Comparison of energy performance between passenger cars and motorcycles in Taiwan by decomposition analysis

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Abstract

Transportation can facilitate the mobility of people and goods over space and time, but it also accelerates energy consumption, and it may cause serious environmental pollution. Based on relevant energy and emission databases, passenger cars and motorcycles are major sources of energy consumption and pollutant emissions in Taiwan. This paper aims to identify the direct and intricate characteristics affecting the energy consumption and performance of passenger cars and motorcycles in Taiwan. Decomposition analysis was used to quantify the relative contributions from energy intensity, the vehicle kilometers per unit car, vehicular structure share, vehicle expansion and economic productivity from 1990 to 2004. The results indicated that the number of passenger cars and motorcycles increased by 138.2% and 62.7% over the 14 years. Also, the increases of aggregate fuel consumption were 4.1 million kiloliters and 1.4 million kiloliters, respectively. Furthermore, the results of decomposition analysis indicated that the economic development and energy intensity were two key factors for the rise of vehicle's fuel consumption, while vehicle intensity had a significant positive contribution to energy conservation. Compared with the increased effect on motorcycles' fuel demand, the ratio of vehicle kilometers per unit car to passenger car was improved because the growth rate of vehicle-km was lower than the number of passenger cars. The share of passenger cars in road transportation increased from 24.6% to 32.7% while it declined in motorcycles from 68.4% to 61.3%, which means the "vehicular structure share" factor had a negative effect on passenger cars' fuel demand and an improvement in motorcycle energy consumption. To improve the energy intensity, the strategies include proper fuel/car taxation, and enhancing high occupancy vehicle measures by regulation and economic incentives. Also, increased use of the mass rapid transit system (MRT) and combining road–rail networks would improve efficiency.
Keywords: decomposition analysis, economic growth, energy consumption, motorcycle, passenger car.

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1 Introduction

A transportation system is fundamental to national progress, economic activity, industrial development and living standard. With the rapid growth of economy and industrial development in Taiwan during the past several decades, the demand of transportation has also increased rapidly. Road transportation is not only the major north-south thoroughfare but also the primary transport mode for most of the people. In order to facilitate the economic activities and to ease the mobility of people and goods over space and time, several projects such as the Sun Yat-sen Expressway, Second Freeway, West Coast Highway and East-West Highway, etc. were constructed in succession. The construction of an integrated road transportation network could accelerate energy consumption and result in serious environmental pollution, even though it can boost regional development, economic activities and the mobility of the people. According to the statistics [1], the number of motor vehicles in Taiwan grew by 80.8% from 1990-2004, with an increase of transport-related energy consumption by 87.1%. By the end of 2004, the energy consumption of the transportation sector reached 14.4 million kiloliters, accounting for 22.7% of total final energy consumption in Taiwan [2]. This suggests that Taiwan is challenged by a high demand of energy consumption from rapid economic development. Recognizing sustainable development as a priority course in the 21st century, the government of Taiwan held a second national energy conference in 2005. The energy performance of major sectors for the past several years was examined in the second national energy conference in order to upgrade energy efficiency and to plan national energy policy for reducing the indirect impacts of the post-Kyoto Protocol period. In this study, the comparisons between passenger car and motorcycle are made by the relevant energy and emission database for the share of private vehicles over 90%. Furthermore, we used the Divisia index approach to explore the relative contributions of different factors to the increase of traffic fuel consumption for getting a more comprehensive understanding of the interrelationships of vehicle growth, economic productivity and energy consumption, and providing a helpful reference for planning the national transport policy in Taiwan.

Decomposition indices, such as Laspeyres and Divisia, are widely-used approaches to explore the relative contribution of different factors affecting the variation of energy use, energy intensity and atmospheric pollution emission. Ang and Lee [3] compared five specific methods and found that the adaptive weighting and the simple average Divisia index approach tended to yield smaller residuals in decomposition. The influences of pollution coefficient, fuel mix, energy intensity, economic growth and industrial structure to the increase of emission changes for the major economic sectors in Taiwan were explored by Lin and Chang [4]. They found that economic growth was the key factor for the increase of CO_2, NO_x and SO_2 during 1980-1992, while the influence of fuel mix was limited. Ang and Pandiyan [5] decomposed energy-related CO_2 emission in the manufacturing industry by Divisia index approach and found that the intensity effect had a great impact on the aggregate CO_2 emission changes in

