OECD report [6], the term “decoupling” means breaking the connection between environmental pressure and economic performance. In other words, the decoupling indicator analyzes the relative growth rate of environmental factors and economic driving forces over a given period. Generally, decoupling index can be further divided into "relative decoupling" and "absolute decoupling" when economic productivity is increasing. Relative decoupling represents the case in which the growth rate of an environmental variable is positive and lower than economic productivity. On the other hand, absolute decoupling signifies a negative growth of environmental pressure (Tapio [5]). In this study, we adopted the concept of decoupling indicator from Tapio to analyze the relative variance between environmental factors and economic driving force. The calculation of the transport elasticity coefficient is calculated as the percentage change in environmental pressure divided by the percentage change in economic driving force in a given time period. That is, Economic performance elasticity of environmental pressure

$$= \%\triangle\text{environmental pressure}/\ \%\triangle\text{economic driving force}$$
$$= \frac{\left(EP_{t1} - EP_{t0}\right)/\left(EP_{t1} + EP_{t0}\right)}{\left(EDF_{t1} - EDF_{t0}\right)/\left(EDF_{t1} + EDF_{t0}\right)} \tag{1}$$

where EP is the environmental pressure, EDF is economic driving force and t_0 is the base year.

Because the percentage change between two variables may indicate coupling, decoupling or negative decoupling, Tapio [5] divided the decoupling indicator into eight categories according to its elasticity value.

Coupling index occurs for elasticity values between 0.8 and 1.2. The further classification of coupling index is expansive coupling and recessive coupling. Expansive coupling typifies the case in which the growth rates of environmental pressure and economic driving force are positive, while the reverse situation suggests recessive coupling. Decoupling index can be classified into weak decoupling, strong decoupling and recessive decoupling. Weak decoupling occurs when the relative growth rate is positive and the elasticity coefficient lies between 0.0 and 0.8. Strong decoupling infers a decreasing effect of environment capacity and increasing effect of economic development. Thus, the elasticity value of strong decoupling is negative (elasticity < 0). Regarding the negative growth rate of variables over a given period, it leads to recessive decoupling and an elasticity value of greater than 1.2. Furthermore, negative decoupling includes three categories, which are expansive negative decoupling, strong negative decoupling and weak negative decoupling. Under the situation of expansive negative decoupling, the variation of environmental stress is higher than economic performance and the variables both increase (elasticity > 1.2). Economic recession and the reduction of environmental stress represent the index of weak negative decoupling (0 < elasticity < 0.8). Similarly, strong negative decoupling not only suggests the deterioration of environmental issues but also implies the decrease of economic productivity (elasticity < 0) [5].

3 Data

The gross domestic product, transport energy consumption and CO_2 emission for each country was taken from the IEA (2006). GDP is measured in purchasing power parties. The fuel consumption of the transport sector in Taiwan was acquired from "Energy Balances in Taiwan, Republic of China, 2004" [7]. The transport CO_2 emission was calculated based on the IPCC guidelines principle (IPCC/OECD, 1996) and was adjusted to the fuel inventory in Taiwan, including fuel density, carbon content of motor gasoline, diesel and fuel oil. Emissions from electricity were calculated from power generation and then redistributed to each sector according to the amount of electricity consumed by each transport mode.

4 Results and discussion

4.1 Transportation energy consumption compared to Japan and South Korea

In Japan, the energy requirement by the transportation system was higher than Taiwan and South Korea and continued to increase with a growth rate of 1.60% per year (Figure 1). By the end of 2003, the transportation activity in Japan consumed 93.2 Mtoe. The growth rate of transport energy demand in South Korea grew extraordinarily. In 2003, the transport energy consumption was 34.1 Mtoe, which was 2.3 times the energy use in 1990 and continued to increase at a rate of 6.57% per year. Similar to South Korea, people in Taiwan have many requirements in transport activity and its service in recent years because of the rapid growth of economy and the improvement of the living standard. As a result, the amount of energy demand grew markedly over 14 years and reached 13.9 Mtoe in 2003, with an annual growth rate of 4.85%.

