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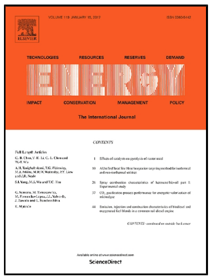
DOI:
10.1016/j.energy.2017.01.143

Accepted Manuscript



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PII:	S0360-5442(17)30155-X
DOI:	10.1016/j.energy.2017.01.143
Reference:	EGY 10278
To appear in:	*Energy*
Received Date:	16 July 2016
Revised Date:	03 January 2017
Accepted Date:	29 January 2017

Please cite this article as: Robert J.R. Elliott, Puyang Sun, Tong Zhu, The Direct and Indirect Effect of Urbanization on Energy Intensity: A Province-level Study for China, *Energy* (2017), doi: 10.1016/j.energy.2017.01.143

Highlights

- The direct and indirect impacts of urbanization on energy intensity is studied.
- Urbanization is measured via formal and informal indicators.
- The direct impact of urbanization is found to be significant and positive.
- The construction channel tends to be the most significant indirect channel.

The Direct and Indirect Effect of Urbanization on Energy Intensity: A Province-level Study for China

Robert J R Elliott*, Puyang Sun** and Tong Zhu*

Abstract

In March 2014 China announced its long awaited plan for managing the migration of the rural population into already overcrowded urban areas. The so called "new style" of urbanization has potentially important implications for China's energy use. However, the relationship between urbanization and energy intensity is not straight-forward. This papers investigates the direct and indirect impacts of urbanization on the intensity of energy use in China using a balanced panel of 30 provinces for the period 1995 to 2012. Using recently developed mean group estimation techniques it is found that the direct impact of urbanization on energy intensity is generally positive while the indirect impact measured through four different channels (construction, industrial upgrading, transportation and changing lifestyles) tends to be negative. On average, a one percentage point increase in urbanization leads to an increase in energy intensity of between 0.753 and 1.473 percent for electricity and coal intensity respectively. The construction channel tends to be the most significant indirect pathway. The transportation and industrial upgrading channels are significant but only under certain circumstances. The results also highlight the difference between formal and informal urbanization as well as the importance of province heterogeneity. The implication is that future national targets should be implemented with care.

JEL: Q43, R11, O14
Keywords: Energy intensity, Income per capita, Industrialization, Urbanization.

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Acknowledgements: We would like to thank Maria Jesus Herrerias for useful comments. All remaining errors are our own.

1. Introduction

The ability of both developed and developing countries to reduce the intensity of energy use is thought to play an important role in determining the world's capacity to grow sustainably in the future. Reducing the energy intensity of firms and households is considered to be a practical solution to many of today's common challenges including global energy shortages; mitigating against further changes in the climate; and reducing the impact on health of local air and water pollution. Understanding the factors that influence energy intensity are of first-order importance for academics and policymakers especially given the rise of rapidly growing and energy hungry economies such as China and India.[1]

The purpose of this paper is to investigate the determinants of province level energy intensity in China. Specifically, we examine the impact of urbanization, income per capita, and industrialization on energy intensity in China for a sample of 30 provinces for the years 1995 to 2012. In addition to examining the direct impact of these variables on energy intensity this research also examines a number of indirect channels (construction, transportation, industrial upgrading, and changing lifestyles) by which changing urbanization may effect energy intensity. This is a period in China's history categorized by rapid economic development and a correspondingly large increase in the demand for energy. From the 1990s to the current day China has experienced a steady but slow decline in energy intensity albeit with a period of rising energy intensity in the middle of the last decade. Hence, understanding the factors that drive changes in energy intensity in China is important for policymakers who are looking to develop instruments to address China's energy security and pollution concerns.

One of the factors thought to be important in the evolution of energy intensity is the role of urbanization. Over the previous 35 years China has witnessed urban population growth of more than 500 million people [1]. Currently, China has the world's largest urban population (758 million), followed by India (410 million) [2]. These two countries now account for 30 per cent of the world's urban population. In the third plenum of the 18th Central Committee of the Communist Party of China made public on October 15th 2013 it became apparent that China's model of urbanization was changing. The previous model of rapid but inefficient urbanization is to be replaced with greater priority given to services and a larger role for the free market. The hope is that the changes will result in high quality urbanization. The thinking is that by putting additional emphasis on technology and the efficient clustering of factors of production there will be improvements in the efficiency of industrialization and hence a more efficient use of energy.

In March 2014, the long awaited first official plan on urbanization, namely the National New-Style Urbanization Plan (2014-2020), was issued by the Central Committee and the State Council to provide guidelines for the reasonable flow of migrants into urban areas. According to the National Migrant Workers Monitoring Survey Report 2014 issued by National Bureau of Statistics of China [3], the total number of migrant workers reached 273.95 million with a growth rate of 1.9% in 2014. With the emphasis on city ecological progress and urban quality, the plan acknowledged an unequal treatment of rural migrant workers (due to the *hukou* system of household registration) and promises to help 100 million of the 260 million migrants and other permanent urban residents to obtain urban household registration within the planned period.[2]

In addition, China is currently experiencing environmental degradation (as a result of local pollution) and energy security concerns. Following two decades of rapid growth, China become the world's largest global energy consumer in 2010 and has surpassed US becoming the world's largest crude oil importer in April 2014 [4]. In 2011 China became the world's largest power generator driven by a rapidly modernizing and industrializing economy. The degree of China's dependence on energy imports has increased continuously. The domestic demand-supply gap in 2014 reached 407 million tons of standard coal equivalent and the reliance on foreign crude oil reached a new record of 59.6% [5]. One of the by-products of increased energy consumption is the proliferation of serious environmental problems caused by the emissions of local and global pollutants. China is coming under increasing pressure from its local population and the rest of the world to reduce their contribution to the emissions of local air pollutants and greenhouse gases which will help to mitigate the effects of pollution on health and climate change respectively. For China to reduce its dependence on foreign energy resources and hence improve energy security it is important to understand the factors that impact on energy efficiency.

China's recognition of these concerns is reflected in the increased emphasis on long term sustainable growth. In terms of the energy sector, the Third Plenum in October 2013 suggests that China is looking to adopt market-based pricing of energy related products at the same time as increasing energy efficiency and investing further in renewable energy. This change builds on the announcement in the twelfth five-year plan of 2011 that set an explicit target of reducing energy intensity by more than 16% by 2015. This target was met in early 2015.

A country's energy intensity is influenced by a wide range of factors. The existing literature generally agrees that income and industrialization have a significant impact on energy intensity. There is a large theoretical and empirical literature showing the income effect on energy consumption based on the Environmental Kuznets Curve (EKC) which suggests a non-linear inverted U-shape relationship between a country's income level and energy usage [6–8]. Industrialization has also been shown to be an important contributor of rising energy intensity. The majority of the current research finds a positive relationship between industrialization and energy consumption for China and more generally [9–11]. The impact of urbanization is a little more complicated. On the one hand, urbanization tends to increase demand for more energy-intensive products as urban residents rely much more on electrical appliances (e.g. air conditioning) and modern transportation (automobiles) which implies a higher energy demand per person than those living in rural areas. On the other hand, the concentration of production and consumption in a relatively small geographical area should provide opportunities for economies of scale that can lead to improvements in overall energy efficiency.

Hence, the contribution of this paper is three-fold. First, previous studies of the relationship between energy intensity and urbanization [10–13] have tended to use only one indicator of urbanization which is usually the urban population rate measured as urban population divided by total population (Urban1). In this paper an additional measure is employed that takes into account China's "*hukou*" system. Since there are two categories of household IDs in China, namely agricultural households and non-agricultural households, there is some debate about whether those individuals that are considered to be part of the short-term floating population can be treated as part of the urban population [14]. The household registration system that has lasted for more than 60 years has resulted in over 250 million rural migrants living in the cities without an urban "*hukou*"[3]. Although migrants provide low-cost labor they are perceived to receive unfair treatment in regard to the availability of public services and social welfare (e.g. education and health care). Based on the studies that examine the demographic measurement of urbanization [15,16], urbanization is measured alternatively as the non-agricultural population divided by total registered population (Urban2) to reflect the formal urbanization level.

The second contribution is to investigate the different channels through which urbanization exerts an indirect impact on energy intensity. Based on previous studies [11,12,17], four indirect channels have been identified, namely a construction pathway, a transportation pathway, an industry upgrade pathway and a residential consumption or lifestyle pathway. However, there has been no previous empirical validation of the magnitude of each of these channels on energy intensity. In this study the indirect effect of urbanization is investigated extensively based on two energy resources (coal and electricity).

The third contribution, following Sadorsky (2013)[11], is to control for heterogeneity across the unit of analysis using two different mean group estimators. Controlling for heterogeneity is important given the considerable variation in the economic development, resource endowments and climate across China's 31 mainland provinces. Such an approach is needed because the strict assumption of parameter homogeneity required for classical regression models is unlikely to hold across Chinese provinces. Moreover, because energy related policies are managed by the central government it is likely to have cross-sectional dependence within the province level panel. Hence, standard panel techniques will tend to produce biased and inconsistent results. More specifically, the extended version of the Mean Group estimator, the Augmented Mean Group (AMG) estimator [18] is employed that takes both heterogeneity across parameters and common factors into account.

