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# Decomposition Analysis on Direct Material Input and Dematerialization of Mining Cities in Northeast China

QIU Fangdao[1, 2], TONG Lianjun[3], ZHANG Huimin[3], ZHANG Na[2]

(*1. School of Urban and Environmental Sciences, Xuzhou Normal University, Xuzhou 221116, China; 2. College of Urban and Environment Science, Northeast Normal University, Changchun 130024, China; 3. Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130012, China*)

**Abstract:** Material dematerialization is a basic approach to reduce the pressure on the resources and environment and to realize the sustainable development. The material flow analysis and decomposition method are used to calculate the direct material input (DMI) of 14 typical mining cities in Northeast China in 1995–2004 and to analyze the dematerialization and its driving factors in the different types of mining cities oriented by coal, petroleum, metallurgy and multi-resources. The results are as follows: 1) from 1995 to 2006, the increase rates of the DMI and the material input intensity of mining cities declined following the order of multi-resources, metallurgy, coal, and petroleum cities, and the material utilizing efficiency did following the order of petroleum, coal, metallurgy, and multi-resources cities; 2) during the research period, all the kinds of mining cities were in the situation of weak sustainable development in most years; 3) the pressure on resources and environment in the multi-resources cities was the most serious; 4) the petroleum cities showed the strong trend of sustainable development; and 5) in recent years, the driving function of economic development for material consuming has continuously strengthened and the controlling function of material utilizing efficiency for it has weakened. The key approaches to promote the development of circular economy of mining cities in Northeast China are put forward in the following aspects: 1) to strengthen the research and development of the technique of resources' cycling utilization, 2) to improve the utilizing efficiency of resources, and 3) to carry out the auditing system of resources utilization.

**Keywords:** direct material input; material flow analysis; dematerialization; decomposition method; mining cities; Northeast China

## 1 Introduction

To develop the circular economy is an important approach to comprehensively implement the scientific outlook on development, to build an energy-efficient and environment-friendly society and to achieve sustainable development (Huang and Bi, 2006). It aims at maximizing the utilizing efficiency of resources and minimizing the waste through transformation or regulation of the existing linear model of material flow (Feng, 2007), and it will also promote material recycling. The establishment and application of material flow analysis (MFA) provide a basic approach to quantitatively assess the material exchange between the economic system and the natural environment (Liu et al., 2005), which is a focus research on sustainable development. For a regional economic system, the more input material, the greater material consumption and waste production will be, and eventually it will result in ecological deterioration. Therefore, reducing consumption of natural resources and emission of pollutants, i.e. achieving dematerialization, provides a new approach to solve the conflict between the resources shortage and environmental pollution, to reduce the vulnerability of the regional economic system, and to protect the sustainability of economic development (Liu et al., 2005; Helmut and Welfens, 2004; Peter, 2004). Recently, most Chinese researchers, referring to foreign researches and applica-

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Corresponding author: TONG Lianjun. E-mail: tonglj@neigae.ac.cn

tion results of material flow analysis, carried out an empirical study of material flow of the economic system in terms of the angles of State, industry and product life cycle (Peng et al., 2006; Huang et al., 2007), but only few did researches on dematerialization of the economic system (Liu et al., 2005; Li and Wang, 2008; Zhang and Lei, 2006).

Mining cities are those developing on the basis of exploiting mineral resources, whose formation, development, prosperity and decline depend mostly upon the amount of exploitable mineral resources. There are 390 mining cities in China at present. As the main resources-supply bases, those mining cities have made great contributions to enhancing Chinese economic strength, pulling regional economic development, driving urbanization and increasing employment opportunity. However, some cities have begun to decline and 12% of them been approaching to exhausting with mineral resources since the 1990s. Therefore, how to utilize the mineral resources reasonably and circularly and revitalize the mining cities have become the focus and difficulty for China to promote the transformation of resources-based cities. Then it is especially vital to revitalize Old Industrial Base in Northeast China, which holds 1/3 mining cities of China. At present, most of researches about the sustainable development of the mining cities are carried out from the angles of the strategies and mechanisms of development (Shen and Cheng, 1999; Fan et al., 2005; Long, 2005; Li and Wang, 2008), industrial transformation (Wang, 2003; Song et al., 2005) and so on. But this paper, based on the method of MFA and taking 14 typical mining cities (prefecture-level cities) in the Northeast China for examples, explores the situation of the sustainable development of the mining cities in the Northeast China from the perspective of dematerialization, with a view to providing a scientific reference for the construction of circular economy development model of the mining cities.