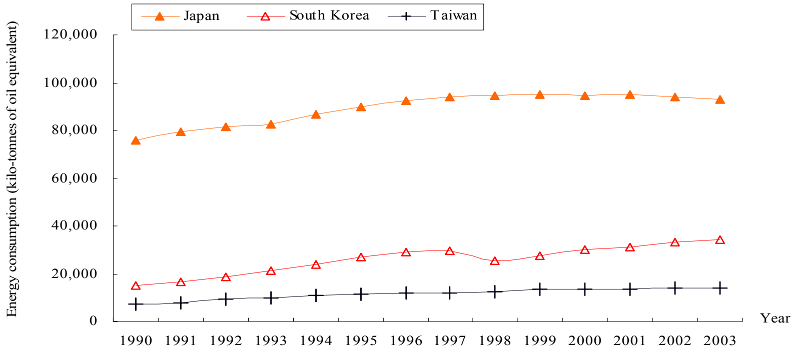

Figure 1: Transport energy consumption of various countries.

The variation of transportation energy consumption per unit GDP indicates the energy performance of the transportation system. The energy intensity of South Korea's transportation sector in 2003 was 38.8 kilo-tonnes of oil equivalent (ktoe) per billion 2000 US dollars, which was higher than Japan and Taiwan by 0.41 and 0.28 times (Figure 2). The measure of transportation energy efficiency in Taiwan indicated an improvement by 5.1% through 1990 to 2003.

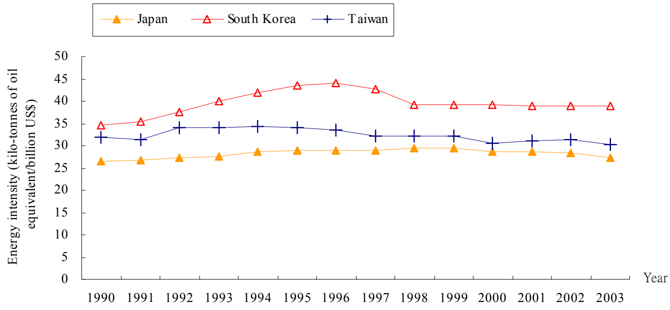

Figure 2: Energy intensity of various countries.

On the other hand, South Korea and Japan experienced deteriorations in energy intensity. That is, the transportation energy efficiency in South Korea and Japan in 2003 was worse than that of in 1990 by 12.5% and 3.6%, respectively.

4.2 Transportation CO_2 intensity among countries

CO_2 emission per unit GDP (CO_2 intensity) for individual countries was analyzed from 1990 to 2003 (Figure 3). The load of environmental capacity from transport activity in South Korea and Japan were heavier than its benefit; thus, the growth pattern of CO_2 intensity followed a steadily increasing pattern. In Taiwan, the CO_2 intensity reached a maximum in 1992 and then decreased gradually by 40.0% in eleven years because of the increased effect of CO_2 being lower than aggregate production. Regarding the variation of emission coefficient, South Korea had more CO_2 emission per unit of energy consumption, followed by Japan and Taiwan. In Taiwan, the encouragement of LPG vehicles usage in the transport sector reflected the decreasing effect on emission coefficient by 4.0% from 1990 to 2003.

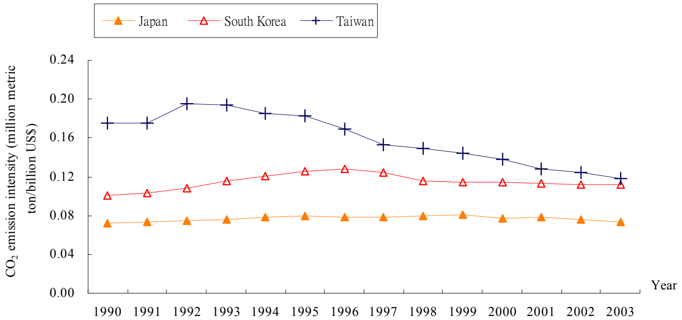

Figure 3: CO_2 emission intensity of various countries.

