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by

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DISCUSSION PAPER 11.25

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ABSTRACT

This paper contributes to the existing literature as well as policy debates by examining energy intensity and its determinants in China's regional economies. The analysis is based on a comprehensive database of China's regional energy balance constructed for this project. Through its focus on regional China, this study extends the existing literature which mainly covers nationwide studies. It is found in this paper that energy intensity declined substantially in China. The main contributing factor is the improvement in energy efficiency. Changes in the economic structure have so far affected energy intensity modestly. Thus there is considerable scope to reduce energy intensity through the structural transformation of the Chinese economy in the future.

Key words Energy intensity, energy efficiency, structural change and China

JEL codes Q43, R11 and Q48

1. Introduction

Over the past three decades the Chinese economy has indeed achieved impressively high growth. This growth is however associated with deteriorating environmental conditions in the country (World Bank 2001, Wu 2010). With increasing environmental awareness in the society and demand for better quality of life by ordinary citizens, Chinese policy makers are under tremendous pressure to rechart the country's course of growth in the coming decades. A key issue of concern is related to energy consumption which is the main source of pollutants in the air, soil and water. China is now the world's largest energy consumer as well as CO_2 emitter. The country's energy consumption pattern will have important implications for the global environment.

So far the literature has focused on forecasting future energy consumption in China particularly at the aggregate level (Crompton and Wu 2003, IEA 2009). There are a few papers which investigated China's energy intensity (defined as the ratio of energy consumption over output such as GDP). As shown in Table 1, these studies can be broadly divided into several groups, namely, national, regional, sectoral and other studies. First, Garbaccio et al. (1999) and Ma and Stern (2008) adopted different decomposition methods to examine energy intensity at the national level. Second, Huang (1993), Sinton and Levine (1994) and Zhang (2003) represented earlier studies of energy intensity in China's industrial sector in the 1980s and 1990s. Recently Liao et al. (2007) and Zhao et al. (2010) extended earlier studies to sub-sectors at the two-digit level. All sectoral studies followed the decomposition method. Zheng et al. (2011) is an exception which applied regression analysis to investigate the impact of exports on energy intensity in 20 sub-sectors during 1999-2007.

Table 1 Major Studies of China's Energy Intensity

Authors	Data	Method
National/aggregate level		
Garbaccio et al. (1999)	1987 & 1992	I-O tables/index method
Ma and Stern (2008)	1980-2003	LMDI
Sectoral level		
Huang (1993)	1980-88	Divisia index/Industry
Sinton and Levine (1994)	1980s	Laspeyres index/Industry
Zhang (2003)	1990s	IDA/29 sub-sectors
Liao et al. (2007)	1997-2006	IDA/36 sub-sectors
Zhao et al. (2010)	1998-2006	LMDI/15 sub-sectors
Zheng et al. (2011)	1999-2007	Regressions/20 sub-sectors (exports)
Regional		
Qi and Luo (2007),	1995-2002	Regressions
Li and Wang (2008)	1995-2005	LMDI
Ma et al. (2009)	1995-2004	Cost functions
Wang and Zhong (2009).	1995-2006	Regressions
Yuxiang and Chen 2010	1996-2006	Regressions/government spending
Other studies		
Fisher-Vanden et al. (2004)	1997-99	Divisia/regressions (firm level)
Golley (2008)	2005	Energy requirement (household level)
Chai et al. (2009)	4 years	I-O tables/30 sub-sectors (1992-2004)

Source: Author's own compilation.
Note: I-O tables: Input-output tables. LMDI: Logarithmic mean Divisia index. IDA: Index decomposition analysis.

Third, several recent papers employed provincial (regional) data and regression techniques to examine China's energy intensity. For example, Qi and Luo (2007) investigated the relationship between energy intensity and economic growth, Wang and Zhong (2009) explored the effect of regional resource endowment on energy intensity, and Yuxiang and Chen (2010) examined the impact of government expenditure on energy intensity. Furthermore, Ma et al. (2009) investigated the substitutability between fuels and between energy and factor inputs (capital and labour) and Li and Wang (2008) adopted the popular logarithmic mean Divisia index

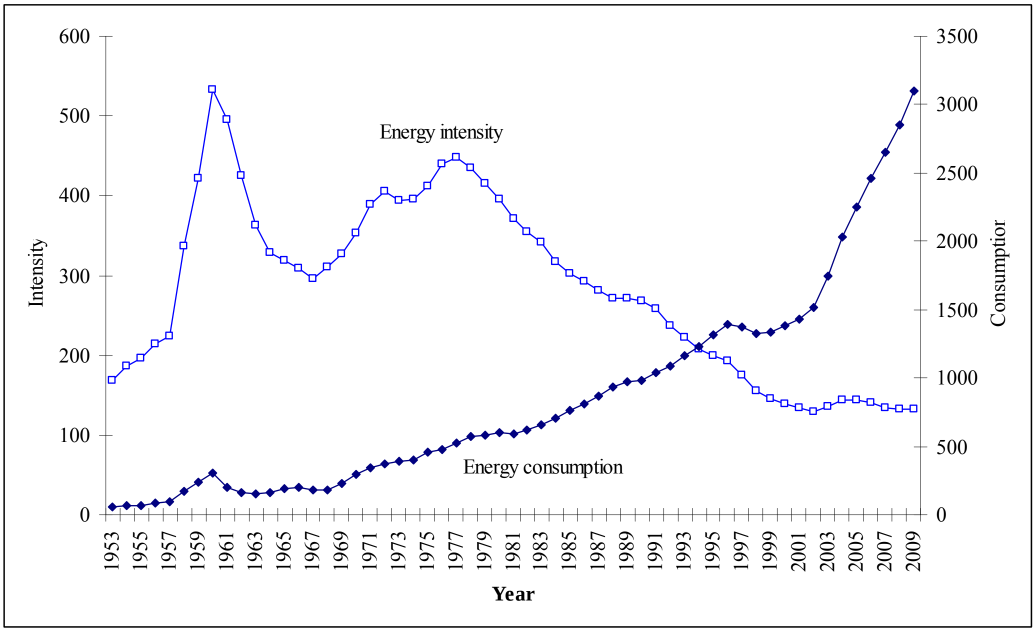
(LMDI) approach to understand energy intensity changes across the regions. Finally, several papers are differentiated from the national, sectoral and regional studies just reviewed. Fisher-Vanden et al. (2004) is the first paper with a focus on energy intensity at the firm-level (involving data of 2500 firms and three years 1997-1999). Golley et al. (2008) presented a detailed study of energy requirement and CO_2 emissions at household level in urban China. Chai et al. (2009) employed a decomposition method involving the input-output table to explore how various factors affect energy intensity in China.