## 2 Data and Methods

### 2.1 Study area

There are 33 mining cities in Northeast China at present, accounting for 1/3 top cities in this region. The population of them was $36.39\times10^6$, and GDP $778.47\times10^9$ yuan (RMB) in 2006. Those mining cities developed rapidly since the 1950s when China was approaching to large-scale industrialization. However, some cities began to decline and their mining industries started to exhaust with mineral resources drying up since the 1990s. This article takes 14 mining cities for examples, including Anshan, Fushun, Benxi, Fuxin, Panjin, Huludao, Liaoyuan, Songyuan, Baishan, Jixi, Hegang, Shuangyashan, Daqing and Qitaihe (Fig. 1). Their total population and GDP occupied 73.22% and 78.58% of mining cities of Northeast China, respectively. As the main mining cities, they are typical ones in Northeast China.

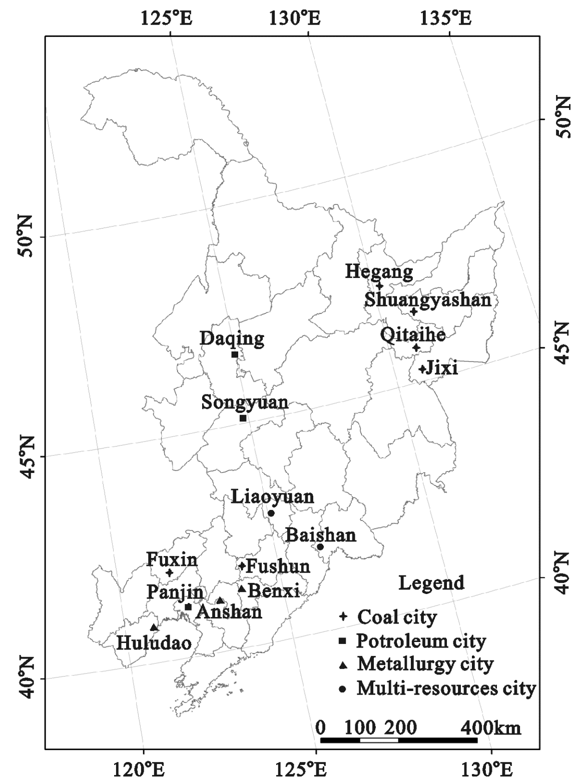



Fig. 1 Location and types of mining cities of Northeast China

### 2.2 Data sources

The original data in this paper were from the followings: 1) *Liaoning Statistical Yearbook* (Liaoning Statistical Bureau, 1996–2007), *Jilin Statistical Yearbook* (Jilin Statistical Bureau, 1996–2007), *Heilongjiang Statistical Yearbook* (Heilongjiang Statistical Bureau, 1996–2007) and *China City Statistical Yearbook* (National Bureau of Statistics of China, 1996–2007); 2) *Anshan Yearbook, Benxi Yearbook, Fushun Yearbook, Fuxin Yearbook, Panjin Yearbook And Huludao yearbook* from 1996 to 2005 and *Hegang Yearbook* from 1996 to 2002; 3) *Statistical Yearbook of Daqing 2007*, *Statistical Yearbook of Shuangyashan from 1996 to 2004*, *Fifty-year of Jixi and*

*Fifty-year of Qitaihe*; and 4) some survey data.

### 2.3 MFA index choices

Since put forward in the 1990s, the material flow analysis (MFA) has been widely applied and fast developed in the western developed countries. It shows the pressure upon the environment caused by the economic activities based on the quantitative assessment of material exchange between the economic system and the environment. The direct material input (DMI) is one of the critical indexes featuring the metabolism of the economic system, and reflecting the influence on natural resources caused by socioeconomic activities. DMI refers to the materials with economic value, directly used in the process of production and consumption, including non-regenerative and regenerative resources. The former contains fossil fuel, such as crude oil, raw coal, natural gas, etc.; industrial minerals, such as all kinds of black, colored and valuable metal minerals, crude salt, etc.; and construction materials, such as sand and stones, cement and so on. While the latter contains biological materials, such as field crops and their by-products, wood, fish, honey, mushroom, nut and so on. Generally the calculation of DMI does not involve water and air (European Communities, 2001), and nor the material exchange capacity between the mining cities and the outward, due to the lack of input and output statistics.

### 2.4 Dematerialization model

Academia both at home and abroad hold four main views of dematerialization. 1) Dematerialization is the natural result of economic development, with the reflection that the weight of the final product decreases with time (Colombo, 1988; Heman et al., 1989). 2) Dematerialization refers to the decrease of consuming intensity of material in economic activities. The measuring index is the ratio of material consumption to GDP (Bernardini and Galli, 1993). 3) Dematerialization means the process that material of low quality is replaced by that of high quality or of higher technology in the process of industrial development (Li and Wang, 2008). 4) Dematerialization indicates the absolute or relative decrease of the consumption of per-unit production and the pollutant discharge (Chen et al., 2003; Wernick and Ausbel, 1996). This is also the researching ideas this paper follows.