China, Taiwan and South Korea. The variation of CO_2 emission from the transportation sector in Italy was decomposed by Mazzarino [6], who found that the growth of GDP was the main factor for the increase of CO_2. Lee and Lin [7] employed input-output structure decomposition analysis to identify the relative contribution of each factor that affected CO_2 emission changes of Taiwan's petrochemical industries during 1984-1994. Ang [80] compared the properties of decomposition analysis and concluded that the multiplicative and additive logarithmic mean Divisia index approach (LMDI) is the best method from a theoretical standpoint, ease of operation and result interpretation. Pollution coefficient, energy intensity, structural changes and economic activity were adopted by Paula et al. [9] to explore the effects for the increase of CO_2 emission in India from 1980 to 1996. Ang [10] proposed a practical guide for the logarithmic mean Divisia index (LMDI) method and used industrial energy consumption and CO_2 emissions as examples for realizing the applications and advantages of the LMDI approach. The simple average Divisia index approach with a rolling base year was adopted by Lin et al. [11] to identify the characteristics of CO_2 emission changes from industrial sectors in Taiwan.

The objective of this study is to examine the historical performances (1990-2004) of energy consumption and environmental emissions from passenger cars and motorcycles in Taiwan. Also, the impacts for the changes in energy intensity, the vehicle kilometers per unit car, vehicular structure share, vehicle expansion and ratio of economic productivity to the increase of transport energy consumption were examined with the aid of decomposition analysis in order to improve future transportation strategies.

2 Methodology

Decomposition analysis has been applied in many fields to assess an industry's direct and intricate characteristics affecting its changes in energy consumption or pollutant emission. In general, these methods decompose an object of interest into a multiplication of several components to identify the relative influence of each factor according to its variation. The simple average Divisia index method is adopted in this study for the reasons of simplicity and small residuals. Since this decomposition approach allows us to decompose energy consumption in a multiplicative form, the fuel consumption of passenger cars and motorcycles can be expressed as:

$$E_{it} = \frac{E_{it}}{VKT_{it}} \times \frac{VKT_{it}}{N_{it}} \times \frac{N_{it}}{N_t} \times \frac{N_t}{G_t} \times G_t \qquad (1)$$

E_{it}: quantity of energy consumption by ith vehicle in year t (million kiloliter),
VKT_{it}: length of the vehicle kilometers of travel by ith vehicle in year t (vehicle kilometer),
N_{it}: number of ith vehicle in year t (unit vehicles),
N_t: number of aggregate motor vehicles in year t (unit vehicles),
G_t: gross domestic product in year t (billion 2000 US dollars),
Equation (1) can be simplified in the following form:

$$E_{it}=I_{it}\times K_{it}\times S_{it}\times V_t\times G_t \quad (2)$$

where

$I_{it} = E_{it}/VKT_{it}$: energy intensity of ith vehicle in year t,
$K_{it} = VKT_{it}/N_{it}$: vehicle kilometers per unit vehicle in year t,
$S_{it} = N_{it}/N_t$: structure share of ith vehicle in year t,
$V_t = N_t /G_t$: motor vehicle growth per unit GDP in year t,

Equation (2) can be further expressed as the decomposition of energy demand growth rate into the sum of the growth rates for each component. That is, differentiating both sides of equation (2) with respect to time t gives:

$$\frac{dE_{it}}{dt}=\frac{dI_{it}}{I_{it}}\times\frac{E_{it}}{dt}+\frac{dK_{it}}{K_{it}}\times\frac{E_{it}}{dt}+\frac{dS_{it}}{S_{it}}\times\frac{E_{it}}{dt}+\frac{dV_t}{V_t}\times\frac{E_{it}}{dt}+\frac{dG_t}{G_t}\times\frac{E_{it}}{dt} \quad (3)$$

By integrating both sides of equation (3) from year 0 to year t yields:

$$\Delta E_{it}=\int_0^t d\,ln(I_{it})\times E_{it}+\int_0^t d\,ln(K_{it})\times E_{it}+\int_0^t d\,ln(S_{it})\times E_{it}+\int_0^t d\,ln(V_t)\times E_{it}+\int_0^t d\,ln(G_t)\times E_{it} \quad (4)$$

From the concept of the simple average parametric Divisia method, the integral of equation (4) can be measured by the mean of the beginning-points and end-points over a short period of time because the data in this study is discrete.

$$\Delta E_{it}=\ln(\frac{I_{it}}{I_{io}})\times(\frac{E_{it}+E_{io}}{2})+\ln(\frac{K_{it}}{K_{io}})\times(\frac{E_{it}+E_{io}}{2})+\ln(\frac{S_{it}}{S_{io}})\times(\frac{E_{it}+E_{io}}{2})+\ln(\frac{V_t}{V_0})\times(\frac{E_{it}+E_{i0}}{2})$$
$$+\ln(\frac{G_t}{G_o})\times(\frac{E_{it}+E_{io}}{2})+RD=DI+DK+DS+DV+DG+RD \quad (5)$$

DI, DK, DV, DS, DV and DG in equation (5) represent the Divisia indices for the contributions due to changes in energy intensity, vehicle kilometers per unit vehicle, vehicular structure share, vehicle intensity and economic productivity; RD is the residual term.