The present study extends the existing literature in two ways. The analysis is for the first time based on sectoral energy consumption data in the Chinese regions. In addition, it applies regression analyses to examine the determinants of energy intensity and its components at the regional level. It is found in this study that there is considerable regional disparity in energy intensity as well as its trend of movement over time. It is also shown in the empirical analysis that changes in regional energy intensity are mainly affected by energy efficiency changes with hardly any impact from economic structural transformation in the regions. This finding implies the need for urgent policy actions in order to reduce energy intensity through structural changes in China's regional economies in the coming decades. Other factors which are important for the reduction in energy intensity include energy prices and adoption of new technologies in regional economies.

The rest of the paper begins with Section 2 where energy intensity at the national level is briefly discussed. Section 3 then presents a preliminary analysis of energy intensity in the regions. Subsequently, regression analysis in Section 4 is employed to investigate the determinants of regional intensity variations. This is followed by further discussions of selected issues in Section 5. The concluding remarks are presented in Section 6.

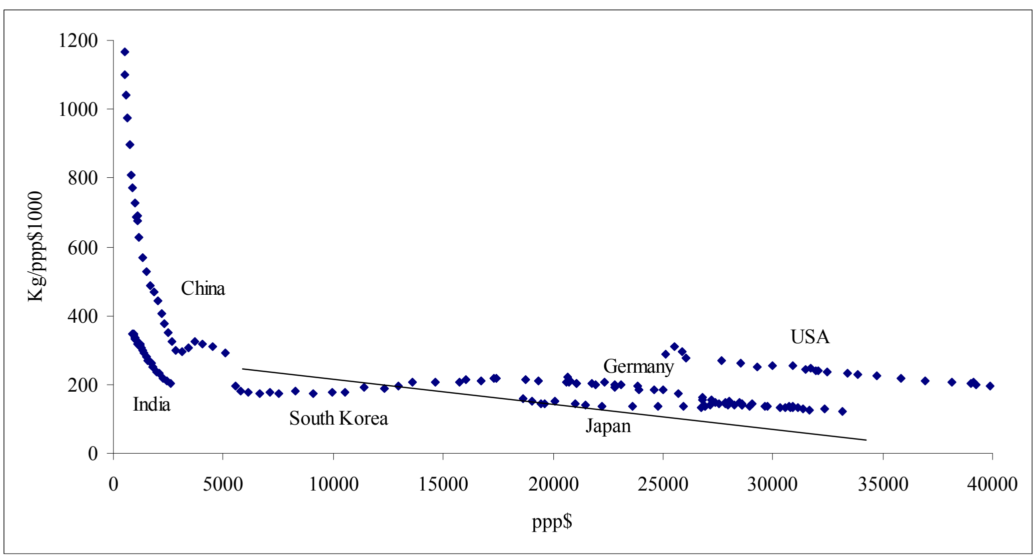
2. Energy Intensity in China

During the period of 1953-2009 the movement of China's energy intensity basically followed an inverted U-shaped curve though total energy consumption increased steadily (Figure 1). Before the country's economic reform program was introduced in 1978, energy intensity fluctuated considerably and its overall trend of changes was upward. It peaked twice in 1960 and 1977, respectively. This course of changes is consistent with the pattern of economic growth before 1978. During that period, the Chinese economy experienced a few ups and downs due to political chaos and poor economic policies. However, during the post-reform decades (1978-2009), energy intensity basically followed a declining trend though there were temporary disruptions in several years, namely, in 1989 and during 2003-2005 when energy intensity was recorded with a minor increase. Thus the "dematerialization" phenomenon was also observed in China as income increases over time (Bernardini and Galli 1993). In international perspectives, China's energy intensity is converging rapidly with major energy consumers in the world (Figure 2). Especially, China seems to follow the similar paths undergone by Japan and South Korea. If the overall trend is maintained, China could even do better than the major economies in terms of energy intensity reduction in the future (refer to the solid line in Figure 2).



Note: Energy intensity is expressed in kilograms coal equivalent per 1000 yuan in 2000 prices and energy consumption in million tons (MTs) coal equivalent.
Sources: NBS (various issues, 2009 and 2010).

Figure 1 China's Energy intensity 1953-2009



Note: The unit of energy intensity is kilogram of oil equivalent per ppp$1000 in 2005 constant prices. The data are based on statistics during 1980-2007 for each country.
Source: Author's own calculation using data from the World Bank (2010).