Here we defines that *DMI* reflects the material demand of regional economic system, and the equation is:

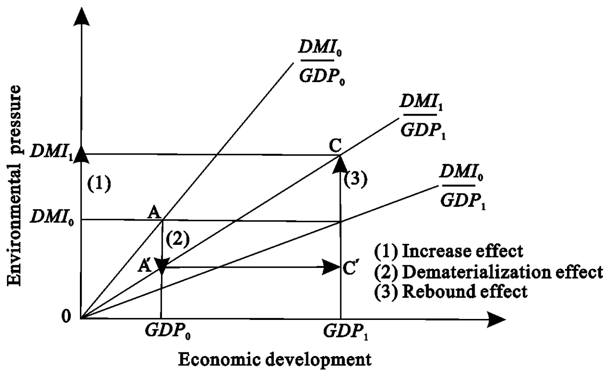
$$DMI = RPC \cdot GDP \tag{1}$$

where *RPC* is the intensity of material demand.

By deducing, we get:

$$\begin{aligned} \Delta DMI &= DMI_t - DMI_0 \\ &= \frac{DMI_0}{GDP_0} \cdot \Delta GDP + \Delta \frac{DMI}{GDP} \cdot GDP_1 \end{aligned} \tag{2}$$

where, $DMI_0$ and $DMI_t$ are the DMIs in the base year and year *t*, respectively; $\frac{DMI_0}{GDP_0} \cdot \Delta GDP$, reflects the rebound effect caused by economic development; $\Delta \frac{DMI}{GDP} \cdot GDP_1$ reflects the dematerialization effect caused by the diminution of material demand. The sum of the two is called the increase effect. To realize the absolute decrease of material demand, the intensity of material demand must be reduced to make the increase effect under zero, i.e. the absolute value of dematerialization effect is greater than rebound effect in economic development. In Fig. 2, the relations of the above variables can be demonstrated, and $DMI_0/GDP_1$ means the material consumption decrease due to raising utilizing efficiency by technology progress.




Source: Zhang and Lei, 2006

Fig. 2 Rebound effect and increase effect of dematerialization

### 2.5 Decomposition model of dematerialization factors

Decomposition analysis, a research method quantitatively disclosing the factors' relative importance for target variable, has been widely applied in lots of fields such as the distinguishing of the influencing factors on energy utilization and environmental pollution. Here, this method is introduced into the research of material exchange between the economic system and environmental system, providing a reliable analyzing approach to disclose the factors influencing material consumption in the economic system. The model is as follows:

$$DMI = \sum_{i=1}^{n} P \cdot R \cdot I \cdot S_i \quad (3)$$

where *DMI* is direct material input; *P*, total population; *R*, per capita GDP, representing economic growth; *I*, material input of per-unit GDP, reflecting the material utilization efficiency; $S_i=DMI_i/DMI$, proportion of material input of *i* type (including the regenerative and non-regenerative resources), showing the material input structure. Compared to the base year, the DMI change ($\Delta DMI$) of the year *t* can be described as follows:

$$\begin{aligned}\Delta DMI_t &= DMI_t - DMI_0 \\ &= \Delta DMI_p + \Delta DMI_R + \Delta DMI_I + \\ &\quad \Delta DMI_S + \Delta DMI_{rsd}\end{aligned} \quad (4)$$

$$D = \frac{DMI_t}{DMI_0} = D_p \cdot D_R \cdot D_I \cdot D_S \cdot D_{rsd} \quad (5)$$

where $\Delta DMI_P$, $\Delta DMI_R$, $\Delta DMI_I$ and $\Delta DMI_S$ are the contribution values of population, economic growth, material utilization efficiency, and material input structure for the change of DMI, while $D_P$, $D_R$, $D_I$ and $D_S$ are the contribution rates of them, respectively; $\Delta DMI_{rsd}$ and $D_{rsd}$ are decomposition allowance, thereinto, $\Delta DMI_{rsd}$=0, $D_{rsd}$=1.

Based on Equations 4–5, the division decomposition method (Ang et al., 1998) can be adopted to figure out the contribution value and rate, and the equations are as follows:

$$\Delta DMI_P = \sum_i W_i \cdot \ln\frac{P_{it}}{P_{i0}}, \quad \Delta DMI_R = \sum_i W_i \cdot \ln\frac{R_{it}}{R_{i0}},$$
$$\Delta DMI_I = \sum_i W_i \cdot \ln\frac{I_{it}}{I_{i0}}, \quad \Delta DMI_S = \sum_i W_i \cdot \ln\frac{S_{it}}{S_{i0}} \quad (6)$$

$$D_P=\exp(W\Delta DMI_P), \quad D_R=\exp(W\Delta DMI_R),$$
$$D_I=\exp(W\Delta DMI_I), \quad D_S=\exp(W\Delta DMI_S) \quad (7)$$

thereinto,

$$W_i = \frac{DMI_{it} - DMI_{i0}}{\ln(DMI_{it}/DMI_{i0})}, \quad W = \frac{\ln DMI_t - \ln DMI_0}{DMI_t - DMI_0}$$