3 Data

The gross domestic product is adopted from the OECD statistics database (1990-2004), whereas the number of motor vehicles in Taiwan is from the report "Statistical Abstract of Transportation and Communications" [2]. The estimate of vehicle's fuel consumption is based on the multiplication of the total number of vehicles and the total vehicle kilometers of travel, which is divided by the average fuel efficiency (km/kiloliter). Furthermore, the adjustment of a motor vehicle's energy requirement is made according to the proportion of the vehicle's energy consumption and the aggregate energy demand of the road transportation sector in Taiwan [1].

4 Results

4.1 Number of motor vehicles in Taiwan

As a developing country, the gross domestic product in Taiwan experienced an increased growth rate of 5.30% per year from 1990 to 2004. This effect is also reflected in the growth of motor vehicles. According to the statistics, the number of motor vehicles in Taiwan increased from 9.2 million vehicles in 1990 to 16.6 million vehicles in 2004, with the annual growth rate of 4.32%. Table 1 shows the structure share of motor vehicles in Taiwan during 1990-2004. It reveals that passenger cars and motorcycles are the major transport modes in Taiwan, which accounted for more than 93% of vehicles, followed by light trucks (4.6%), heavy trucks (1.1%) and buses (0.5%). Despite motorcycles having the advantage of mobility and being inexpensive in comparison to passenger cars, the number of motorcycles increased by 3.9 million vehicles over the 14 – year period, with the proportion of motorcycles decreasing from 68.4% to 61.3%. On the other hand, the number of passenger cars in road transportation grew at a rate of 6.39% per year, with a structure share of 24.6% in 1990 compared to 32.7% in 2004.

Table 1: Structure share of motor vehicles in Taiwan.

Year	Bus	Heavy Truck	Light Truck	Passenger Car	Motorcycle
1990	0.47%	1.29%	5.22%	24.62%	68.39%
1991	0.39%	1.08%	4.68%	22.99%	70.86%
1992	0.39%	1.12%	4.64%	23.96%	69.89%
1993	0.40%	1.11%	4.43%	24.62%	69.44%
1994	0.41%	1.07%	4.21%	25.14%	69.17%
1995	0.51%	1.29%	4.86%	31.81%	61.54%
1996	0.50%	1.18%	4.73%	31.51%	62.08%
1997	0.49%	1.12%	4.65%	31.33%	62.42%
1998	0.48%	1.07%	4.49%	31.05%	62.91%
1999	0.49%	1.07%	4.37%	31.44%	62.64%
2000	0.50%	1.04%	4.36%	31.51%	62.59%
2001	0.50%	1.02%	4.43%	31.67%	62.38%
2002	0.49%	1.00%	4.48%	31.92%	62.10%
2003	0.49%	0.98%	4.55%	32.26%	61.73%
2004	0.48%	0.97%	4.56%	32.43%	61.57%

4.2 Fuel consumption of passenger cars and motorcycles

Accompanying the growth of motor vehicles, the consumption of fuel increased. By the end of 2004, the energy requirement of the road transportation system reached 14.4 million kiloliters, which was 1.9 times that in 1990 and consumed 22.7% of the total energy in Taiwan (Figure 1). Despite motorcycles being the primary transport mode for most of the people in Taiwan, the fuel consumption by motorcycles was only 10% of the road transportation total. As for the variation of motorcycle energy consumption, it was 0.5 million kiloliters in 1990 and 1.9 million kiloliters in 2004, for an increase of 9.89% per year. Besides, the aggregate fuel demand of passenger cars was estimated to be 3.3 million kiloliters in 1990, accounting for approximately 43.0% of road transportation's energy consumption. The fuel requirement of passenger cars resulted in 4.1 million kiloliters of energy increase through 1990 to 2004 and continued to rise at an annual growth rate of 5.90% because of the rapid increase in the number of passenger cars. This situation indicates that the high ownership rate and the frequent use of passenger cars and motorcycles will accelerate energy exhaustion, reinforce the seriousness of global warming and deteriorate environmental quality, even though it can facilitate the mobility of people and goods over space and time.