4.3 Variables of decoupling and linkage effects

In general, the growth of GDP and population has a close relationship with the variation of transportation activity. Thus, economic driving forces such as GDP and population were chosen as the variables in this study to identify the relationship between environmental pressure and economic performance by statistical analysis. The regression equations were estimated as Eq. (2) and (3):

$$\underset{}{CO_2} = \underset{(4.37)}{0.050GDP} + \underset{(2.35)}{0.0022Population} - \underset{(-2.34)}{38.2978} \qquad (2)$$

$$Energy = \underset{(6.28)}{0.0280GDP} + \underset{(1.04)}{0.0004Population} - \underset{(-1.08)}{6.7874} \qquad (3)$$

The results of regression indicated that economic driving force-GDP had a significant influence on transport energy consumption and CO_2 emission. Hence, we chose GDP as the economic performance variable to analyze the linkage effects between economic growth vs. transport energy demand and economic growth vs. CO_2 emission.

4.3.1 Effects between energy consumption and gross domestic product

The growth patterns of transport energy consumption and economic benefit in Japan demonstrated a weak decoupling between 1980 and 1985, followed by expansive coupling during 1985-1990, expansive negative decoupling in the early 1990s, expansive coupling again in the late 1990s and a strong decoupling effect between 2000 and 2003, for a negative growth rate in energy consumption and a positive effect on economic growth. In South Korea, the substantial increase in fuel consumption caused expansive negative decoupling during 1985-1995 (elasticity values of 1.62 and 1.62). The slight difference between energy variables and economic effects revealed weak decoupling and expansive coupling in the late 1990s and the early 2000s. The decoupling indicator of transport system in Taiwan showed expansive coupling for the periods 1980-1985 and 1990-1995 (elasticity of 0.80 and 1.18, respectively). The expansive negative decoupling effect during 1985-1990 was an important warning for the government of Taiwan to reduce the environmental pressures from the great demand of transportation activity.

4.3.2 Effects between CO_2 emission and gross domestic product

In Japan, there was a weak decoupling in the early 1980s and the late 1990s with the elasticity values of 0.09 and 0.66. Besides, the elasticity of the transportation CO_2 emission with respect to productivity indicated expansive coupling (elasticity of 1.15) for the period 1985-1990 and expansive negative decoupling (elasticity of 2.19) in the early 1990s. From 2000 to 2003, the indicator showed strong decoupling (elasticity of -1.01) for the improvement in CO_2 emission mitigation and the increasing effect in economic benefits. In South Korea, the indicators depicted a weak decoupling with GDP for the periods 1980-1985 and 1995-2000. The elasticity values of 1.75 and 1.61 inferred an enormous emission

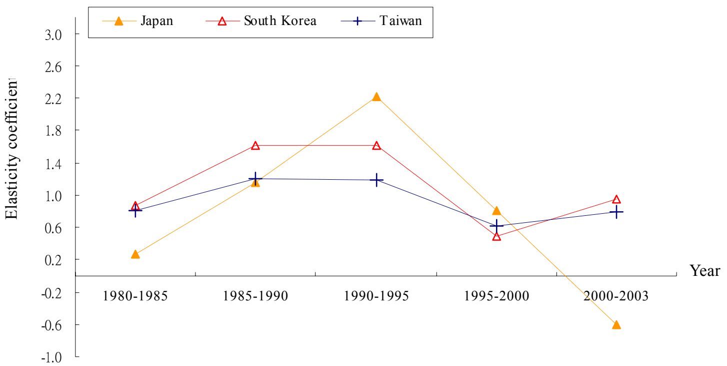

Figure 4: GDP elasticity of transport energy demand.

increase and resulted in an expansive negative decoupling during 1985-1995. The emission growth rate of the transport sector in Taiwan was positive and lower than the aggregate production through 1980 to 1990 (an expansive coupling). In the 1990s, the percentage change between CO_2 and economic productivity resulted in expansive coupling and weak decoupling. In the early 2000s, an expansive coupling was still observed in Taiwan with an elasticity coefficient of 1.10 since the increased effects of CO_2 was larger than GDP.