## 3 Efficiency and Intensity of DMI

### 3.1 Growth trend analysis of DMI

From 1995 to 2006, the DMIs of coal, metallurgy and multi-resources cities accelerated with rates of 0.96%, 1.82%, and 4.77% and the GDP of the cities with rates of 10.59%, 11.52% and 11.92%, respectively (Table 1). It shows that the rapid increase of the economy has stimulated the rapid increase of material consumption, with the growth rate far less than that of GDP. In the same period, the GDP in petroleum cities increased with a rate of 12.54%, but the average annual decrease of DMI reached to 0.22%. It showed an unhook trend between the economic development and material consumption of petroleum cities. From changing process, DMIs of three types mining cities including coal city, petroleum city and metallurgy city, increased in the beginning and then tended to decrease. However, it increased again in the end. While DMI of multi-resources cities experienced the process of decrease first and then increase. The reasons are the periodic fluctuation of domestic economic development and international mineral resources market and the decline of exploitable volume of mineral resources. Around 2000, DMIs of most mining cities in Northeast China came to their minimum. After that, transformation policy of resources-based cities and revitalization strategy of Northeast China was continuously put forward, which accelerated the economic development. Subsequently, the demand for material was higher than before and the amount of DMI increased sharply.

### 3.2 Input intensity of DMI

Here we defines that per capita DMI denotes the input intensity of DMI of regional economic system. The per capita DMIs of coal, petroleum, metallurgy, and multi-resources cities in Northeast China in 2006 were 12.23t, 13.54t, 8.90t and 10.44t, which were 1.95 times, 2.16 times, 1.58 times and 1.66 times as many as that of Guangdong Province in 2005 (Zhang et al., 2007) and 3.79 times, 4.19 times, 3.07 times and 3.23 times as many as that of the Chinese average level in 2002 (Liu et al., 2005). It shows that compared with the developed areas, the input intensity of DMI of mining cities in Northeast China is still high and the development of mining cities has the obvious resources-driven features. The input intensity of DMI of coal, metallurgy, and multi-resources cities had a rising trend in general from 1995 to 2006 (Fig. 3). The input intensity of DMI of multi-resources cities increased tremendously by 65.85%, showing that this kind of mining cities had the most serious resources pressure. However, the input intensity of DMI of petroleum cities reduced with a rate of 1.14%, showing that the resources dependence of economic development was decreasing.

Table 1 Indicators of DMI and socio-economy of mining cities

| | Coal cities | | | Petroleum cities | | | Metallurgy cities | | | Multi-resources cities | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DMI ($\times10^6$t) | GDP ($\times10^9$yuan) | Population ($\times10^6$) | DMI ($\times10^6$t) | GDP ($\times10^9$yuan) | Population ($\times10^6$) | DMI ($\times10^6$t) | GDP ($\times10^9$yuan) | Population ($\times10^6$) | DMI ($\times10^6$t) | GDP ($\times10^9$yuan) | Population ($\times10^6$) |
| 1995 | 105.2011 | 41.834 | 9.4388 | 93.6038 | 70.965 | 6.0930 | 63.3587 | 46.287 | 7.5284 | 15.8346 | 20.620 | 2.5145 |
| 1996 | 108.3193 | 47.203 | 9.5043 | 96.7916 | 80.793 | 6.1850 | 64.0150 | 50.556 | 7.5638 | 15.5528 | 23.225 | 2.5410 |
| 1997 | 109.5770 | 53.164 | 9.5388 | 93.1103 | 92.419 | 6.2646 | 65.8226 | 55.248 | 7.6000 | 15.7830 | 25.719 | 2.5655 |
| 1998 | 91.5932 | 56.422 | 9.5341 | 97.8003 | 97.900 | 6.3349 | 61.7528 | 60.457 | 7.6125 | 13.1391 | 28.038 | 2.5631 |
| 1999 | 83.2846 | 58.629 | 9.5704 | 95.5843 | 111.267 | 6.3855 | 50.0074 | 65.827 | 7.6318 | 14.6872 | 29.122 | 2.5655 |
| 2000 | 78.3802 | 62.517 | 9.6305 | 87.6032 | 148.414 | 6.4620 | 44.2642 | 73.954 | 7.6992 | 14.7723 | 31.247 | 2.5559 |
| 2001 | 76.7807 | 68.774 | 9.6318 | 90.3223 | 155.678 | 6.5072 | 43.7067 | 81.882 | 7.7046 | 15.0707 | 34.136 | 2.5699 |
| 2002 | 87.9800 | 76.026 | 9.6326 | 90.8629 | 157.797 | 6.5624 | 40.8633 | 89.050 | 7.7213 | 15.6085 | 37.611 | 2.5720 |
| 2003 | 99.4574 | 86.740 | 9.6185 | 89.2214 | 168.904 | 6.6172 | 44.4531 | 102.503 | 7.7329 | 19.2400 | 43.150 | 2.5717 |
| 2004 | 106.4103 | 103.485 | 9.6102 | 88.2447 | 189.339 | 6.6778 | 71.6067 | 129.960 | 7.7645 | 22.0033 | 52.205 | 2.5464 |
| 2005 | 107.3581 | 109.636 | 9.5709 | 90.5420 | 220.759 | 6.6776 | 74.2240 | 136.130 | 7.7770 | 23.1623 | 59.708 | 2.5367 |
| 2006 | 116.8938 | 126.603 | 9.5604 | 91.3400 | 260.316 | 6.7461 | 77.2970 | 153.635 | 7.8090 | 26.4439 | 71.162 | 2.5320 |