To briefly preview the results, it is shown that urbanization exhibits a positive direct impact on energy intensity generally. Urbanization measured by the "*hukou*" system has a significant impact on the total energy intensity while urbanization measured by the percentage of the floating urban population shows a positive and significant direct impact on coal consumption intensity and electricity consumption intensity. A one percentage point increase in urbanization based on the floating population is shown to increase coal intensity and electricity intensity by 1.5% and 0.8% respectively. As for the indirect channels, they turn out to be negative or insignificant determinants of energy intensity. The indirect effect through the construction sector is shown to be the most significant channel. Transportation and industrial upgrading are found to be significant determinants but only under certain circumstances. Different lifestyles, whether in high or low urbanized areas, appear to have a similar contribution to aggregate energy intensity when taking into account cross-sectional dependence and province level heterogeneity. Other covariates such as income per capita and industrialization tend to play more important roles than urbanization in affecting China's provincial energy intensity perhaps as a result of the negative impact of the indirect urbanization channels. Income per capita has a negative and stable influence on energy intensity while industrialization has the expected positive effect. In terms of the two urbanization proxies, the informal measurement based on floating urban population generally affects energy usage through the first three channels while the formal measurement of urbanization based on the "*hukou*" system tends to affect energy usage through the construction and transportation pathways.

The remainder of the paper is organized as follows. Section 2 discusses the mechanisms by which urbanization, income and industrialization are expected to impact on a country's energy intensity.

Section 3 presents the methodological approach while Section 4 provides a summary of the data. The results are presented in Section 5 before Section 6 concludes.

2. Literature review

In this review of the literature we concentrate on the impact of urbanization on energy efficiency but also comment on the impact of industrialization and income of energy efficiency.

2.1 The impact of urbanization on energy intensity

According to the 2012 UN Environment Programme [19], urban areas, which currently occupy around 3% of the world's surface area, were estimated to consume approximately 75% of the natural resources and account for 60-80% of all greenhouse gas emissions. Urbanization can impact energy use through direct and indirect channels. The direct impact refers to the straightforward effect that urbanization exerts on energy use. The seminal study from Jones (1989)[20] demonstrates that energy consumption increases as a result of, not only income per capita and industrial structure, but also the rate of urbanization. The elasticity of income per capita, industrialization and urbanization with respect to energy use were estimated to be 1.10, 1.08 and 0.48 respectively. Jones (1991) [12] went on to investigate the direct mechanism by which urbanization impacts energy use employing similar cross-sectional data and found the long term urbanization elasticity to be 0.35. Similarly, Parikh and Shukla (1995)[21] estimate the relationship between urbanization and increasing resource consumption for a range of developing and developed countries between 1965 and 1987 and find that the elasticity of energy intensity with respect to urbanization is 0.47. Likewise, York (2007)[13] and Rafiq *et al.* (2016)[22] find similar effects with significant and positive elasticities for urbanization for the 14 EU countries and 22 emerging countries respectively.

In contrast, other papers have found that under certain conditions urbanization can have a negative direct impact on energy consumption. Martinez-Zarzoso and Maruotti (2011)[23] find an inverted U relationship between CO2 emissions and urban population density for half of their developing country sample with a threshold effect for urbanization's impact where once a threshold has been reached, further urbanization does not result in greater emissions. Everything else equal, they find the highest emission levels come at an urbanization level of 59% to 63% (which compares to China's current level of around 54%). More recently, Zhu *et al.* (2012)[24], in a study of 20 emerging countries between 1992 and 2008, finds little evidence of an inverted U-shape relationship between urbanization rate and CO2 emissions.

Others have argued that the impact of urbanization on energy consumption varies considerably depending on the level of development. Mishra *et al.* (2009)[25] examine nine Pacific Island countries and find that urbanization affects different economies in opposite directions while Poumanyvong and Kaneko (2010)[26] find that although urbanization appears to exert a negative impact on energy use for low-income groups it is positive for middle- and high-income country groups. From the perspective of ecosystem integration, Long *et al.* (2016)[27] finds that urbanization has a potential to decrease the ecological footprint associated with increased income.

For China specifically, a number of studies examine the direct relationship between energy consumption and urbanization [10,28–31]. For example, Jiang and Lin (2012)[10] show that trends in industrialization and urbanization predicts that China's energy demand will keep rising until 2020. In terms of urbanization, Liu (2009)[28] finds unidirectional Granger causality from urban population density to total energy consumption although the contribution from urbanization tends to be smaller in the later years of the sample. At the province level, Zhang and Lin (2012)[29] show that urbanization has a positive effect on both energy consumption and CO_2 emissions although when they take China's unbalanced regional development into account they find that energy consumption decreases dramatically as one moves from the western to the eastern provinces.

More recently, Ma (2015)[30] finds that urban infrastructure to be a major determinant of the positive short-run relationship between urbanization and energy intensity, while the long term increase in energy use associated with urbanization is driven by residential consumption patterns and urban transport systems. Although Ma (2015) touches on the transport, residential consumption channels, the effectiveness and magnitude of each is not examined in any detail. Finally for China, Yan (2015)[31] also uses province level data and finds a positive and significant impact of urbanization on both aggregate energy intensity and disaggregate energy intensity with the elasticities ranging from 0.111 to 0.287 for the proportion of the population that is urban and from 0.269 to 0.350 for the proportion of the population that is non-agricultural.

Turning to the indirect channels by which urbanization impacts energy efficiency, several have been identified by Jones (1991)[12] and Madlener and Sunak (2011)[17] and summarized by Sadorsky (2013)[11]. The arguments are briefly rehearsed again here. The first indirect channel is the need for growing cities to absorb ever increasing volumes of high energy intensive products such as steel and cement. Urbanization means additional demand for building stock and other infrastructure resulting in inner-city clustering and land shortages which can lead to a greater use of multi-level building [21]. Office buildings, power plants, sewage networks are generally accompanied by significant ongoing energy inputs. Likewise, the maintenance of completed infrastructure projects tends to be energy hungry. In addition, in developing countries, the process of urbanization is often associated with the uncontrolled diffusion of informal settlements and illegal housing which are usually inefficient in their use of energy, even though informal dwellings (e.g. shanty towns) often lack access to basic amenities including electricity.

The second channel is that as the scale of urban production increases, raw materials need to be transported from their often rural origin to the urban production center and final goods in turn need to be transported to the destination of consumption which is likely to be other urban conurbations or overseas. Urbanization also increases intra-city mobility which causes the emissions of various pollutants especially in developing countries where the basic transit infrastructure is generally poor leading to the greater use of private trucks and automobiles.

Thirdly, urbanization is associated with a concentration of economic activity and hence an increase in urban production. When people move to the city from rural areas the result is that more human resources are absorbed by the relatively more energy intensive secondary and tertiary sectors. The decline in the agricultural population can also lead to an increasingly mechanized and more energy intensive agricultural production process[32]. In addition, in those countries that have a large informal market where economic activities are neither taxed nor registered, energy consumption can rise [33]. Counter balancing these effects is the notion that rising competitive pressures and land scarcity tends to drive urban production to be more innovative and to use modern and more technologically advanced capital which is likely to be more environmental friendly[20].

Finally, a forth channel by which urbanization impacts energy intensity is through the change in lifestyle and consumption patterns of the newly urbanized citizens who tend to be more dependent on certain energy intensive products such as air conditioners, refrigerators and private vehicles[20]. Increasing disposable income also increases the likelihood that households will purchase more electrical appliances. In addition, urban dwellers are more likely to derive their energy from coal or natural gas and not from decentralized sources of energy such as wood.

Although the previous literature discusses the indirect mechanisms by which urbanization impacts energy intensity, few provide a systematic assessment of these different channels. One exceptions is Liddle (2004)[34] who finds that densely populated countries tend to have a lower personal vehicle demand. Similar results are found for an input-output life-cycle assessment model for Toronto[35]. Transportation-related greenhouse gas emission per capita are estimated to be 3.7 times higher from low residential density areas. The rank-size relationship is also true when considering the embodied energy and pollutants from the construction industry.

With regard to lifestyle and residential energy consumption, Krey *et al.* (2012)[36] focus on urbanization in China and India using an integrated assessment model and show that total consumption of fossil fuels in the residential sector is not sensitive to urbanization arguing that it is the evolution of labor productivity induced by urbanization that really matters. O'Neill *et al.* (2012)[37] finds similar results for China and India using a computable general equilibrium (iPETS) model. Minx *et al.* (2011)[38] employ a structural decomposition approach to examine Chinese carbon dioxide (CO_2) emissions and finds increasing export demand and structural changes to be the largest contributors to CO_2 emissions with capital investment accounting for 61 percent of emission growth between 2005 and 2007. The effect of urbanization and the related evolution of lifestyles are shown to be more significant than other social-demographic factors such as population and household size with the overall emission effect of urbanization still coming out as positive even after netting out the potential carbon savings due to economies of scale. Finally, Wang (2014)[39] examines different types of energy consumption and finds that urbanization reduces residual energy consumption per capita but substantially increases aggregate energy consumption. In a related literature, Khanna *et al.* (2013)[40] examine the local enforcement of two of China's recent energy efficiency policies based on household appliances across several pilot locations between 2006 and 2009. They generally find high compliance but with a large variation with insufficient organizational coordination between government agencies and the low priority given to energy efficiency in national quality testing as the main challenges.

2.2 The impact of income per capita on energy intensity

A number of studies that examine the relationship between income and energy consumption with mixed results. Malenbaum (1978)[6] was the first to show resource intensity changing with income. Galli (1998)[7] in turn estimated the long-term relationship between energy intensity and income for ten Asian emerging countries across 28 years and found a negative and significant coefficient for the squared income term. Zhao and Fan (2007)[8] examined the relationship between growth and energy consumption for different Chinese regions using a smooth transfer regression (STR) estimation and found a stationary nonlinear relationship even during different developing phases. A recent study by Song and Zheng (2012)[41] shows that although the evaluation process of China's energy intensity follows a U-shape, the turning point is higher than 95% of the sample meaning that for most years, energy intensity follows a declining trend with regard to GDP per capita. Jiang *et al.* (2014)[42] find similar results showing that for 19 out of 29 provinces between 2003 and 2011, energy intensity fell with the growth of income. In contrast, Shao and Jia (2006)[43] and Liu (2007)[44] find no strong causal relationship between Chinese economic growth and the energy consumption.