Figure 2 Energy intensity and Economic Development

To gain a better understanding of the trend in China's energy intensity, the following decomposition approach is considered

$$I_t = C_t / Y_t = \Sigma_i \frac{C_{it}}{Y_{it}} \frac{Y_{it}}{Y_t} = \Sigma_i E_{it} S_{it} = \Sigma_i I_{it} \qquad (1)$$

where I_t, C_t and Y_t represent energy intensity, energy consumption and GDP. The economy is divided into three sectors, namely, the primary, manufacturing and service sectors.[1] Energy is consumed in the three sectors and for residential purposes (i=1, 2, 3 and 4). E_{it} and S_{it} are employed to measure energy use efficiency and shares of economic activities (or value-added over GDP in the sectors). For the residential sector, value-added is replaced by the value of household consumption.

Equation (1) implies that energy intensity is linked with energy efficiency and sectoral output shares, respectively. This is the so-called index decomposition analysis (IDA) technique proposed and widely used in the literature. Empirically authors have adopted either the Divisia index or the Laspeyres index method.[2] Several comparative studies however show that the log mean Divisia index (LMDI) method is preferred to other index approaches (Greening et al. 1997, Ang 2004). Following the IDA approach, changes in energy intensity (ΔI_t) can be decomposed into two components which may be called the efficiency and structural change components, respectively. On the one hand, the efficiency component (ΔE_t) refers to changes in energy intensity which are associated with changes in energy use efficiency. On the other hand, the

[1] Ma and Stern (2008) presented a more disaggregate decomposition analysis at the national level for the period of 1994-2003.

[2] Ang and Zhang (2000) presented a comprehensive review of the literature, particularly various IDA methods.

structural change component (ΔS_t) captures the contribution of economic structural changes to energy intensity variation. Symbolically, the additive version can be presented as[3]

$$\Delta I_t = \Delta E_t + \Delta S_t \qquad (2)$$

where

$$\Delta I_t = I_t - I_{t-1} \qquad (3)$$

$$\Delta E_t = \Sigma_i \frac{I_{it} - I_{i,t-1}}{\ln I_{it} - \ln I_{i,t-1}} \ln(\frac{E_{it}}{E_{i,t-1}}) \qquad (4)$$

$$\Delta S_t = \Sigma_i \frac{I_{it} - I_{i,t-1}}{\ln I_{it} - \ln I_{i,t-1}} \ln(\frac{S_{it}}{S_{i,t-1}}) \qquad (5)$$

Following the system of Equations (1) to (5), the year-to-year variations in energy intensity together with the contributions of the efficiency and structural change components are estimated. The 5-year span mean values are presented in Table 2. The 5-year spans correspond to China's Five Year Plan cycles. According to this table, China's energy intensity declined in most periods during 1981-2007 with the exception of the years of 2001-2005.[4] The main contributing factor for the decline in energy intensity is efficiency improvement. With the exception of the period of 1981-1985, structural change has only made marginal contributions to the decline in energy intensity. This phenomenon is clearly demonstrated in the three indexes reflecting the accumulated changes in energy intensity, the efficiency and structural change components over time (see Figure 3). While energy intensity fell substantially between 1980 and 2007, the curve of the structural change index is almost flat. Thus

[3] Technical details are available in Ang (2005).

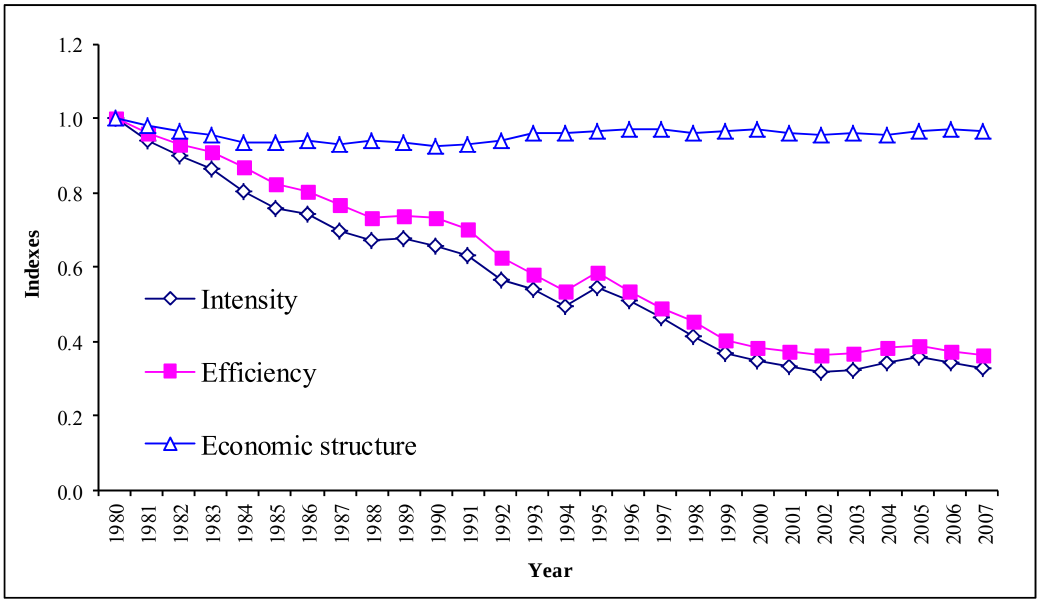
[4] For detailed exploration of the fall and rise of energy intensity in China, the redears may refer to Liao et al. (2007) and Zhao et al. (2010).

economic structural change in China has hardly made any contribution towards the decline in energy intensity for about three decades. This is consistent with the findings in the existing studies using aggregate data (such as Ma and Stern 2008, Liao et al. 2007). It seems that, only during the period of 1981-1985, the Chinese economy maintained continuously a good balance between efficiency improvement and structural changes as far as the trend of energy intensity is concerned. This is worrying for Chinese policy makers who are attempting to steer the economy to an alternative model of development which replies less upon the growth in labour-intensive sectors and which emphasizes innovation and growth of the service sector.