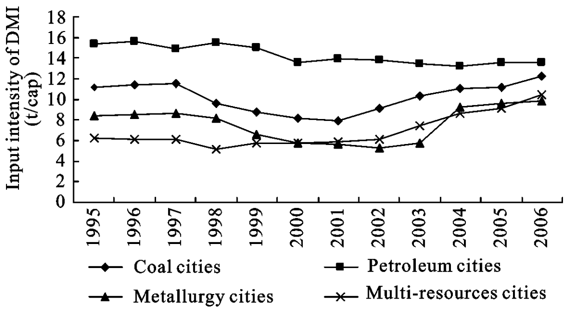



Fig. 3 Input intensity of DMI of mining cities in Northeast China in 1995–2006

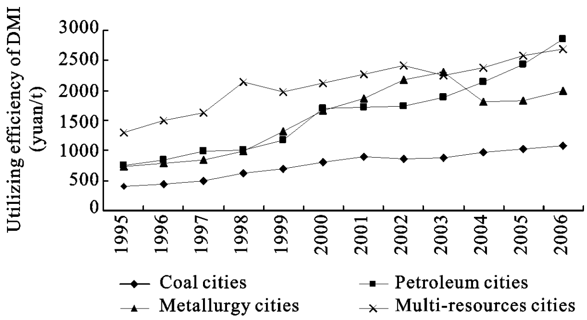



Fig. 4 Utilizing efficiency of DMI of mining cities in Northeast China in 1995–2006

### 3.3 Utilizing efficiency of DMI

The utilizing efficiencies of DMIs of coal, petroleum, metallurgy, and multi-resources cities in Northeast China in 2006 were 1083 yuan/t, 2850 yuan/t, 1988 yuan/t and 2691 yuan/t (Fig. 4), which were 3.75%, 9.87%, 6.89% and 9.32% as many as that of Guangdong Province in 2005 (Zhang et al., 2007) and 43.55%, 114.60%, 79.94% and 108.20% as many as that of the national average level in 2002 (Liu et al., 2005). It shows that the mining cities in Northeast China have an extensive utilization of material, especially the coal cities. The utilizing efficiency of DMI of coal, petroleum, metallurgy, and multi-resources cities showed the rising trend in general from 1995 to 2006. With the highest annual growth rate of 12.79%, the petroleum cities have taken faster steps on exploring the development model of circular economy.

## 4 Dematerialization Analysis

### 4.1 Effect decomposition of dematerialization

The rebound effect and the dematerialization effect are figured out by Equation (2) in various types of mining cities during 1995 to 2006 (Table 2).

As a result of economic growth, the rebound effect of DMI had a general rising trend in mining cities in Northeast China during 1995–2006. In 2006, compared to that in 1996, the rebound effects of coal, petroleum, metallurgy, and multi-resources cities increased by 23.04%, 25.15%, 63.34%, and 122.14%, respectively. The multi-resources cities have played the most significant role in driving material demand. Meanwhile, because of the decreasing intensity of material demand of per unit GDP, the dematerialization effects on petroleum and metallurgy cities increased by 52.35% and 20.74%

Table 2 Dematerialization effect analysis of mining city in Northeast China ($\times10^3$t)