2.3 The impact of industrialization on energy intensity

Industrialization, which refers to the process by which a society transforms itself from a traditional agricultural society to one based on higher value added manufacturing, means that mechanized mass production and assembly lines are used to replace craftsmen and individual manual labor. The result is higher energy consumption driven by certain heavy industries (for example ferrous and nonferrous metals processing, petroleum refining and paper and allied production). Sadorsky (2013)[11] finds in the long-run that a 10% increase in industrialization causes a 0.7% to 1.2% increase in energy intensity. Feng *et al.* (2009)[9] who investigate the long-term relationship between economic structure, energy consumption and energy intensity between 1980 and 2006 for China find that economic structure Granger causes energy intensity NS I

To explain the impact of industrialization more precisely, Fisher-Vanden *et al.* (2004)[45], Ma and Stern (2006)[46] and Liao *et al.* (2007)[47] divide the economic structure of a country into a number of sub-sectors and identify structural and efficiency effects. Liao *et al.* (2007)[47] find an efficiency effect where the role of technology is considered to be the dominant contributor to the change in energy intensity. Structural change at the industry level increases energy intensity while structural shifts between sub-sectors decreases overall energy intensity[46]. Using a panel of approximately 2,500 large and medium-sized industrial enterprises between 1997 and 1999, Fisher-Vanden *et al.* (2004)[45] demonstrate that the efficiency effect plays an important role in reducing energy intensity at the firm-level and accounts for 47% of the decline. For the service sector in the OECD Mulder *et al.* (2014)[48] argue that structural changes had an increasingly important effect on aggregate energy intensity especially after 1995.

Advances in technology can also make production more environmental friendly. In China, non-state and foreign investment has also had a significant impact on the diffusion of energy-saving technologies[49]. The cleaning effect of new technology is also found by Garbaccio *et al.* (1999)[50] who finds that technical change within an industry is the main driver of a declining energy-output ratio (with structural change increasing energy consumption).

3. Methodology

The empirical approach of this paper follows Sadorsky (2013) who uses Jones' (1991) original estimating equation to enable us to estimate the relationship between three measures of energy intensity and income per capita, industrialization and two alternative measures of urbanization. The estimating equation (in logs) is therefore given by:

$$EI_{it} = \alpha + \beta_{1i} YPC_{it} + \beta_{2i} IND_{it} + \beta_{3i} URBAN_{it} + \xi_t + v_i + \varepsilon_{it} \quad (1)$$

The subscripts *i* and *t* denotes a province and year respectively. The dependent variable EI_{it} is either total energy intensity (TEI), coal energy intensity (CEI) or electricity energy intensity (EEI). The right hand-side variables are measures of income per capita (YPC), industrialization (IND) and the measures of urbanization (Urban1 and Urban2). ξ_t captures year fixed effects and v_i captures province fixed effects. ε_{it} is the error term.

Using logs and assuming the error term ε_{it} is distributed with zero mean and constant variance-covariance matrix the coefficients can be interpreted as elasticities. One concern however is that classical panel regression techniques could produce misleading and inconsistent results because of the homogeneity assumption across provinces. Under the homogeneity assumption pooled OLS and various fixed effects specifications impose the condition that $\beta_{1i} = \beta_1$, $\beta_{2i} = \beta_2$, $\beta_{3i} = \beta_3$ and negates the possibility of individual panel specificity. In this case, this is a concern because the variables are measured at the province level where there are considerable differences in growth and development between the coastal and inland provinces.

The ideal solution to address this possible source of bias is to estimate β_{1i}, β_{2i}, β_{3i} separately. A starting point is to use the standard Mean Group (MG) estimator developed by Pesaran and Smith (1995)[51]. The β coefficients are estimated separately for each province and the simple arithmetic average is taken. For $i = 1,2,3 \cdots N$, $t = 1,2,3 \cdots T$, let;

$$EI_{it} = \alpha_i + \boldsymbol{\beta_i}' \boldsymbol{X_{it}} + \varepsilon_{it} \quad (2)$$

$$\hat{\boldsymbol{\beta}}_{MG} = N^{-1} \sum_i \hat{\boldsymbol{\beta}}_i$$

where $\boldsymbol{\beta_i}$ is the panel-specific coefficient vector and $\boldsymbol{X_{it}}$ is the vector of independent variables including YPC_{it}, IND_{it} and $URBAN_{it}$ where subscript *i* represents an individual province.

Although Mean Group (MG) estimators can account for parameter heterogeneity they are still based on the assumption of cross sectional independence. If the assumption fails to hold then the MG estimation procedure will lead to biased and inconsistent results. To address this problem Eberhardt and Teal (2008)[18] developed the Augmented Mean Group (AMG) estimator which takes into account both parameter heterogeneity and possible cross-sectional dependence. The AMG estimator includes a "common dynamic process" extracted from a pooled OLS regression of first differences which provides a panel-equivalent average movement of the unobserved common factors. Common factors are those that are time specific and common across provinces. The AMG approach follows a two-stage procedure;

$$\Delta EI_{it} = \boldsymbol{\beta_i}'\Delta \boldsymbol{X_{it}} + \Sigma_{s=2}^{T} c_s \Delta D_s + \Delta e_{it} \tag{3}$$

$$\Rightarrow \hat{c}_s \equiv \hat{\mu}^*{}_t$$

$$EI_{it} = \alpha_i + \boldsymbol{\beta_i}'\boldsymbol{X_{it}} + \kappa_i \hat{\mu}^*{}_t + e_{it} \tag{4}$$

$$\hat{\boldsymbol{\beta}}_{AMG} = N^{-1}\sum_i \hat{\boldsymbol{\beta}}_i$$

In the first stage (Equation 3) a standard first difference OLS regression with $T - 1$ year dummies denoted by D_s is estimated. The coefficients on the year dummy $\hat{c}_s$ are recorded and relabeled as $\hat{\mu}^*{}_t$. In the second stage (Equation 4) the variable $\hat{\mu}^*{}_t$ is included to represent the evolution of the unobservable common factor over time.[3]

To identify the channels by which urbanization impacts energy intensity the estimating equation also includes the energy intensity of different sectors and the corresponding interaction term. The estimated coefficients on the interaction terms capture the direction and magnitude of the indirect impact of urbanization on energy intensity. A significant interaction term implies that the intensity contribution from that subsector is dependent on the level of urban development. The estimating equation is therefore:

$$EI_{it} = \alpha + \beta_{1i}YPC_{it} + \beta_{2i}IND_{it} + \beta_{3i}URBAN_{it} + \beta_{4i}SUB\_EI_{it}$$
$$+ \beta_{5i}URBAN_{it} \times SUB\_EI_{it} + \xi_t + v_i + \varepsilon_{it} \tag{5}$$

The subsector intensity SUB_EI_{it} is calculated by measuring CEI/EEI for the construction, transportation, tertiary and residential sectors. Detailed definitions can be found in Table B1 of appendix B.

4. Data

4.1 Data description

The province level data are collected from China Statistical Yearbooks, China Population Statistical Yearbooks and China Energy Statistical Yearbooks. Tibet is excluded since it contains only a small numbers of observations and has extreme high values of energy intensity due to the low real GDP. A linear interpolation is used to account for the boundary change for Chongqing. Classified by energy resources, three types of energy intensities are analyzed, namely total energy intensity (TEI), coal intensity (CEI) and electricity intensity (EEI) which are measured by energy consumption per real GDP, coal consumption per real GDP and electricity consumption per real GDP respectively. According to the purpose of energy use, energy intensity is disaggregated so that it corresponds to each of the four impact channels. Income per capita refers to the real gross domestic product per capita and industrialization is measured as the industrial value added divided by GDP. Two measures of urbanization (discussed in more detail later) are defined as the percentage of the population living in urban areas by total province population at year end (Urban1) and the percentage of non-agricultural population by the number of people registered in the province (Urban2). Table B2 provides a simple correlation matrix for the main variable of interest. The raw data suggest a negative correlation between total energy intensity and income per capita, industrialization and urbanization.

Figure 1 presents the composition of China's energy consumption from 1995-2012 while Figure 2 presents the provincial average trend in China's energy intensity between 1995 and 2012. Figure 1 shows that China's energy consumption grew rapidly after 2000. Observe that although there has been an increase in energy supplied from renewable sources, coal and oil continue to supply the overwhelming majority of energy consumed. From 2003 coal consumption increased significantly leading to a rapid increase in overall energy consumption. This rise matches the period when both aggregate energy intensity and coal intensity in China reversed its previous decline and rose slightly in 2003 before resuming its gradual decline. According to the World Bank (2015) the energy intensity in China fell by 41.88% from 1995 to 2011, while for the same period the US experienced a decrease of 28.20%, the EU by 25.74%, and Japan by 16.96%.[4]

[Figure 1 about here]

[Figure 2 about here]

Table 1 provides a summary of the key variables for each of China's 30 provinces between 1995 and 2012. The heterogeneity across provinces is evident with aggregate energy intensity ranging from a low of 0.816 in Guangdong to 3.428 for Ningxia. The industrialization and urbanization variables have a lower variance although Beijing still has an urbanization rate that is more than double that of many of the other provinces in China.