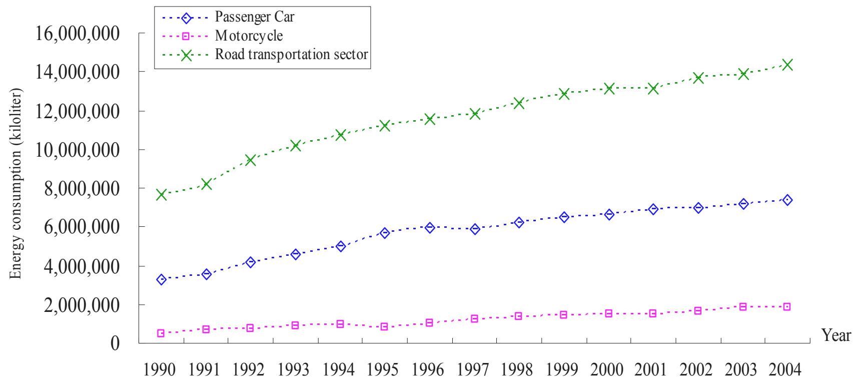

Figure 1: Energy consumption of motor vehicles in Taiwan.

Table 2: Exhaust emission from passenger cars and motorcycles.

unit: metric tons

Year	Passenger car			Motorcycle		
	NOx	CO	HC	NOx	CO	HC
1990	99,065	1,101,328	259,292	17,824	153,473	127,379
1991	98,122	1,053,608	235,986	19,373	166,723	134,076
1992	101,671	1,076,887	232,457	20,141	176,246	136,008
1993	97,096	1,002,990	207,683	20,158	180,209	134,311
1994	94,979	982,191	193,760	19,402	180,993	128,848
1995	87,665	875,294	167,074	19,047	183,971	125,692
1996	79,217	774,333	144,422	18,739	188,732	124,323
1997	69,733	684,917	124,020	22,793	223,380	133,866
1998	63,700	614,343	110,208	21,347	213,402	124,100
1999	60,020	555,842	100,867	20,239	226,706	120,754
2000	57,982	530,181	72,365	18,682	225,324	110,442
2001	57,489	533,504	72,813	17,440	205,189	101,608
2002	76,518	969,294	120,082	18,452	219,820	106,375
2003	77,262	1,010,382	123,752	20,587	238,448	115,734
2004	72,697	937,745	115,259	23,404	237,734	118,271

4.3 Pollutant emission of passenger cars and motorcycles

As mentioned above, road transportation, especially for passenger cars and motorcycles, is responsible for a large share of energy consumption in Taiwan. The transport-related exhaust emissions, such as NOx, CO and HC, also play an important role in the development of a sustainable city. The emission data of different pollutants is shown in Table 2. According to the third stage exhaust emission standards, the NOx emission from automobiles should decrease from 0.62 g/km in 1990 to 0.25 g/km. Thus, the NOx emission from passenger cars decreased from 99 thousand tons to 73 thousand tons from 1990 to 2004, accounting for 24% of emissions in the road transportation system. During the same period, the NOx emission of motorcycle increased by 6 thousand tons. In addition, the trends of CO emission changes from passenger cars and motorcycles were similar to those of NOx. The motorcycle CO emission increased 84 thousand tons, while it declined for passenger cars by 164 thousand tons. The HC released from passenger cars and motorcycles both decreased. For example, the HC reduced from 55.6% for cars and 7.2% for motorcycles with respect to the HC emissions in 1990.

4.4 Decomposition of energy consumption in passenger cars and motorcycles

4.4.1 Passenger cars

The fuel consumption of passenger cars has increased 4,069 thousand kiloliters during 1990-2004 (Table 3). The energy intensity was the most important factor for the increase, due to the steady growth of vehicle kilometers of travel and the rapid increase in energy consumption. In total, it contributed 4,286 thousand kiloliters of energy increase. Besides, economic driving force was another indispensable factor that caused increased energy demand. Overall, the fuel consumption for the growth of economy was up to 3,862 thousand kiloliters. Compared to the other increasing factors, the influence of vehicular structure share was much less obvious and the contribution of aggregate energy requirement was 1,472 thousand kiloliters. The index of the vehicle kilometers per unit car had a large positive effect on the reduction of fuel demand in each period, especially for 1990-1993, with a total decrease of 4,638 thousand kiloliters. Furthermore, the aggregate energy conservation based on vehicle expansion was 698 thousand kiloliters because the growth rate of motor vehicles was lower than the increase of economic productivity, which had relatively little effect on energy conservation.