| | Coal cities | | | Petroleum cities | | | Metallurgy cities | | | Multi-resources cities | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dematerialization effect | Rebound effect | Increase effect | Dematerialization effect | Rebound effect | Increase effect | Dematerialization effect | Rebound effect | Increase effect | Dematerialization effect | Rebound effect | Increase effect |
| 1995–1996 | –9203.5 | 13503.0 | 4299.5 | –8586.6 | 12963.6 | 4377.0 | –4749.0 | 5843.2 | 1094.2 | –2026.0 | 2000.2 | –25.9 |
| 1996–1997 | –11028.2 | 13678.5 | 2650.3 | –15393.9 | 13927.8 | –1466.1 | –3782.9 | 5941.7 | 2158.8 | –1300.5 | 1670.4 | 369.9 |
| 1997–1998 | –23273.0 | 6715.7 | –16557.4 | –785.9 | 5522.4 | 4736.6 | –9390.3 | 6205.8 | –3184.5 | –3730.5 | 1422.9 | –2307.6 |
| 1998–1999 | –11443.9 | 3582.9 | –7861.0 | –13698.4 | 13352.7 | –345.7 | –15824.8 | 5484.9 | –10339.8 | 1001.3 | 508.1 | 1509.3 |
| 1999–2000 | –9778.8 | 5523.0 | –4255.9 | –29907.7 | 31911.4 | 2003.7 | –10607.7 | 6174.2 | –4433.5 | –919.1 | 1071.3 | 152.2 |
| 2000–2001 | –8584.4 | 7843.9 | –740.5 | –1495.3 | 4287.5 | 2792.3 | –4789.3 | 4745.4 | –44.0 | –977.3 | 1366.0 | 388.7 |
| 2001–2002 | 2806.3 | 8097.1 | 10903.4 | –680.0 | 1229.9 | 549.9 | –6132.6 | 3826.1 | –2306.5 | –904.3 | 1534.2 | 629.9 |
| 2002–2003 | –806.9 | 12398.0 | 11591.1 | –7508.6 | 6395.7 | –1112.9 | –2244.3 | 6173.2 | 3928.8 | 1161.8 | 2298.6 | 3460.4 |
| 2003–2004 | –10266.0 | 19200.7 | 8934.7 | –10500.6 | 10794.3 | 293.6 | 12024.9 | 11907.6 | 23932.5 | –1053.5 | 4037.8 | 2984.3 |
| 2004–2005 | –5075.2 | 6324.7 | 1249.5 | –10589.3 | 14643.8 | 4054.6 | –746.9 | 3399.6 | 2652.7 | –1751.5 | 3162.2 | 1410.7 |
| 2005–2006 | –6129.6 | 16613.8 | 10484.2 | –13081.8 | 16223.9 | 3142.1 | –5734.1 | 9544.5 | 3810.4 | –974.7 | 4443.3 | 3468.6 |
| 1995–2006 | –201480.1 | 213172.8 | 11692.7 | –252020.5 | 249756.8 | –2263.7 | –133003 | 146941.2 | 13938.2 | –28202.2 | 38811.5 | 10609.3 |

respectively, compared to those in 1996. However, the dematerialization effects in coal and multi-resources cities decreased by 33.40% and 51.89%. Because of the opposite effect between dematerialization effect and rebound effect, the increase effect of the petroleum cities decreased by 28.21% compared to that in 1996, which did not reach an absolute dematerialization expected less than zero. Because of the exceedingly rapid growth of rebound effect in metallurgy cities, the increase effect increased 2.48 times. The decrease of dematerialization effect and the increase of rebound effect worked together, making the material demand rise. Material demand in coal cities did increased 1.44 times and that in multi-resources cities did from $-25.9\times10^3$t to $3468.6\times10^3$t. It is a substantial change from absolute dematerialization to relative one in economic development.

All the above analysis can tell that due to the economic development, coal, metallurgy and multi-resources cities in Northeast China are under increasingly severe environmental pressure. However, such pressure of the petroleum cities have weakened, showing the trend of strong sustainable development.

### 4.2 Assessment of sustainable development based on dematerialization

The realization of an unhook trend between economic development and material consumption depend not only on the reduction of material input into economy system, but also on the decrease of material consuming intensity, which is the aim of carrying out the dematerialization research. According to the relation between increase effect and material demanding intensity, the sustainable development of mining cities can be divided into three types: 1) when $\Delta DMI<0$, and $\Delta\frac{DMI}{GDP}<0$, i.e. when the substance needed for economic development is absolutely decreasing, it can be called strong sustainable development; 2) when $\Delta DMI>0$, and $\Delta\frac{DMI}{GDP}<0$, i.e. when the substance needed for economic development is relatively decreasing, it can be called weak sustainable development; 3) when $\Delta DMI>0$, and $\Delta\frac{DMI}{GDP}>0$, i.e. when both the amount of material demand and the demanding intensity of material are in growing trend, because of the extensive use of material, it can be called unsustainable development.

From the Table 2 and Fig. 5, we can know during the research period (1996–2006), the time that coal, petroleum, metallurgy and multi-resources cities was in weak sustainable development were 6 years, 8 years, 5 years, and 7 years respectively, accounting for 54.5%, 72.7%, 45.5%, 63.6% of the whole research period. This shows that the mining cities in Northeast China were in the situation of weak sustainable development in recent 10 years.