Table 2 Energy Intensity Decomposition, 1981-2007

			Changes				Shares (%)	
Year		Efficiency	Structure	Intensity		Efficiency	Structure	Intensity
1981-85		-12.5	-4.8	-17.3		72	28	100
1986-90		-6.4	-0.9	-7.2		88	12	100
1991-95		-9.7	2.0	-7.7		127	-27	100
1996-00		-13.9	-0.2	-14.0		99	1	100
2001-05		0.4	0.1	0.4		87	13	100
2006		-5.7	1.3	-4.4		131	-31	100
2007		-4.1	-1.0	-5.1		80	20	100

Sources: Author's own calculation. The raw data are drawn from various issues of China's Energy Statistics Yearbook and China's Statistics Yearbook (NBSC, various issues).



Sources: Author's own calculations. The raw data are drawn from various issues of China's Energy Statistics Yearbook and China's Statistics Yearbook (NBSC, various issues).

Figure 3 Intensity, Efficiency and Structural Indexes, 1980-2007

3. Energy Intensity in the Regions

There are few studies focusing on energy intensity in China's regional economies largely due to the scarcity of data. Hu and Wang (2006) and Dan (2007) are two exceptions. Hu and Wang employed the data envelopment analysis (DEA) approach to compare the potential energy consumption with actual energy use in the regions. They divided China geographically into three regions and found that the central region had the lowest average energy efficiency during the period 1995-2002. Dan examined the so-called regional energy efficiency which is defined as the ratio of gross regional product (GRP) per unit of energy use (this is contrary to the conventional energy intensity concept). Dan showed the existence of substantial variations in regional energy efficiency and argued that the coastal regions on average performed better than the rest of the country during 1990-2004. None of them however explored energy intensity at the sector level among the regions. To prepare for this paper, a comprehensive database is compiled. The database contains energy consumption information at the sectoral level for twenty-seven Chinese regions during the period of 1997-2007.[5] As shown in Table 3, there is considerable variation in energy intensity among the regions ranging from around 60 to more than 400 kilogram coal equivalent (*KgCE*) per 1000 *yuan* output.[6] Over time the mean intensity declined from 206 to 149 *KgCE* per 1000 *yuan* between 1997 and 2007. So did the standard deviation from 103 to 76 *KgCE* per 1000 *yuan*. However, the coefficient of variations remains almost the same being around 0.5 which implies no convergence in regional energy intensity during 1997-2007.

Following the IDA approach described in Section 2, changes in energy intensity in each region is decomposed into two components which reflect the contributions of energy efficiency and economic structural changes, respectively. The decomposition results are presented in Table 3. In general, the western regions were recorded with the highest average energy intensity in 1997 followed in turn by the central and coastal regions. During the decade of 1997-2007, energy intensity fell in 23 regions out of 27 regions considered. In terms of absolute changes, several regions (namely, Beijing, Jilin, Inner Mongolia, Guizhou, Qinghai and Xinjiang) were recorded with a big fall in energy intensity between 1997 and 2007. It is interesting to note that on average the reduction in intensity in the western regions is twice as great as those in the coastal and central regions. Once again it is found that, of the two components, energy efficiency improvement is the dominant contributor to the decline in intensity. In fact, the average contribution of economic structural changes to intensity decline is negative in the three regional groups, that is, the coastal, western and central regions.

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[5] There are thiry-one administrative regions in mainland China. Due to missing data four regions (Tibet, Hainan, Chongqing and Ningxia) are excluded in this study.
[6] The Chinese currency unit is *yuan*. In 2010, the exchange rate is approximately 6.6 yuan/US$.

These regional differences call for further investigation into the determinants of the variation in regional energy intensity.

Table 3 Energy Intensity and Changes between 1997 and 2007

Regions	Energy intensity		Absolute	Component changes	
	1997	2007	changes	Efficiency	Structure
Beijing	206.4	83.6	-122.7	-97.3	-25.4
Tianjin	187.1	94.8	-92.4	-96.6	4.3
Hebei	246.8	225.5	-21.3	-31.1	9.9
Liaoning	310.0	284.4	-25.6	-32.7	7.1
Shanghai	170.6	82.9	-87.8	-83.2	-4.6
Jiangsu	104.5	81.3	-23.2	-28.9	5.6
Zhejiang	78.9	60.1	-18.8	-17.1	-1.7
Fujian	59.7	80.9	21.3	15.2	6.1
Shandong	98.2	98.6	0.3	-9.8	10.1
Guangdong	81.3	62.0	-19.3	-22.3	3.1
Coastal mean	*154.4*	*115.4*	*-39.0*	*-40.4*	*1.4*
Shanxi	404.5	391.5	-12.9	-36.9	24.0
Jilin	328.5	167.8	-160.7	-183.8	23.1
Heilongjiang	186.9	112.3	-74.6	-67.5	-7.2
Anhui	164.1	109.5	-54.6	-39.7	-14.9
Jiangxi	141.6	181.4	39.9	13.2	26.6
Henan	161.5	132.6	-28.9	-45.4	16.5
Hubei	170.2	124.4	-45.8	-34.7	-11.1
Hunan	134.9	133.9	-1.0	-4.6	3.6
Central mean	211.5	169.2	*-42.3*	*-49.9*	*7.6*
InnerMongolia	435.3	224.8	-210.5	-261.5	51.1
Guangxi	111.4	140.6	29.2	22.9	6.3
Sichuan	154.6	90.0	-64.5	-66.5	1.9
Guizhou	384.5	226.5	-157.9	-175.6	17.6
Yunnan	192.5	187.9	-4.6	9.8	-14.4
Shaanxi	196.0	102.1	-93.9	-109.6	15.7
Gansu	271.5	184.4	-87.1	-91.3	4.2
Qinghai	307.3	182.3	-125.0	-180.1	55.0
Xinjiang	284.2	174.9	-109.3	-139.4	30.1
Western mean	*259.7*	*168.2*	*-91.5*	*-110.1*	*18.6*