[Table 1 about here]

Table 2 provides data descriptive for the key variables for each of China's 30 provinces. It shows that income per capita grew by an average of 11.2% a year while energy intensity fell by an average of 3.7% a year. The decline in coal intensity averages 6.3% a year which is a lot faster than that for electricity intensity which declined by just 1.3%. At the same time industrialization increased by an average of 0.78% a year. The average annual growth rates for urbanization indicators Urban1 and Urban2 were 4.3% and 2.5% respectively.

[Table 2 about here]

Figures B1, B2 and B3 in Appendix B show the trends in urbanization, industrialization and income per capita for the period 1995 to 2012. Both urbanization indicators have increased over time while the growth of Urban2 is smoother than Urban1. Figure B2 shows industrialization was relatively stable until 2002 when it experienced rapid growth before declining as the global economic crisis of 2008/2009 impacted the Chinese economy before resuming its upward trajectory. Figure B3 shows that income per capita continued to rise throughout this period.

4.2 Formal and informal urbanization

Studies that distinguish between formal and informal urbanization in China date back to the nineties. For example, Liu and Liang (1997)[15] provide a detailed case study of the informal urbanization on the fringe of Beijing. In addition to political, cultural and social reasons, economic factors are regarded as some of the most important determinants of rural-urban migration. Zhu (1998)[16] argues that the distinction between formal and informal urbanization is important to understand the urbanization process in China and provides a precise definition of formal and informal urbanization. The formal urban population refers to the *de jure* urban citizens who have the non-agricultural *hukou* registration while the informal urban population also includes some *de facto* urban inhabitants that consist of the floating population that have arrived from other areas as well as local residents that only hold the agricultural *hukou* registration even if they are involved in non-agricultural activities.

Following previous studies a distinction is made between measures of urbanization based on *hukou* registration (Urban 2) and those based on the urban floating population (Urban 1). Table 3 provides the annual average population based on these two definitions from 1995 to 2012. At the first glance one can observe that the urban population is consistently higher than the non-agricultural population that is currently registered in that province. The difference between the floating population and local citizens is the agricultural population that have arrived from rural areas and other non-agricultural people from other cities. Guangdong, and Zhejiang have the largest recorded difference between the two measures and considered to the largest hosts for migrants during the period of analysis, a finding that matches that of Zhang and Song (2003)[52] who find that at the end of 1998, Guangdong, Zhejiang, Fujian and Jiangsu were the top-four migration host provinces.

5. Empirical Results

Before we present our results, note that classic panel unit root tests that do not take cross-sectional dependence into account can be misleading (low power). Standard unit root tests can over reject as a consequence of considerable size distortion[53]. Hence, Pesaran (2007)[54] developed the CIPS test (Cross-sectional Im-Pesaran-Sin test) for stationarity that can also be used as a test for cross-sectional dependence. Table 4 presents the CIPS test and the CD test for cross-sectional dependence[55] for each of the variables. The *p*-values in the second column of Table 4 show that each of the series rejects the null hypothesis of cross-sectional independence except CEI in transportation industry. The CIPS test which contains two lags, a trend term and an intercept also indicates that the series include a unit root. When searching for an appropriate model to test the hypothesis one should look for a high *p*-value for the CD test and a low *p*-value for the CIPS test. The results at this stage are similar to those of Sadorsky (2013) whose data also exhibit cross-sectional dependence with each series containing a unit root.

[Table 4 about here]

To investigate the relationship between urbanization, industrialization, income per capita and energy intensity a series of models under different assumptions are estimated Tables 5 and 6 present the results using pooled OLS and simple fixed effects models to benchmark the results against those of previous studies. Three types of energy intensity are investigated, namely total energy intensity (TEI), coal energy intensity (CEI) and electricity energy intensity (EEI). Table 7 presents the mean group estimations that take into account cross-sectional dependence while Table 8 presents the results from the AMG estimations that allow for both cross-sectional dependence and heterogeneous slope parameters. Finally, Tables 9 to 12 present the indirect results where the four channels by which urbanization may have an indirect impact on energy usage are estimated. Year dummies are included and all models are estimated with robust standard errors. As part of a series of robustness checks all models were re-estimated including quadratic terms (which were nearly always insignificant and hence not reported) and using the alternative measure of industrialization (secondary sector value added divided by GDP) which gave quantitatively and qualitatively similar results.

Table 5 reports the pooled OLS results which reveal a consistent negative and significant effect of income per capita on energy intensity. The coefficients of income per capita estimations range between -0.803 and -1.517 with the impact being larger for the energy intensity of coal (CEI). The results also show that industrialization is a strong positive determinant of energy intensity and the coefficient is significant across all specifications with relatively stable elasticities ranging between 1.696 and 3.517 across all six models. Since coal is an important input into the process of industrialization, the marginal impact of industrialization on energy usage is consistently stronger for CEI. For urbanization a positive and significant impact for both of the urbanization measures is found. The coefficients range from 1.345 to 2.255, which implies that a one percentage point increase in urbanization would induce a 1.345% to 2.255% increase in energy use holding other covariates constant.

In Table 6 province fixed effects are included. The results are broadly similar although the magnitude of the effects are now smaller. Concentrating on urbanization, the coefficients for the fixed effects estimations range from between 0.875 and 1.126 which are consistent with Zhang and Lin (2012) who find an urban impact of 0.41 and Ma (2015) who presents an impact range from 0.20 to 0.29.[5] The Urban2 and Urban1 results are broadly similar.

[Table 5 about here]

[Table 6 about here]

The difficulty with the results presented in the previous two tables is that under the null hypothesis of cross-sectional independence, all *p*-values associated with the CD test for TEI and CEI reject the null hypothesis which means there is a problem of cross-sectional dependence. The fact that electricity use suffers less from cross-sectional dependence might be due to the multiple power generation approaches and well-developed power distribution and transmission network occupied by the State Grid Corporation of China (covering 88% of Mainland China) and China Southern Power Grid Company Limited (covering Guangdong, Guangxi, Yunnan, Guizhou and Hainan).[6] Equally problematic is that the CIPS test results suggest that the fixed effects regressions are poorly fitted due to non-stationary residuals. The first attempt to address these concerns is to use mean group (MG) model the results of which are presented in Table 7.

[Table 7 about here]

The results in Table 7 show that the coefficients on income per capita and industrialization remain statistically significant at the 1% level (with the exception of the coefficient on industrialization in column (6) which is now insignificant). Income per capita is again negative and industrialization appears to have a large impact on the use of coal. Urbanization continues to have a positive impact on energy intensity in three of the six specifications. The coefficients on both income per capita and industrialization are now much smaller than those of the OLS regressions in Table 5 but consistent with those from the fixed effect model in Table 6. In contrast to what was found in previous tables, all the MG regressions have stationary residuals according to the CIPS test. However, the CD test results continue to suggest that there is an issue with cross-sectional dependence. Hence, Table 8 presents the results from the augmented mean group estimations and are the preferred specification.

[Table 8 about here]

The coefficients on income per capita shown in Table 8 remain generally negative and significant at the 5% level. The coefficients range from -0.29 to -0.81 which is consistent with the elasticities found by Sadorsky (2013) who estimates a range of elasticities from -0.57 to -0.53 and -0.45 to -0.35 for the short run and long run elasticities respectively. The income elasticities for EEI are larger than those of CEI implying that provinces with higher income per capita tend to consume electricity more efficiently. Returning to industrialization, under the AMG specification, it is found to be insignificant in four out of six regressions. The significant coefficients are also smaller than those of the previous tables and are now consistent with the findings of Ma (2015) which is 0.217 although slightly higher than the long-run effect of 0.07 to 0.12 found by Sadorsky

(2013) who looks at developing countries more generally. Considering the disaggregated energy types, urbanization (Urban1) has a positive and significant impact on CEI and EEI at the 5% level (Column (2) and (3)). In each case the AMG models pass both tests which gives us greater confidence in the findings. The results suggest that the impact of urbanization on energy intensity is not as clear cut as may have initially thought from the OLS and FE regressions.

To further examine the various channels though which urbanization has an impact on energy use, interaction terms of sector energy intensity and the measures of urbanization are not included. The four sectors are (1) Construction; (2) Transport, storage and post; (3) Wholesale, retail trade, hotel, and restaurants; and (4) Residential consumption. The results are shown in Tables 9 to 12 using both MG and AMG approaches for the three types of energy intensity and two urban indicators.

Table 9 presents the analysis of the construction channel. Both the energy intensity in the construction sector and its interaction term with urban indicators are included. It is reasonable to assume that the energy intensity at the sector level will make a positive contribution to aggregate energy intensity. As a result, both CEI and EEI in the construction sector have positive coefficients at least at the 10% significant level. According to Parikh and Shukla (1995), the process of urbanization tends to be accompanied by increased building and other infrastructure activities. However, the interaction terms between the urban indicators and energy intensity in the construction sector also show a significant and negative impact on both types of energy intensities. This suggests that in those provinces that have higher urbanization levels, the contribution to energy intensity from the construction sector to aggregate energy intensity is lower than that in the less urbanized provinces. In other words, the construction sector uses energy more efficiently in already highly urbanized areas. Given the rapid rate of urbanization in China, the importance of energy conservation in the construction sector has become an important area of policy with the Chinese central government launching a serious of regulations and criteria targeted at the construction sector. For example, the Public Infrastructure Energy Conservation Criteria implemented in 2005 has set various explicit standards from the building designing stage to the construction and maintenance of the new structure.