## 5 Decomposition Analysis on DMI Factors

In accordance with the Equations (6) and (7), the change of material input of mining cities in Northeast China can be figured out by the following four factors such as

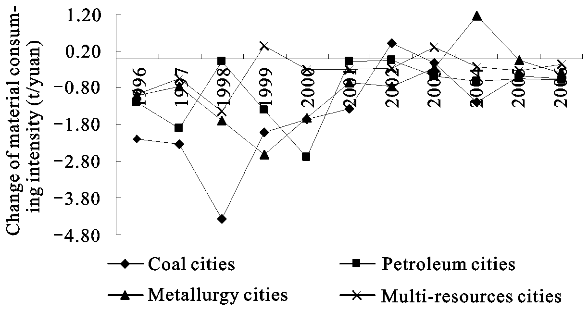



Fig. 5 Change of material consuming intensity of mining cities in Northeast China in 1996–2006

population, economic level, material utilizing efficiency and material input structure. We can get from the Fig. 6 that the great improvement of economic growth is the main factor to cause the increase of material input of mining cities in Northeast China. The trend of the contribution value of material input caused by economic growth is rising as a whole but with different fluctuation. The three mining cities such as coal, metallurgy, and multi-resources cities experienced the process of decrease first and then increase; while the petroleum cities experienced the process of decrease-increase-decrease-increase. Since 2004, the contribution value of material input caused by economic growth in various mining cities has showed a fluctuating growth. This trend is not only restrained by the process of China's economic growth, but also reflects the change of resources demand caused by economic development. The population growth in the mining cities in Northeast China was not large in the past 10 years, during which population decrease came up especially in coal cities, making the pulling effect, caused by population change, small on material demand. Meanwhile, material input in mining cities is mainly non-regenerative resources accounting for 70% of material input. Therefore the material input structure on the whole has a relatively small influence upon the change of material input in mining cities (Fig. 6).

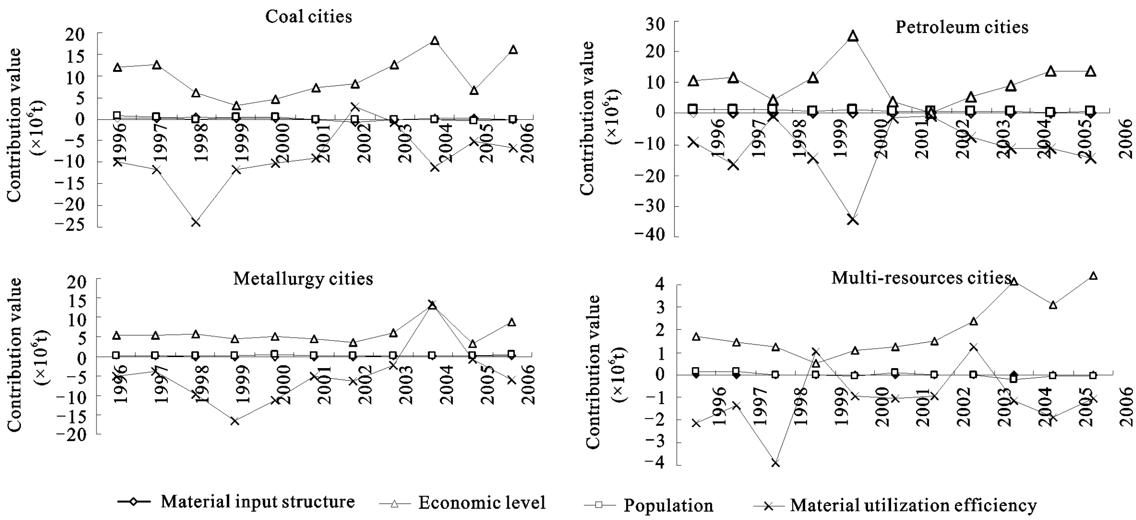



Fig. 6 Contribution value of to DMI in mining cities in Northeast China in 1996–2006

The inhibiting effect on the material input of mining cities in Northeast China mainly comes from the improvement of material utilizing efficiency caused by the technological progress. As Fig. 6 shows, the contribution of the material utilizing efficiency to the decrease of the DMI is increasing with different degrees in various mining cities. And for coal cities, this contribution value has gone through the process of increase, decrease and increase in the whole. Especially since 2005, because of pulling effect of the economic growth surpasses decreasing effect of the material utilizing efficiency, material consumption has increased. Since 2002, in the petroleum cities the inhibiting effect of material utilizing efficiency surpasses the pulling effect of the economic growth, which has resulted in the slow increase of material consumption. Since 2004, in the metallurgy cities the inhibiting effect, growing significantly, is near to the pulling effect of the economic growth, which has led to the slow increase of material consumption. However, since 2005, in multi-resources cities, the superposition of the two effects has contributed greatly to a sharp increase of material input.