Sources: Author's own calculation. The raw data are drawn from various issues of China's Energy Statistics Yearbook and China's Statistics Yearbook (NBSC, Various issues).

4. Determinants of Regional Energy Intensity

To understand regional variation in energy intensity and its determinants, three regional indices similar to those in Figure 3 are computed using the decomposition results from Section 3. The indices relative to the initial year (1997) capture the trends in energy intensity change and its two components over time. To examine the determinants of regional variation, the indices reflecting the two components, namely, the energy efficiency (EE_{it}) component and structural change (SC_{it}) component, are regressed against a set of region-specific covariates or explanatory variables (X_{it}). Symbolically,

$$Y_{it} = \alpha_0 + \Sigma_j \alpha_j X_{ijt} + \varepsilon_{it} \qquad (6)$$

where Y_{it} represents either the efficiency index (EE_{it}) or the structural change index (SC_{it}) for region i and at year t. The covariates (X_{ijt}) are selected to capture specific characteristics of regional economies and detailed as follows.

An income (*Income*) variable is included to reflect the level of economic development in the regions. It is measured by per capita gross regional product (GRP) which is expressed in 2000 constant prices. It is argued that energy efficiency generally improves as an economy develops.[7] In accordance with this argument, the coefficient of the *Income* variable is expected to be negative.

[7] "A Better World for All", a report of the Progress towards the International Development Goals project jointly conducted by the IMF, OECD, United Nations and World Bank, 2000 (http://www.paris21.org/sites/default/files/bwa_e.pdf).

A price (*Price*) variable is considered to evaluate the impact of fuel prices on energy intensity. As China's fuel price data are not available, the fuel price index for each region is employed as a proxy of fuel prices. It is also expressed in terms of 2000 constant prices. In general, an increase in energy prices raises the cost of production. Producers may respond by improving energy efficiency. Thus the coefficient of the *Price* variable is expected to be negative.

Other variables considered include the capital-labour ratio (*Klratio*) and the growth rate of capital stock (*Krate*). On the one hand, it is argued that energy and technology or capital may be substitutes (Thompson and Taylor 1995, Metcalf 2008). The capital-labour ratio here is employed as a proxy of the level of technology involved. Thus the capital-labour ratio (*Klratio*) variable may be negatively related to energy intensity. That is, energy intensity is expected to decline as production technology improves. On the other hand, the growth of capital stock may to some extent reflect the speed of old machines and structures being replaced and is hence introduced as a measure of the vintage of capital. New capital may be endowed with energy-saving technology and is thus more energy efficient. Therefore, the coefficient of the *Klratio* variable is expected to be negative. A time trend (*Time*) is also included in the model to capture the trend of change over time and is expected to have a negative coefficient.

The baseline model estimated is a fixed effect log-log model. The estimation results are presented in Table 4. The lagged values of some explanatory variables are employed to avoid the problem of simultaneity. Model 1 is the simple version of Equation (6). The estimated coefficients of the *Income*, *Price* and *Time* trend variables have the expected sign and are statistically significant. The coefficients of the capital-labour ratio (*Klratio*) and capital stock growth (*Krate*) variables have the wrong sign. To consider the possibility of non-linearity, the squared terms of those variables are added to the model. The estimation results of the optional model (Model 2 in Table 4) confirm the existence of nonlinear relationship as the estimated coefficients of the squared terms are statistically significant. The values of the adjusted R^2 also indicate that Model 2 is preferred to Model 1. The F test statistic also shows that the fixed effects are statistically significant.[8]

[8] The fixed effect model is also tested against the random effect model. However, for both Models 1 and 2, the Hausman test statistics are collapsed. The estimation results of the random effect model (not reported) do show insignificant coefficients for several explanatory variables.

Table 4 Estimation Results

Variables	Model 1 α	Model 1 p	Model 2 α	Model 2 p	Model 3 α	Model 3 p	Model 4 α	Model 4 p
log(*Income*)	-0.433	0.001	-0.304	0.015	0.151	0.000	0.157	0.000
log($Price_{-1}$)	-0.163	0.008	-0.158	0.003	-0.056	0.001	-0.052	0.001
log($Klratio_{-1}$)	0.566	0.000	0.562	0.000	0.039	0.215	0.032	0.333
$\log^2$($Klratio_{-1}$)			-0.054	0.000			-0.004	0.099
log($Krate_{-1}$)	1.357	0.000	10.755	0.000	-0.215	0.045	-0.343	0.366
$\log^2$($Krate_{-1}$)			-38.125	0.000			0.421	0.753
Time	-0.027	0.004	-0.055	0.000	-0.009	0.004	-0.010	0.011
F-value	27.820	0.000	35.280	0.000	30.859	0.000	27.228	0.000
Fixed effect test (*F*)	25.349	0.000	22.849	0.000	22.397	0.000	16.194	0.000
Adjusted R^2	0.775		0.824		0.793		0.781	
Sample size	243		243		243		243	
Dependent variable	log(*EE*)		log(*EE*)		log(*SC*)		log(*SC*)	

Notes: The estimated coefficients of the variables are listed in the α columns and the corresponding *p*-values are printed aside in smaller fonts.