Returning to the results it shows that the MG results still suffer from non-stationary residuals. Focusing on the AMG model (which passes both the CD test and CIPS test) the coefficients on the sector energy intensity and the interaction term obtained with Urban2 are generally larger (approximately 3 times) than those for Urban1. One possible explanation is that local residents with non-agricultural *hukou* have a better chance to purchase one or more houses. Therefore, through the construction channel, the model specification with Urban2 based on the *hukou* system would lead to a larger impact of urbanization. The income per capita variables remain a negative and significant determinant of energy intensity under the MG and AMG assumptions except in columns (2) and (6). However, the finding for industrialization suggests it only has a minor influence on aggregate energy intensity with the AMG specification showing only one out of four of the coefficients being significant at the 10% level.

[Table 9 about here]

The second channel where urbanization can have an impact is through the transportation sector. Energy consumption and emissions tend to raise substantially as intra-city and inter-city mobility increases. At first glance, the transport pathway that links urbanization and energy efficiency suggests an inverted relationship. The results suggest that transportation tends to be more energy efficient in highly urbanized provinces. This is consistent with Norman *et al.* (2006) who shows that low density areas have relatively a lower number of public transit users. Furthermore, residents living in low density areas have a much higher vehicle dependency than those living in the city center. According to the CIPS test, the AMG specification results are more reliable where the urban impact pathway through the transportation channel found to be weaker. The coefficients for the interaction terms in column (4) and (6) are significant at the 5% level implying that under some circumstances, the transportation sector is less energy intensive in urbanized areas. As for the other control variables, income per capita remains generally negative and significant under both the MG and AMG specifications, while industrialization drops out in most of the AMG estimations.

[Table 10 about here]

As noted in Section 2, urbanization is associated with a concentration of economic activity. The usual process of development is from the primary to secondary to tertiary. Table 11 investigates the industry composition channel by including energy intensity in the tertiary sector and its interaction with urban indicators. Energy intensity in the tertiary sector is measured as coal or electricity consumption in wholesale, retail trade and hotel, restaurants subsectors divided by real value added in those subsectors. Column (1), (2), (4), (6) and (8) pass the CD and CIPS test at the 1% level which suggests cross-sectional independent and stationary residuals. The results show that coal consumption tends to be affected the most through this channel. In the first two columns, not surprisingly it is found that coal energy intensity makes a positive contribution to the aggregate coal intensity. The interaction terms have a negative and significant impact on aggregate CEI which implies that in highly urbanized provinces the contribution from the tertiary sector is lower than in less urbanized areas. However, the mechanism is less clear when electricity intensity is considered. Under this impact scenario, income per capita remains the most robust factor and all coefficients are negative and significant at the 1% level. The significance and magnitude of the income effect is fairly stable across all of the channels in Tables 7 to 12, ranging from approximately -0.3 to -0.8. As for the industrialization variable, it performs differently for different energy types with coal use seemingly more affected than electricity use.

[Table 11 about here]

The final channel is lifestyle and residential energy consumption. Residual coal/electricity consumption per capita and its corresponding interaction term with two urban indicators are included in both the MG and AMG specifications. It is notable that under this channel, urbanization performs differently for each of the two energy types. More specifically, when the residential energy consumption is taken into account, residential CEI and EEI are positively related to the aggregate intensity with the aggregate CEI seemingly more affected. The AMG estimation results are presented in columns (5) to (8) in Table 12. Both of the urban indicators shows a negative impact on aggregate CEI although the interaction terms are insignificant. It implies a significant impact through the other channels and the insignificance of channel four. As for the other covariates, income per capita remains a negative and robust influence on both energy types, and industrialization increases energy intensity.

[Table 12 about here]

To summarize the results, for each of the four channels only one of the four channels is found to offer a robust explanation for how urbanization affects energy intensity. Energy use in the construction sector in highly urbanized areas tends to be more efficient relative to provinces with low urbanization levels. When considering specific measures of urbanization, Urban1 exerts a significant impact on CEI through the construction and industrial upgrading channel, while Urban2 has an indirect impact on CEI through the construction and transportation channels. Electricity intensity tends to be affected only through the first two channels. Results show that the impact from the last channel, residential consumption, is not as large as expected. This may be for two reasons. First, the four channels described in the literature are mainly based on the energy consumption amount rather than energy intensity. For example, urbanization is usually accompanied by increased transportation in the city area, while mobility in the city-country fringe tends to have a higher reliance on vehicle transport rather than urban mass transit [35]. The concentration of economic activity also brings the opportunity for the more efficient use of energy. Based on the theory of industrial symbiosis, firms which are geographically close could form an industrial ecosystem by utilizing the waste materials from one production process into another. Both economic profits and environmental benefits are maximized via the cycling and reusing of resources such as water and energy [56,57]. After standardizing by the real value added in each sector, using energy intensity is more meaningful since it measures the efficiency of energy use.

Secondly, disaggregating by energy type may be missing differences at a more disaggregated level. For example, industries such as transport, storage and post tend to be more petroleum intensive. As a result, this might explain the insignificant finding for coal/electricity consumption through channel two. The inconsistent performance of two urban indicators reflects the substantial difference between these measures and emphasizes the importance of distinguishing between formal and informal urbanization.

6. Conclusions

Using a balanced panel of 30 Chinese provinces covering the period 1995 to 2012 this paper investigates the impact of urbanization, income per capita, and industrialization on energy intensity. The recently developed econometric techniques are employed to take into account the substantial heterogeneity across Chinese provinces. First and foremost, empirical results show that the direct impact of urbanization on energy intensity is positive although not as strong as previous predictions. When considering the indirect influence, four major impact channels are investigated and the results are in consistent with previous studies. More specifically, the indirect effect through the construction sector is shown to be the most robust impact channel whilst the industrial upgrading (sector change) and transportation pathways tends to be significant under certain circumstances. Different lifestyles around high/low urbanized areas are likely to have the same contribution to the energy intensity taking the cross-sectional dependence and provincial heterogeneity into consideration. Two of the urbanization indicators also behave differently under certain circumstances which demonstrates the importance of distinguishing between informal and formal urbanization. Province level heterogeneity also proved to have a substantial influence on the estimation for China. The relationship between economic growth, industrialization and urbanization energy can be captured more precisely by taking heterogeneous parameters and common factors into account which are tested for using the CD and the CIPS tests.

The results show that for China, urbanization impacts on energy intensity through the direct and indirect mechanisms. Urbanization measured by the percentage of the floating urban population shows a positive and significant direct impact on both coal consumption intensity and electricity consumption intensity. One percentage point increase in Urban1 is predicted to increase CEI and EEI by approximately 1.5% and 0.8% respectively. The indirect effect of urbanization through the construction sector is generally negative significant and the magnitude of the impact is larger when based on a formal measure of urbanization (Urban2) than that from the informal one (Urban1). The interpretation of the interaction term between urban indicator and energy intensity in the construction sector is that in highly urbanized provinces the construction sector contributes less to the aggregate energy intensity level. In other words, the construction sector utilizes energy more efficiently in highly urbanized provinces. Similar results are found under some circumstances when the transportation and the industrial upgrading channels are considered. Energy consumption due to residents' consumption was shown to be an efficient channel through which urbanization impacts energy intensity.

With regards to income per capita, there is strong evidence that per capita real GDP affects energy intensity estimated using both classic and more advanced econometric techniques. The elasticity is relatively large for the pooled OLS and ranges from -0.8 to -1.5, whilst it is smaller and stable for the fixed effect and mean group related estimations. The elasticity for the direct effect ranges from -0.3 to -0.8 which is generally consistent with Sadorsky (2013) who estimates elasticities between -0.57 to -0.53 and from -0.45 to -0.35 for the short run and long run respectively. The findings indicate that income per capita is one of the most important drivers of reductions in energy consumption and is in consistent with previous studies that also focus on China's provincial data [30,41,42].

Industrialization is regarded to be one of the overwhelming contributors to China's economic growth. Although energy intensity is found to increase as the percentage of industrial value added increases, the magnitude is not perhaps as strong as expected. It may due to the cleaner production benefiting from technology improvement [49,50]. Since accession to the World Trade Organization (WTO), the Chinese central government has launched a series of nation-wide policies focusing on energy conservation and emission reductions. These policies cover various aspects of secondary industry such as power generation and the manufacture sector. Increasing openness could also lead to the diffusion of energy-saving technologies. As a result, the positive effect of industrialization on energy intensity tends to be limited because of the active or passive technology change.

The findings in this paper suggest a number of interesting policy implications. First, the sensitivity of the results to the use of mean group techniques emphasizes the importance of provincial heterogeneity in China. Different geographical structures, nature features, energy storage and availability and even local culture and preference could all be part of the explanation. As a result, national targets need to be reconsidered taking into account local features. Identifying the inherent features of a region and implementing energy and environment policy at the local levels should be considered. Secondly, more attention should be given on the differences between informal urbanization and formal development. Behind the different performances from the two urban measurements however are questions relating to the quality of the urbanization. Without basic infrastructure and urban planning, many urban areas in China are abandoned (so called ghost cities) while others consist of large numbers of high-rise buildings. Reform of *hukou* system will help to improve information management and optimize urban planning. Finally, policies to develop and plan for changes in industrial structure and technological upgrading need to be carefully considered. There is no doubt that urbanization and industrialization will continue for the foreseeable future despite the global slowdown in growth. Improving the efficiency of energy use may have a short term detrimental impact on economic growth but needs to be considered as part of a bigger picture to reduce urban air pollution and reduce China's dependence on imported energy. Finally, it is possible that the recent policy to encourage further urbanization may not have the negative impact on energy intensity and hence pollution that some expect. Equally, urbanization may not deliver the reductions in energy intensity that others might expect.