For in-depth analysis of the contribution rate caused by the four factors—population, economic growth, material utilizing efficiency and the material input structure in mining cities in Northeast China, it can be divided into two kinds—pulling factors (population and economic growth) and inhibiting factors (material utilizing efficiency and material input structure). Meanwhile, we make the reciprocal of the contribution rate of the inhibiting factors, which can be called the contribution rate for the material input decrease, which can help us compare the development trends of the contribution rates of the inhibiting and pulling factors to the DMI in mining cities (Fig. 7).

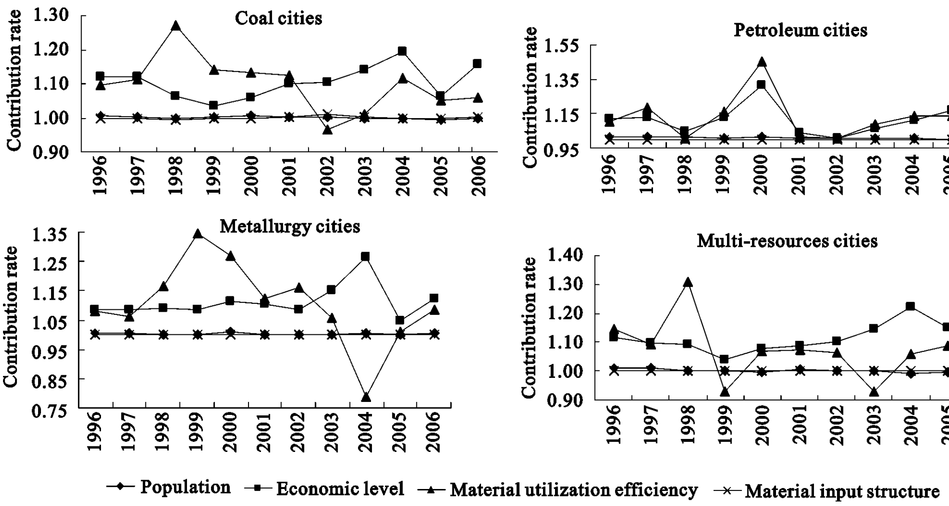



Fig. 7 Contribution rate to DMI in the mining cities in Northeast China in 1996–2006

Figure 7 shows basically a growing trend of the contribution rate of the economic growth to DMI in the mining cities in Northeast China. And it was lower than that of the material utilizing efficiency to DMI increase before and since 2000 (except the multi-resources cities). Afterwards, the economic factor led to a sharp rise of the material input in mining cities (except the petroleum cities). The contribution rate of population factor in driving and restraining the increase of DMI was consistent with that of material input structure. And this rate was far lower than that of economic growth and material utilizing efficiency. Undoubtedly, with the decrease of non-regenerative resources exploitation, the regenerative resources will play a supporting role in the mining cities' economic growth. So the material input structure will have an ever-increasing effect on the change of material consumption of the mining cities.

## 6 Conclusions

According to the calculation and the analysis of the dematerialization of the DMI of the economic system of the mining cities in Northeast China during 1995–2006, the conclusion can be drawn as follows:

(1) With the rapid economic growth during 1995–2006, the DMI of the economic system of the mining cities in Northeast China presented a continuously increasing trend as a whole (with the exception of the petroleum cities), and the input intensity of DMI of the mining cities in Northeast China is not only higher than the national average level, but also much higher than that of the developed regions such as Guangdong Province, which shows the distinguishing characteristic that the development of the mining cities is driven by resources. From different types of resources, the increase rates of the DMI and the material input intensity of mining cities are declining following the order of multi-resources, metallurgy, coal, and petroleum cities; and the material utilizing efficiency declining following the order of petroleum, multi-resources, metallurgy, and coal cities.

(2) In recent ten years, the rebound effect of the DMI, caused by the economic growth of the mining cities in Northeast China, is in an increasing trend as a whole. The increase rate of the rebound effect of the mining cities is in the order of multi-resources, metallurgy, petroleum and coal cities from rapidness to slowness while the dematerialization effect is in the order of petroleum, metallurgy, coal and multi-resources cities from strongness to weakness. It can be seen that the pressure of the resources and environment upon the multi-resources cities is the most serious, while the petroleum cities show the trend of strong sustainable development of the

absolute dematerialization. Basing on the comprehensive consideration of material increase effect and the change of material consuming intensity, we may hold the mining cities in Northeast China are basically in the situation of weak sustainable development.

(3) The two leading factors, economic growth and material utilizing efficiency, restrain the material consumption of mining cities. In recent years, the driving effect of economic growth on material consumption has been continuously strengthened while the inhibiting effect of material utilizing efficiency on material consumption has been weakened. So, to further research and develop the technology of resources recycling, to advance the utilizing efficiency of resources and to implement the auditing system of resources utilization are the major measures at present and also in the fairly long time thereafter to promote sustainable utilization of resources.

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