Several conclusions can be drawn from the estimation results of the fixed effect model. First, energy efficiency improves as income per capita increases among the Chinese regions. Thus, as the regions become more developed, energy use becomes more efficient and hence energy intensity falls. Second, energy price movement is negatively related to energy efficiency. That is, the efficiency component index tends to decline (a positive contribution to intensity decline) as prices increase. The average price elasticity is estimated to be -0.158. This finding is consistent with the observation by Ma et al. (2009) who showed that energy intensity declined by approximately 20% during 2000-2004 due to increasing energy prices. Third, it is confirmed that the efficiency index and capital-labour ratio variable have an inverted U-shaped relationship. However the estimated average turning point is far greater than the actual capital-labour ratios for the Chinese regions. Thus at the current level of development, it seems that there is no substitution effect between capital and energy in China's regional economies. Fourth, the non-linear relationship between the efficiency component index and growth in capital stock or vintage of capital variable shows that technology embodied in new capital may help improve efficiency after growth reaches certain level. The estimated turning point is an average rate of growth of 15.1 per cent. In 2007, seven out of the 27 regions included in the sample surpassed the turning point rate of growth. Thus those regions may have benefited from the speedy replacement of old equipment and structures. Finally, the estimation results show that the efficiency component index tends to fall over time. This is consistent with the positive contribution of the efficiency component to the decline in energy intensity observed in the preceding section.

For the purpose of comparison, the structural change component index is also regressed against the same set of covariates. The regression results are presented in Table 4 (Models 3 and 4). Apparently Model 3 without the squared terms is preferred to Model 4 in which the two estimated coefficients of the squared terms are statistically insignificant. The estimated coefficients in Model 3 have the expected sign with two exceptions. First, the estimated coefficient of the *Income* variable in Model 3 is positive and statistically significant. Thus as regional economies grow, structural change has not led to the reduction in energy intensity. On the contrary, it might play the role in raising energy intensity in some regions. This is consistent with the findings from the preliminary analysis. Second, Model 3 also shows a positive relationship between the structural change component index and capital-labour ratio but this relation is statistically insignificant.

5. Further Considerations

The analyses in the preceding section are likely affected by several factors. The first factor is the possible existence of unit roots in the variables included in the models. The results of five tests for unit roots are mixed as some tests are statistically significant and others are not (see Table 5). To explore this issue further, the popular generalized method of moments (GMM) is employed to re-estimate the models. In addition, it is assumed that the use of GMM may also correct potential problems with multicollinearity, heteroscedasticity and autocorrelation of unknown forms in the models. Finally, there may be potential problems with endogeneity in the models reported in Table 4. This is another reason to adopt the GMM approach.

Table 5 Unit Root Test Results

Variables	LLC	Breitung	IPS	ADF	PP
log(*EE*)	-7.104	-0.687	-0.225	63.927	81.980
	0.000	*0.246*	*0.411*	*0.167*	*0.008*
log(*SC*)	-5.739	2.293	0.759	40.518	60.064
	0.000	*0.989*	*0.776*	*0.913*	*0.266*
log(*Income*)	-20.178	0.585	-4.085	162.082	44.209
	0.000	*0.721*	*0.000*	*0.000*	*0.827*
log(*Price*)	-16.500	0.980	-3.366	142.243	180.869
	0.000	*0.837*	*0.000*	*0.000*	*0.000*
log(*Klratio*)	-16.108	-2.463	-1.941	111.487	62.114
	0.000	*0.007*	*0.026*	*0.000*	*0.210*
$\log^2$(*Klratio*)	-18.182	1.104	-4.296	168.922	103.456
	0.000	*0.865*	*0.000*	*0.000*	*0.000*
log(*Krate*)	-5.562	1.040	0.655	47.076	132.445
	0.000	*0.851*	*0.744*	*0.736*	*0.000*
$\log^2$(*Krate*)	-2.601	7.864	1.256	38.012	110.487
	0.005	*1.000*	*0.896*	*0.951*	*0.000*

Notes:

The *p*-value is presented underneath each statistic.
LLC: Levin, Lin and Chu *t* test;
Breitung: Breitung *t* statistic;
IPS: Im, Pesaran and Shin Wald statistic;
ADF: ADF Fisher χ^2 test; and
PP: PP Fisher χ^2 test.

Source: Author's own calculation.

The estimation results are illustrated in Table 6 (Models 5 and 6) are estimated using the efficiency component index as the dependent variable. A major issue with the GMM approach is the choice of instrumental variables (IVs) which can lead to over-identification of the model. To deal with this problem, the number of IVs is controlled and the Sargan test is conducted. The IVs used in each model are described in the notes to Table 6. Both models (5 and 6) passed the Sargan test for over-identification.

To tackle the possible presence of serial correlation, the estimation method built-in in Eviews 7 is employed here.[9] It is assumed that the errors for a cross-section are heteroscedastic and serially correlated. Under this assumption, the coefficient covariance is calculated and hence the corrected standard errors of the estimated coefficients are reported. The results from the static GMM estimation (Model 5) are generally consistent with those from Model 2 in Table 4.