4.4.2 Motorcycles

The aggregate change of motorcycle energy consumption increased by 1,374 thousand kiloliters from 1990 to 2004 (Table 3). The steadily increasing trend of economic growth was the most important factor for the increase of vehicular fuel demand. In total, it caused an increase of 858 thousand kiloliters. Because energy intensity contributed 651 thousand kiloliters of energy increase, the measures such as reducing weight, adjusting speed limits, scrapping old vehicles and labeling fuel efficiency, etc. should be considered in order to improve vehicular energy efficiency. The relative variation of vehicle kilometers of travel with the number of motorcycles caused an increased energy requirement of 338 thousand kiloliters, which was the result of the higher growth rate in vehicle kilometers of travel. In addition, the major factor for the decrease of fuel demand was vehicle expansion, with an aggregate decrease of 155 thousand kiloliters. Despite the increase in the number of motorcycles by 62.7% for the past 14 years, the proportion of motorcycles decreased from 68.4% in 1990 to 61.3% in 2004. Thus, the factor of vehicular structure share had a considerable positive contribution to energy conservation and caused a reduction of 125 thousand kiloliters.

Table 3: Decomposition of vehicular energy changes for passenger cars and motorcycles in Taiwan.

unit: thousand kiloliter

Motor Vehicle	Year	Index*						
		DI	DK	DS	DV	DG	EC	RD(%)
Passenger car	1990-1993	1372.80	-1709.62	0.90	782.99	841.60	1277.35	-0.89%
	1993-1996	1444.77	-1122.49	1294.86	-1275.43	996.90	1331.41	-0.54%
	1996-1999	425.91	-344.56	-14.74	-473.44	1009.97	602.67	-0.08%
	1999-2002	350.16	-564.70	103.71	103.54	475.78	468.29	-0.04%
	2002-2004	423.53	-589.80	112.96	-181.61	624.59	389.58	-0.02%
	1990-2004	4286.31	-4637.87	1472.06	-697.71	3862.32	4069.29	-5.30%
Motorcycle	1990-1993	258.26	-170.21	10.38	136.05	146.23	371.22	-2.55%
	1993-1996	-42.13	320.04	-104.46	-226.68	177.18	123.77	-0.15%
	1996-1999	115.59	206.35	10.82	-92.24	196.77	432.60	-1.08%
	1999-2002	106.57	-6.65	-13.23	23.56	108.27	218.15	-0.17%
	2002-2004	92.50	42.54	-15.27	-44.50	153.04	227.99	-0.14%
	1990-2004	651.40	338.18	-124.81	-155.01	858.11	1373.73	-14.13%

* DE: energy intensity, DK: vehicle kilometers per unit vehicle, DS: vehicular structure share, DV: vehicle intensity, DG: economic productivity, EC: emission changes, RD: residuals.

5 Conclusion

Results of this study indicate that the high economic growth and the frequent use of private vehicles are the major factors for the greater transport volumes among vehicles. Accompanying the growth of motor vehicles, the consumption of vehicle fuels for passenger cars and motorcycles increased at the annual growth rate of 5.90% and 9.89% from 1990 to 2004. The transport-related exhausted emission from automobile had a steady tendency toward decline, while the performances of motorcycle's NOx and CO emissions suggest that the retirement of high-aged vehicles and the implementation of green transport modes should be enhanced. Furthermore, the analysis of decomposition methodology reveal that Taiwan's economic growth and energy intensity are two key factors for the rise of vehicular fuel consumption, while vehicle intensity had a significant effect on energy conservation. The factor of vehicle kilometers per unit car had a negative effect on motorcycle energy requirements but it contributed 4,638 thousand kiloliters of energy conservation by passenger cars. The increase of passenger car share caused an increase in energy demand of 1,472 thousand kiloliters. Compared with the increased effect to passenger car's fuel demand, the reduction of energy consumption reached 125 thousand kiloliters because the share of motorcycles decreased from 68.4% to 61.3%.

Because of high population density, the limitations of topography and natural resources and the shortage of a well-established public transport system, the ownership of private vehicles, especially for motorcycles, is higher than that in most other countries. To reduce the requirements of energy consumption and the ownership of private vehicles, the strategies include (1) proper fuel/car taxation; (2) a well-developed feeder system by MRT and integrated road-rail networks; (3) enhancing high occupancy vehicle measures and bus lanes by regulatory and economic incentives; and (4) adjusting speed limits and strengthening energy conservation standards for new vehicles.

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