4.3.3 Coupling effects of road transport in Taiwan

Because road transportation is the primary transport mode for most of people, we further analyzed the coupling indicators of the road transport. By the end of 2004, the number of registered motor vehicles in Taiwan was up to 19.2 million vehicles and the total road length was 38 thousand kilometers. Accompanying the expansion of road infrastructure and the constant growth of motor vehicles in the 1980s, the indicator experienced expansive coupling and expansive negative decoupling, respectively. In the 1990s, the fuel consumption and CO_2 emission both expressed expansive coupling and weak decoupling with the variation of GDP growth. Expansive negative coupling happened again because the number of registered motor vehicles increased during 2000-2003.

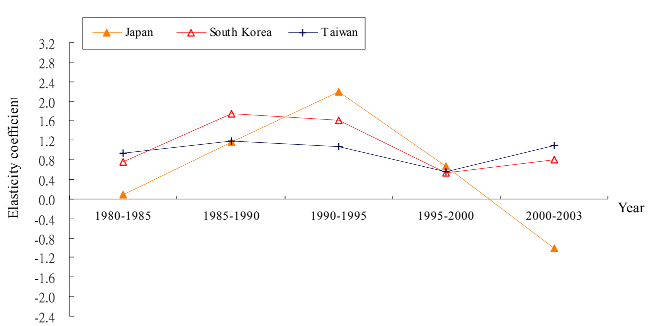

Figure 5: GDP elasticity of transport CO_2 emission.

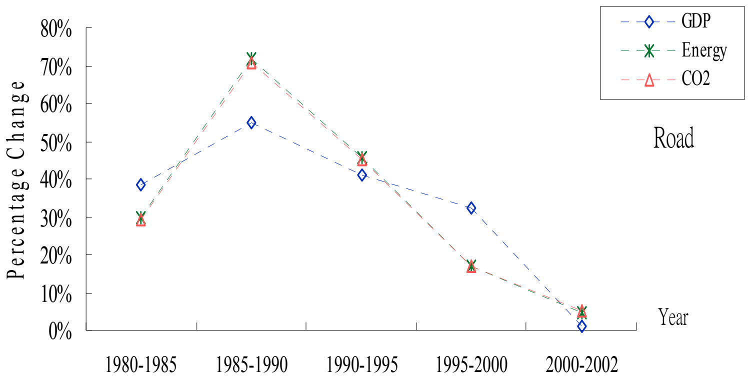

Figure 6: Decoupling effect of road transportation.

5 Conclusion

In this study, we found that the transportation energy use and CO_2 emission for all compared countries had significantly increased from 1990 to 2003. As a developing country, transportation fuel consumption and CO_2 emission in Taiwan increased at the rates of 5.3% and 4.8% over this period, which were much higher than most of other countries. In addition, results from three countries indicated expansive negative decoupling and expansive coupling for the period of 1985-1990 and 1990-1995. After that, the relative growth rate of GDP and CO_2 emission showed decoupling effects in Japan, while strong connections between GDP vs. energy consumption and GDP vs. CO_2 emission were observed in South Korea and Taiwan. As for the GDP elastic coefficient of transport modes in Taiwan, the road transportation had poor performance in energy consumption and CO_2 emission. Because road transportation is not only the major north-south thoroughfare but also the primary transport mode for most of the people, the strategic measures for improvement may include (1) carrying out high occupancy vehicle control, ridesharing and right of way; (2) implementing an Intelligent Transportation System (ITS) along with transportation demand management; (3) restraining the growth of private vehicles by fuel taxation and higher parking fees; (4) encouraging the use of green transport modes, maximizing energy efficiency and strengthening the emission standards of new vehicles; and (5) integrating land-use planning and transport construction projects. Although not a member of the UNFCCC, the government of Taiwan is striving to mitigate its challenges in global warming issues as well as to enhance the economic competition. Consequently, the emphasis for national transport policy in the 21st century should be set to pursue sustainable development through the harmonization of energy consumption, economic growth and environmental protection. The relationship among GDP, energy consumption and CO_2 emission can be further carried out by decomposition to identify the major factors contributing to the emission and energy consumption changes. Results from further study can be of value for setting priority strategies of transport CO_2 mitigations.

Acknowledgement

We wish to thank the National Science Council (Project NSC 94-2211-E-006-031) for financial support.

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