Table 6 GMM Estimation Results

	Model 5		Model 6		Model 7		Model 8	
Variables	:	*p*	:	*p*	:	*p*	:	*p*
log(EE_{-1})					0.310	*0.000*		
log(SC_{-1})							*0.579*	*0.000*
log(*Income*)	-0.284	*0.000*	0.147	*0.000*	-0.010	*0.961*	0.057	*0.000*
log($Price_{-1}$)	-0.268	*0.000*	-0.011	*0.059*	-0.166	*0.045*	-0.009	*0.415*
log($Klratio_{-1}$)	0.351	*0.000*	0.015	*0.001*	0.422	*0.000*	0.018	*0.061*
$\log^2$($Klratio_{-1}$)	-0.047	*0.000*			-0.042	*0.001*		
log($Krate_{-1}$)	2.857	*0.004*	0.226	*0.000*	2.795	*0.049*	0.165	*0.000*
$\log^2$($Krate_{-1}$)	-8.040	*0.010*			-10.189	*0.023*		
Time	-0.022	*0.068*	-0.010	*0.000*	-0.060	*0.043*	-0.004	*0.046*
Sargan statistic	20.340	*0.729*	26.527	*0.489*	12.613	*0.943*	19.352	*0.681*
Sample size	216		216		216		216	
Dependent variable	log(*EE*)		log(*SC*)		log(*EE*)		log(*SC*)	

Notes: The estimated coefficients of the variables are listed in the α columns and the corresponding *p*-values are printed aside in smaller font. The IVs used in each model include all independent variables and the dependent variable with lags (from 3 to 5 using the @DYN (log (*EE*),-3,-5) command in model 5, @DYN (log (*SC*),-3,-6) in model 6, @DYN (log (*EE*),-4,-6) in model 7 and @DYN (log (*SC*),-4,-7) in model 8. The *Time* trend variable is untransformed using the @LEV(*Time*) command. The standard errors of the estimated coefficients are corrected for serial correlation.

The second factor is associated with the inclusion of lagged values. In the preceding sections, while one-period lagged values are used to avoid the potential problem of simultaneity, the lag period could last well beyond one year. For example, a change in energy prices or capital-labour ratios may affect energy intensity (as well as its

[9] In Eviews, it is called the "white period method" (Arellano 1987, White 1980).

components) over a few years. To deal with this problem, a partial adjustment model is considered.[10] This model can be expressed as follows

$$Y_{it}^{*} = \alpha_0 + \Sigma \alpha_j X_{ijt} + \varepsilon_{it} \tag{7}$$

$$Y_{it} - Y_{i,t-1} = \delta (Y_{it}^{*} - Y_{i,t-1}) \tag{8}$$

where Y_{it}^{*} is the desired efficiency (component) in the i^{th} region and t^{th} year and δ is the coefficient of adjustment. Combining Equations (7) and (8) yields

$$Y_{it} = \delta \alpha_0 + \Sigma_j \delta \alpha_j X_{ijt} + (1-\delta) Y_{i,t-1} + \delta \varepsilon_{it} \tag{9}$$

where $\delta\alpha_j$ is the short-run impact of a change in X on Y and α_j gives the long-run impacts. Thus the model becomes a dynamic panel data model and can also be estimated using GMM which is now called the dynamic GMM (vs static GMM). The estimation results are reported in Table 6 (Models 7 and 8). For the dynamic GMM estimation, the estimated coefficients of all variables but *Income* are statistically significant. The estimated adjustment coefficient is 0.69.[11] Thus the elasticity of 'efficiency' with respect to price is -0.166 in the short run (Model 7) and -.241 in the long run.[12] These numbers imply that energy price may play a more important role in reducing intensity in the long run.

[10] Metcalf (2008) employed the same adjustment process to examine energy intensity and its determinants at the state level in the US.

[11] The adjustment coefficient δ=0.69 is derived using the coefficient (1- δ) of log(EE_{-1}) in Model 7.

[12] The long run price elasticity (-0.241) is the short run elasticity (-0.166) divided by the coefficient of adjustment (0.69).

For the structure models (Models 6 and 8), the results from both static and dynamic GMM estimations are generally consistent with those from the fixed effect estimation, that is, Model 3 in Table 4. Energy price is found to have a negative impact on the structural change component (and hence a positive effect on the reduction of energy intensity) but this effect is not statistically significant. The coefficients of other variables (*Income*, *KLratio* and *Krate*) are also estimated with the wrong sign which is consistent with the decomposition result that structural change component has made little contribution towards the fall in energy intensity among the Chinese regions during 1998-2007.

The last point is however subjected to serious qualification. It should be emphasized that, due to data constraints, the analyses in this paper are highly aggregate and only cover three sectors, agriculture, manufacturing and services. During the sampled period of 1998-2007, structural change might take place within the manufacturing sector in each region. This change cannot be captured in the empirical exercises here and may be partly responsible for the decline in energy intensity and hence efficiency improvement. To shed some light on this issue, Table 7 presents the output shares and energy intensity in China's twenty-eight manufacturing sectors in 1998 and 2007, respectively. Within a decade, energy intensity in the manufacturing sector declined by about two-thirds. If we follow the index decomposition analysis proposed in section 2, we can show that the decline (-34.5) is purely due to energy efficiency improvement (-37.8) with structural changes having a negative contribution (3.3). This is confirmed in Table 7 which demonstrates that the high energy-intensive sectors (the top 10) all experienced a decline in energy intensity while the changes in output shares are mixed. This is of course based on economy-wide statistics. There may be regional variations which call for further investigation when information becomes available.