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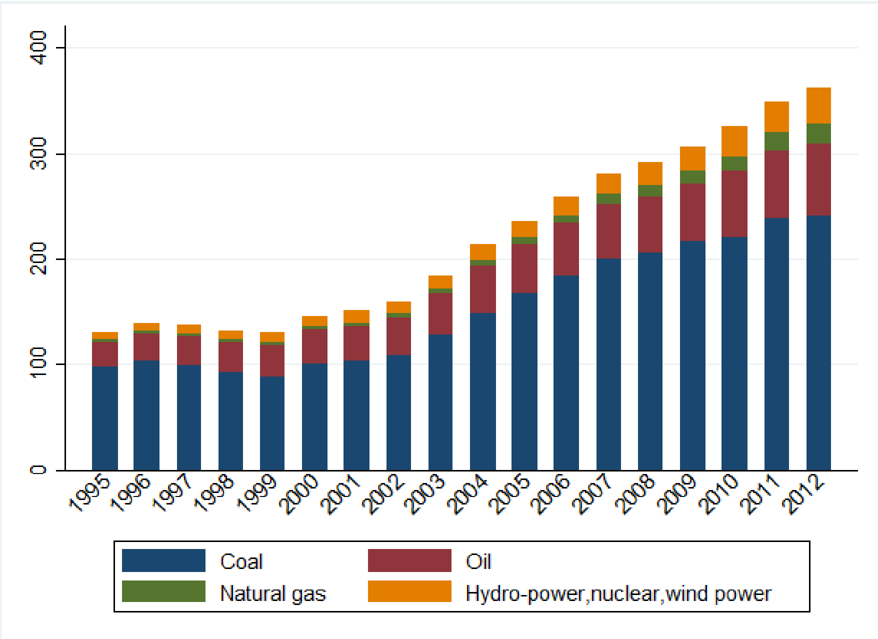
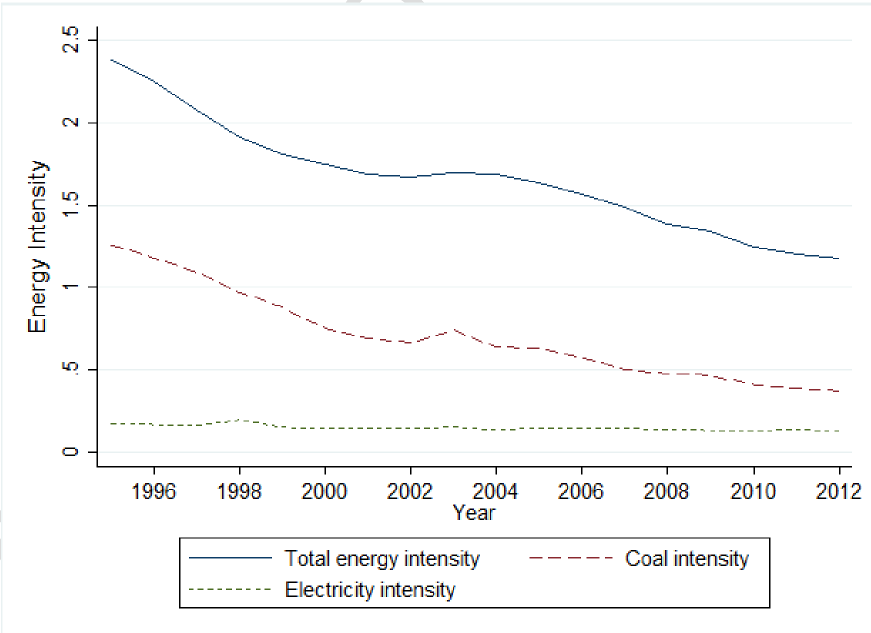
Figures and tables

Figure 1 Chinese national energy consumption composition (1995-2012)



Source: China Statistical Yearbook 2013 (Units: ten million tons of standard coal equivalent)

Figure 2 Chinese aggregate energy intensity, coal intensity and electricity intensity (1995-2012)



Source: China Statistical Yearbook 2013 (Units: tons of standard coal equivalent / RMB 10,000 in 2005 prices). The unit for coal intensity is tons / RMB 10,000 in 2005 prices and the unit for electricity intensity is kWh / yuan in 2005 prices.

Table 1: Energy, income per capita, industrialization and urbanization in China's 30 provinces (1995-2012) in 2005 prices

Province	Income per capita	Industrialization	Energy Intensity	Coal Intensity	Electricity Intensity	Urban 1	Urban 2
Shanghai	4.414	0.465	0.996	0.164	0.0981	0.783	0.804
Beijing	4.066	0.301	1.009	0.287	0.0865	0.809	0.726
Tianjin	3.459	0.528	1.312	0.446	0.108	0.709	0.593
Zhejiang	2.581	0.529	0.882	0.280	0.108	0.461	0.255
Jiangsu	2.446	0.531	0.915	0.316	0.103	0.459	0.393
Guangdong	2.327	0.485	0.816	0.191	0.105	0.530	0.425
Liaoning	2.023	0.498	1.890	0.567	0.137	0.551	0.478
Fujian	1.976	0.465	0.829	0.300	0.0995	0.434	0.277
Shandong	1.952	0.524	1.217	0.464	0.110	0.402	0.322
Inner Mongolia	1.896	0.440	2.162	1.097	0.163	0.466	0.374
Jilin	1.452	0.439	1.777	0.921	0.121	0.461	0.445
Hebei	1.412	0.507	1.937	0.878	0.145	0.329	0.251
Heilongjiang	1.395	0.516	1.692	0.504	0.114	0.540	0.470
Chongqing	1.388	0.473	1.266	0.741	0.109	0.439	0.265
Hubei	1.264	0.426	1.532	0.854	0.119	0.415	0.326
Xinjiang	1.246	0.417	2.320	0.905	0.128	0.372	0.389
Shanxi	1.226	0.520	3.327	1.332	0.221	0.394	0.293
Hainan	1.161	0.246	0.860	0.134	0.157	0.396	0.319
Shannxi	1.150	0.479	1.553	0.715	0.133	0.347	0.262
Ningxia	1.140	0.446	3.428	1.511	0.396	0.381	0.330
Hunan	1.119	0.401	1.311	0.730	0.0998	0.347	0.210
Henan	1.119	0.504	1.379	0.666	0.129	0.289	0.198
Sichuan	1.048	0.424	1.483	0.526	0.110	0.294	0.223
Qinghai	1.046	0.466	2.916	0.872	0.374	0.387	0.297
Jiangxi	0.987	0.436	1.059	0.505	0.0923	0.345	0.246
Jiangxi Anhui	0.950	0.422	1.345	0.882	0.109	0.329	0.206
Guangxi	0.920	0.387	1.154	0.554	0.121	0.309	0.182
Yunnan	0.813	0.426	1.603	0.634	0.141	0.261	0.162
Gansu	0.764	0.439	2.440	0.982	0.252	0.287	0.221
Guizhou	0.592	0.384	3.278	2.164	0.261	0.244	0.153

Notes: Data source China Statistical Yearbooks, China Population Statistical Yearbooks and China Energy Statistical Yearbooks. Income is the annual average real GDP per capita (10,000 RMB/person); Industrialization is the annual average secondary industry value added divided by GDP; Energy intensity is the annual average energy consumption per real GDP (tons standard coal/10,000 RMB); Coal intensity is the annual average coal consumption per real GDP (tons/RMB 10,000) and the electricity is the annual average electricity consumption per real GDP (kWh/yuan); The two urban indicators are urban population density and nonagricultural population density.

Table 2: Summary statistics for China's 30 provinces (1995-2012) in 2005 prices

Variable	Obs	Mean	Std. Dev.	Min	Max
Income per capita	540	1.638	1.379	0.217	7.416
Industrialization	540	0.386	0.081	0.121	0.530
Energy Intensity	540	1.659	0.866	0.480	6.470
Coal Intensity	540	0.704	0.532	0.059	3.380
Electricity Intensity	540	0.147	0.084	0.049	0.504
Urban1	540	0.425	0.165	0.135	0.893
Urban2	540	0.336	0.161	0.135	0.898
Growth rates					
Income per capita	510	0.112	0.0459	-0.0376	0.261
Industrialization	510	0.00782	0.0331	-0.0898	0.171
Energy Intensity	510	-0.0373	0.0615	-0.269	0.259
Coal Intensity	510	-0.0627	0.131	-0.650	0.694
Electricity Intensity	510	-0.0132	0.0806	-0.312	0.565
Urban1	510	0.0433	0.105	-0.423	1.295
Urban2	510	0.0225	0.0465	-0.135	0.586

Source: China Statistical Yearbooks, China Population Statistical Yearbooks and China Energy Statistical Yearbooks.

Table 3: Annual average population summary in 30 provinces (1995-2012)

Rank of difference value	Province	Urban population at year end	Non-agricultural population	Difference value
1	Guangdong	6419	3796	2623
2	Zhejiang	3111	1281	1830
3	Shandong	4581	3209	1371
4	Henan	3442	2129	1312
5	Hunan	2718	1494	1223
6	Jiangsu	4390	3198	1192
7	Anhui	2487	1411	1076
8	Sichuan	3092	2034	1057
9	Hebei	2996	1940	1056
10	Fujian	1984	1054	931
11	Guangxi	1812	939	873
12	Yunnan	1536	728	808
13	Shanghai	1924	1143	781
14	Jiangxi	1863	1150	713
15	Beijing	1543	898	645
16	Hubei	2703	2089	614
17	Liaoning	2645	2045	599
18	Shanxi	1603	1029	575
19	Shaanxi	1609	1043	565
20	Chongqing	1455	893	563
21	Guizhou	1100	620	481
22	Tianjin	949	574	375
23	Inner Mongolia	1290	930	360
24	Heilongjiang	2107	1803	304
25	Gansu	875	617	258
26	Jilin	1456	1211	245
27	Hainan	416	291	125
28	Qinghai	237	156	81
29	Ningxia	287	212	75
30	Xinjiang	867	809	57

Source: NBSC website, http://data.stats.gov.cn/. Unit: 10,000 person. For Tibet, the urban population at year end is 650,000 and non-agricultural population is 440,000.