Table 7 China's Energy Intensity and Output Shares by Sector

Sectors	Energy intensity				Value-added shares		
	1998	2007	Changes		1998	2007	Changes
Smelting and Pressing of Ferrous Metals	184.8	53.0	-131.7		6.5	9.7	3.1
Raw Chemical Materials and Chemical Products	142.3	37.1	-105.2		7.4	7.9	0.5
Petroleum Processing and Coking	139.8	42.5	-97.2		3.5	3.3	-0.2
Nonmetal Mineral Products	135.5	42.0	-93.5		6.1	5.2	-0.8
Smelting and Pressing of Nonferrous Metals	99.1	23.9	-75.2		2.2	4.8	2.6
Chemical Fiber	77.7	19.2	-58.5		1.2	0.9	-0.4
Papermaking and Paper Products	60.9	19.2	-41.8		2.1	1.9	-0.2
Rubber Products	30.7	13.1	-17.6		1.4	1.0	-0.3
Textile Industry	30.3	12.6	-17.6		6.8	5.3	-1.5
Food Production	30.2	7.1	-23.1		2.2	2.0	-0.2
Timber Processing, Palm Fiber and Straw Products etc	30.1	8.0	-22.1		0.8	1.1	0.4
Food Processing	26.9	5.0	-21.9		4.5	5.0	0.5
Ordinary Machinery	22.4	5.1	-17.3		4.6	5.5	0.9
Furniture Manufacturing	21.1	2.3	-18.8		0.5	0.7	0.2
Metal Products	20.7	9.4	-11.3		3.4	3.2	-0.1
Plastic Products	19.3	7.6	-11.7		2.4	2.3	-0.1
Medical and Pharmaceutical Products	19.3	5.2	-14.1		2.9	2.5	-0.4
Equipment for Special Purposes	18.3	4.7	-13.6		3.2	3.3	0.1
Beverage Production	14.2	5.2	-9.0		3.6	2.0	-1.6
Transportation Equipment	14.1	3.4	-10.7		7.2	7.5	0.3
Printing and Record Medium Reproduction	9.6	4.7	-5.0		1.2	0.7	-0.5
Electric Equipment and Machinery	7.4	2.5	-4.8		5.9	6.5	0.7
Leather, Furs, Down and Related Products	5.8	2.5	-3.3		1.8	1.6	-0.2
Garments and Other Fiber Products	5.8	3.0	-2.8		3.2	2.4	-0.8
Cultural, Educational and Sports Articles	5.6	3.7	-1.9		0.9	0.6	-0.3
Instruments, Meters, Cultural and Office Machinery	4.9	2.2	-2.7		1.1	1.3	0.1
Electronic and Telecommunications Equipment	4.4	2.5	-1.9		7.5	8.5	1.1
Tobacco Processing	2.9	0.8	-2.1		5.9	3.1	-2.8
Total	51.1	16.7	-34.5				

Note: Value-added shares are percentage shares. Energy intensity is expressed in kilograms coal equivalent per 1000 yuan.

6. Conclusion

To sum up, it is shown in this study that the overall trend of the movement of China's energy intensity in the past decades has been declining. The main driving force for the decline is due to the improvement in energy efficiency while the impact of structural changes in the economy is very limited. There is however substantial variation in energy intensity and its trend of changes in Chinese regional economies. In absolute terms, among the 27 regions considered, the highest energy intensity is six or seven times as high as the lowest one. During the period of 1997-2007, the average energy intensity declined. In conformity with the national trend, the decline is mainly due to efficiency improvement with little contribution from economic structural changes. But the changes in energy intensity are very uneven. Some regions experienced a substantial decrease in energy intensity while others were recorded with a modest increase during 1997-2007. Furthermore, it seems that there was no evidence of convergence in regional energy intensity in the past decade.

To understand regional variation in energy intensity, the intensity component indices, namely the efficiency and structural change indices, are regressed against several region-specific covariates. It is found that energy intensity declines as income rises among the regions. Thus China's regional economies generally follow the same dematerialization process as most developed economies have undergone. However "dematerialization" at the current stage of development in China is not due to shifts in manufacturing activities rather it is mainly because of energy efficiency improvement within the sectors. It can be anticipated that China's energy intensity can be reduced further when structural changes become the main driver for dematerialization. For this reason, an optimistic view is that in terms of energy intensity China could even perform better than its East Asian counterparts, Japan and South Korea. It is also found in this study that energy intensity is responsive to energy prices in both the short run and the long run. Thus getting energy prices right is important for reducing energy consumption and hence emissions in China.

Finally, there is evidence of the existence of nonlinear relationship between energy intensity and capital-labour ratios. However, it seems that all Chinese regions are still on the left hand side of the inverted U-shaped curve. Hence the sample considered does not support the argument that capital and energy are substitutes in China. This study also shows a non-linear relationship between energy intensity and the growth in capital stock or vintage of capital. Some Chinese regions have already passed the turning point of the inverted U-shaped curve. Energy intensity in those regions may be reduced due to the adoption of energy-saving technology embodied in rapidly growing new capital. Thus, while new technology may play a role in improving energy efficiency and hence reducing energy intensity, growth in capital intensity alone would not bring the decline in energy consumption in China, at least in the short run. Other factors such as fuel prices and economic structural changes are also important and should be the focus of economic policies in the coming decades.

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