Table 4: Tests for cross-section dependence and units roots

Variable	CD-test	*p*-value	corr	abs(corr)	CIPS	*p*-value
TEI	70.790	0.000	0.800	0.800	-2.372	0.328
CEI	72.370	0.000	0.818	0.819	-1.819	0.995
EEI	21.060	0.000	0.238	0.520	-2.265	0.555
Income per capita	88.000	0.000	0.994	0.994	-1.815	0.995
Industrialization	32.020	0.000	0.362	0.640	-1.718	0.999
Urban1	80.100	0.000	0.905	0.905	-1.863	0.990
Urban2	79.880	0.000	0.903	0.903	-1.299	1.000
CEI in Construction Industry	33.550	0.000	0.379	0.550	-1.615	1.000
EEI in Construction Industry	19.300	0.000	0.218	0.429	-1.849	0.992
CEI in Transport Industry	0.230	0.820	0.003	0.369	-1.586	1.000
EEI in Transport Industry	72.790	0.000	0.832	0.823	-2.392	0.290
CEI in Tertiary Industry	6.390	0.000	0.072	0.437	-2.436	0.214
EEI in Tertiary Industry	11.390	0.000	0.129	0.499	-2.926	0.000
Residential Coal Intensity	14.530	0.000	0.164	0.369	-2.120	0.821
Residential Electricity Intensity	82.590	0.000	0.933	0.933	-1.635	1.000

Note: For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. Column 1 and 5 show the statistical values of the CD test and CIPS test while column 2 and 6 provide the corresponding *p*-values. Column 3 and 4 provide the average correlation and the average absolute correlation between the cross-sectional units.

Table 5: Determinants of TEI, CEI and EEI (Pooled OLS estimates 1995-2012)

VARIABLES	(1) OLS TEI	(2) OLS CEI	(3) OLS EEI	(4) OLS TEI	(5) OLS CEI	(6) OLS EEI
Income per capita	-1.052***	-1.517***	-0.804***	-1.136***	-1.491***	-0.803***
	(0.054)	(0.090)	(0.058)	(0.045)	(0.078)	(0.059)
Industrialization	1.923***	3.337***	1.696***	2.304***	3.517***	1.865***
	(0.185)	(0.440)	(0.184)	(0.181)	(0.444)	(0.188)
Urban1	2.011***	1.795***	1.392***			
	(0.163)	(0.294)	(0.165)			
Urban2				2.255***	1.648***	1.345***
				(0.138)	(0.242)	(0.162)
Observations	540	540	540	540	540	540
Adjusted R-squared	0.491	0.647	0.283	0.569	0.654	0.303
CD test (p value)	0.005	0.008	0.072	0.005	0.007	0.076
CIPS test (p value)	0.995	0.982	0.992	0.937	1	1

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively. Year dummies are included in each specification.

Table 6: Determinants of TEI, CEI and EEI (Fixed effects estimates 1995-2012)

VARIABLES	(1) FE TEI	(2) FE CEI	(3) FE EEI	(4) FE TEI	(5) FE CEI	(6) FE EEI
Income per capita	-0.469**	-0.400*	-0.492*	-0.421**	-0.369	-0.435*
	(0.184)	(0.233)	(0.249)	(0.171)	(0.244)	(0.222)
Industrialization	1.325**	1.676**	1.309**	1.474**	1.731*	1.479**
	(0.507)	(0.792)	(0.513)	(0.572)	(0.886)	(0.537)
Urban1	0.919***	0.753	1.126***			
	(0.277)	(0.456)	(0.326)			
Urban2				0.875*	0.112	0.964*
				(0.447)	(0.748)	(0.497)
Observations	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30
Adjusted R-squared	0.782	0.795	0.403	0.767	0.790	0.353
CD test (p value)	0.004	0.013	0.069	0.004	0.011	0.059
CIPS test (p value)	0.422	0.746	0.998	0.668	0.821	0.989

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively. Year dummies are included in each specification.

Table 7: Determinants of TEI, CEI and EEI (Mean group estimates 1995-2012)

Dependent variables	(1) MG TEI	(2) MG CEI	(3) MG EEI	(4) MG TEI	(5) MG CEI	(6) MG EEI
Income per capita	-0.493***	-0.772***	-0.298***	-0.542***	-0.824***	-0.291***
	(0.072)	(0.136)	(0.071)	(0.065)	(0.130)	(0.067)
Industrialization	1.399***	2.364***	1.005***	1.397***	2.891***	0.406
	(0.252)	(0.691)	(0.316)	(0.279)	(0.782)	(0.312)
Urban1	0.207	-0.237	0.761**			
	(0.344)	(0.571)	(0.300)			
Urban2				2.211**	1.368	1.286**
				(0.981)	(1.280)	(0.591)
Observations	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30
RMSE	0.055	0.119	0.063	0.059	0.133	0.066
CD test (p value)	0.000	0.000	0.000	0.000	0.000	0.000
CIPS test (p value)	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 8: Determinants of TEI, CEI and EEI (Augmented mean group estimates 1995-2012) IVA

Dependent variables	(1) AMG TEI	(2) AMG CEI	(3) AMG EEI	(4) AMG TEI	(5) AMG CEI	(6) AMG EEI
Income per capita	-0.662***	-0.287**	-0.690***	-0.630***	-0.162	-0.809***
	(0.054)	(0.136)	(0.090)	(0.047)	(0.186)	(0.098)
Industrialization	0.632**	0.902	0.510*	0.452	0.755	0.379
	(0.247)	(0.607)	(0.283)	(0.296)	(0.649)	(0.288)
Urban1	0.496	1.473**	0.753**			
	(0.377)	(0.730)	(0.319)			
Urban2				1.024**	1.272	0.256
				(0.503)	(1.580)	(0.607)
Observations	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30
RMSE	0.037	0.097	0.056	0.039	0.099	0.058
CD test (p value)	0.046	0.144	0.063	0.181	0.058	0.046
CIPS test (p value)	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 9: Mean group estimation on **channel one** "Construction" (Heterogeneous estimates 1995-2012)

VARIABLES	(1) MG CEI	(2) AMG CEI	(3) MG EEI	(4) AMG EEI	(5) MG CEI	(6) AMG CEI	(7) MG EEI	(8) AMG EEI
Income per capita	-0.549***	-0.119	-0.288***	-0.790***	-0.617***	-0.085	-0.275***	-0.691***
	(0.180)	(0.134)	(0.084)	(0.092)	(0.150)	(0.183)	(0.057)	(0.108)
Industrialization	2.068***	0.809*	0.378	0.294	2.517***	0.905	0.029	-0.119
	(0.645)	(0.432)	(0.343)	(0.309)	(0.723)	(0.558)	(0.328)	(0.271)
EI in construction sector	0.479***	0.285**	0.253*	0.323***	1.123***	0.650**	0.372*	0.605*
	(0.135)	(0.121)	(0.146)	(0.123)	(0.397)	(0.314)	(0.204)	(0.356)
Urban1	-2.169	0.055	-1.196	-2.439**				
	(2.118)	(1.236)	(1.601)	(1.167)				
Urban1 * EI in construction sector	-1.135***	-0.520*	-0.640	-0.831***				
	(0.396)	(0.315)	(0.433)	(0.320)				
Urban2					-11.143**	-5.766	-0.442	-5.945
					(4.852)	(4.021)	(2.015)	(5.417)
Urban2 * EI in construction sector					-3.809***	-1.842*	-1.205**	-2.234**
					(1.213)	(1.105)	(0.568)	(1.071)
Observations	540	540	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30	30	30
RMSE	0.099	0.085	0.047	0.041	0.098	0.071	0.049	0.042
CD test (p value)	0.000	0.474	0.000	0.468	0.000	0.095	0.000	0.469
CIPS test (p value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 10: Mean group estimation on **channel two** "Transport" (Heterogeneous estimates 1995-2012)

VARIABLES	(1) MG CEI	(2) AMG CEI	(3) MG EEI	(4) AMG EEI	(5) MG CEI	(6) AMG CEI	(7) MG EEI	(8) AMG EEI
Income per capita	-0.739***	-0.408***	-0.422***	-0.712***	-0.788***	-0.094	-0.422***	-0.796***
	(0.132)	(0.121)	(0.077)	(0.078)	(0.132)	(0.184)	(0.081)	(0.070)
Industrialization	1.921***	1.032**	1.221***	0.303	2.349***	0.990	0.726*	0.210
	(0.703)	(0.448)	(0.291)	(0.338)	(0.799)	(0.623)	(0.384)	(0.371)
EI in transport sector	0.205	0.277	0.034	0.323***	0.629*	0.501*	-0.149	0.341**
	(0.257)	(0.186)	(0.082)	(0.076)	(0.374)	(0.290)	(0.199)	(0.168)
Urban1	-0.342	-0.897	1.654	-2.273				
	(3.219)	(2.537)	(1.158)	(1.450)				
Urban1 * EI in transport sector	-0.161	-0.514	0.064	-0.589**				
	(0.561)	(0.428)	(0.170)	(0.231)				
Urban2					-9.958*	-12.900**	5.037	-2.847
					(5.885)	(5.970)	(3.657)	(3.484)
Urban2 * EI in transport sector					-1.923	-1.930**	0.395	-0.738
					(1.201)	(0.937)	(0.682)	(0.663)
Observations	540	540	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30	30	30
RMSE	0.089	0.076	0.042	0.034	0.098	0.074	0.044	0.037
CD test (p value)	0.040	0.198	0.000	0.071	0.000	0.066	0.000	0.033
CIPS test (p value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 11: Mean group estimation on **channel three** "Wholesale" (Heterogeneous estimates 1995-2012)

VARIABLES	(1) MG CEI	(2) AMG CEI	(3) MG EEI	(4) AMG EEI	(5) MG CEI	(6) AMG CEI	(7) MG EEI	(8) AMG EEI
Income per capita	-0.686***	-0.343***	-0.269***	-0.632***	-0.622***	-0.402***	-0.277***	-0.585***
	(0.117)	(0.114)	(0.079)	(0.070)	(0.151)	(0.145)	(0.061)	(0.067)
Industrialization	2.042***	0.804**	0.563*	0.071	2.370***	1.221***	-0.050	-0.305
	(0.607)	(0.344)	(0.334)	(0.341)	(0.678)	(0.322)	(0.293)	(0.264)
EI in tertiary sector	0.510***	0.332**	0.031	-0.003	0.974**	0.312	-0.397	0.177
	(0.164)	(0.156)	(0.160)	(0.129)	(0.477)	(0.318)	(0.416)	(0.275)
Urban1	-2.293	-1.565	2.914***	1.819				
	(1.611)	(1.446)	(1.071)	(1.262)				
Urban1 * EI in tertiary sector	-1.001***	-0.633*	0.413	0.194				
	(0.385)	(0.381)	(0.384)	(0.489)				
Urban2					-5.510	-4.199	6.824	2.412
					(4.076)	(3.527)	(5.324)	(4.742)
Urban2 * EI in tertiary sector					-2.595*	-1.073	1.374	-0.122
					(1.548)	(1.053)	(1.416)	(1.193)
Observations	540	540	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30	30	30
RMSE	0.083	0.074	0.045	0.038	0.090	0.074	0.048	0.041
CD test (p value)	0.119	0.316	0.000	0.046	0.000	0.254	0.000	0.206
CIPS test (p value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 12: Mean group estimation on **channel four** "Residential" (Heterogeneous estimates 1995-2012)

VARIABLES	(1) MG CEI	(2) AMG CEI	(3) MG EEI	(4) AMG EEI	(5) MG CEI	(6) AMG CEI	(7) MG EEI	(8) AMG EEI
Income per capita	-0.688***	-0.503***	-0.501***	-0.822***	-0.662***	-0.399**	-0.592***	-0.847***
	(0.122)	(0.088)	(0.086)	(0.081)	(0.114)	(0.169)	(0.092)	(0.086)
Industrialization	1.591***	0.684	1.116***	0.505*	2.102***	1.178*	0.781**	0.491
	(0.609)	(0.578)	(0.346)	(0.273)	(0.633)	(0.657)	(0.398)	(0.367)
Residential EI	0.960***	0.405*	0.156**	0.260***	2.103***	0.898*	-0.094	0.256
	(0.197)	(0.233)	(0.069)	(0.053)	(0.589)	(0.482)	(0.219)	(0.171)
Urban1	-5.017***	-2.314	0.881	0.110				
	(1.896)	(1.464)	(0.811)	(0.944)				
Urban1 * Residential EI	-2.107***	-0.785	0.113	0.010				
	(0.563)	(0.585)	(0.180)	(0.232)				
Urban2					-17.298***	-9.239*	9.587**	2.670
					(5.212)	(5.121)	(3.928)	(2.775)
Urban2 * Residential EI					-5.593***	-2.322	1.460*	0.180
					(1.687)	(1.451)	(0.870)	(0.705)
Observations	540	540	540	540	540	540	540	540
Number of provinces	30	30	30	30	30	30	30	30
RMSE	0.089	0.081	0.039	0.030	0.091	0.079	0.038	0.031
CD test (p value)	0.000	0.389	0.000	0.363	0.000	0.154	0.000	0.118
CIPS test (p value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation is based on a balanced panel of 30 provinces 1995 to 2012. P values are reported for the CD and CIPS tests. For the CD test, the null hypothesis is cross sectional independence. For the CIPS test, the null hypothesis is non-stationarity. RMSE (root mean square error). Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Appendix A

Terminology

1. **Energy intensity** measured as (1) the primary energy supply divided by the output ratio (GJ/$) or (2) energy consumption of standard coal equivalent per GDP. In this paper energy intensity and energy efficiency are used interchangeably. However, strictly speaking, energy intensity is an indicator of, rather than equivalent to, energy efficiency. **Energy efficiency** means using less energy to provide the same service while energy intensity is a precise unit of measurement.
2. **Urbanization** is defined as the physical growth of urban areas associated with the movement of labor from rural and suburban areas to the city center. If China was to reach Western levels of urbanization it would need to increase the level of urbanization by more than 23 percentage points. According to the Department of Economic and Social Affairs of the UN, the urbanization rate of China will reach 55.6% in 2015 which is slightly higher than the world average of 54% but still considerably below the urbanization rate of 78.3% for developed countries.
3. **Industrialization** refers to the process by which a society transforms itself from a traditional agricultural society to one based on higher value added manufacturing activities.

Appendix B

Table B1: Variables explanations

Variables	Meaning	Units
Total Energy Intensity (TEI)	Total energy consumption/Real GDP	Tons standard coal/10,000 RMB
Coal Intensity (CEI)	Coal consumption/Real GDP	10,000 tons/10,000 RMB
Electricity Intensity (EEI)	Electricity consumption/Real GDP	100 million kWh
Income per capita	Real GDP/Total population at year end	10,000 RMB/person
Industrialization	Industrial value added/GDP	
Urban1	Urban population at year end/Total population at year end	
Urban2	Non-agricultural population/Total registered population	
Coal Intensity in Construction Industry	Coal consumption in construction industry/Real value added in construction industry	10,000 tons/10,000 RMB
Electricity Intensity in Construction Industry	Electricity consumption in construction industry/Real value added in construction industry	kWh/yuan
Coal Intensity in Transport Industry	Coal consumption in transport, storage and post industry/ Total population at year end	Tons/person
Electricity Intensity in Transport Industry	Electricity consumption in transport, storage and post industry/ Total population at year end	10,000 kWh/person
Coal Intensity in Tertiary Industry	Coal consumption in wholesale, retail trade and hotel, restaurants industry/Real value added in wholesale, retail trade and hotel, restaurants industry	10,000 tons/10,000 RMB
Electricity Intensity in Tertiary Industry	Electricity consumption in wholesale, retail trade and hotel, restaurants industry/ Real value added in wholesale, retail trade and hotel, restaurants industry	kWh/yuan
Residential Coal Intensity	Residential coal consumption/Total population at year end	Tons/person
Residential Electricity Intensity	Residential electricity consumption/Total population at year end	10,000 kWh/person

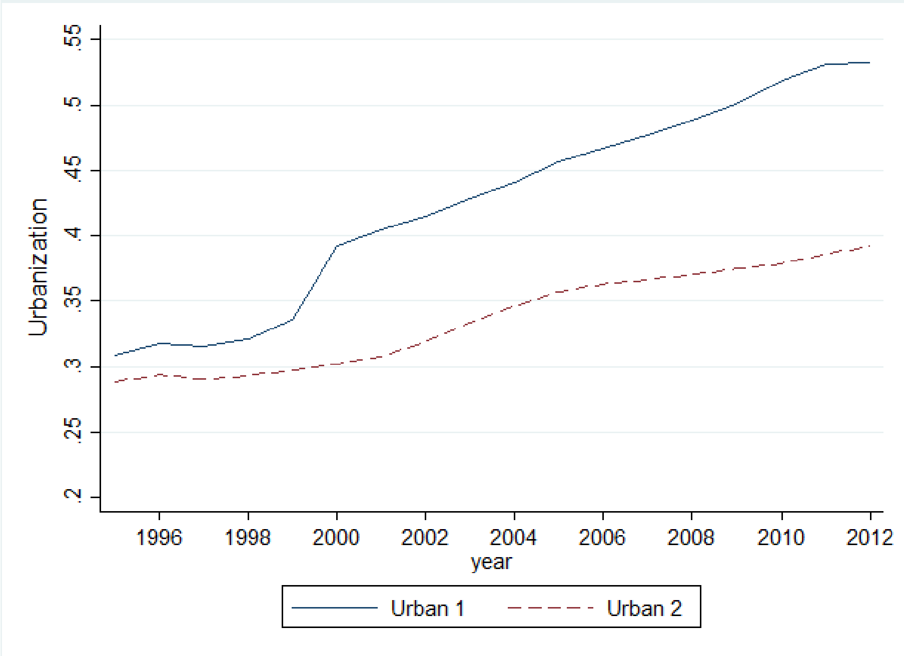
Source: China Statistical Yearbooks, China Population Statistical Yearbooks and China Energy Statistical Yearbooks for various years on China Data Online.

Table B2: Correlation matrix for primary variables

	Total energy intensity	Income per capita	Industrialization	Urban1	Urban2
Total energy intensity	1.000				
Income per capita	-0.606	1.000			
Industrialization	-0.508	0.613	1.000		
Urban1	-0.449	0.847	0.365	1.000	
Urban2	-0.296	0.696	0.218	0.895	1.000

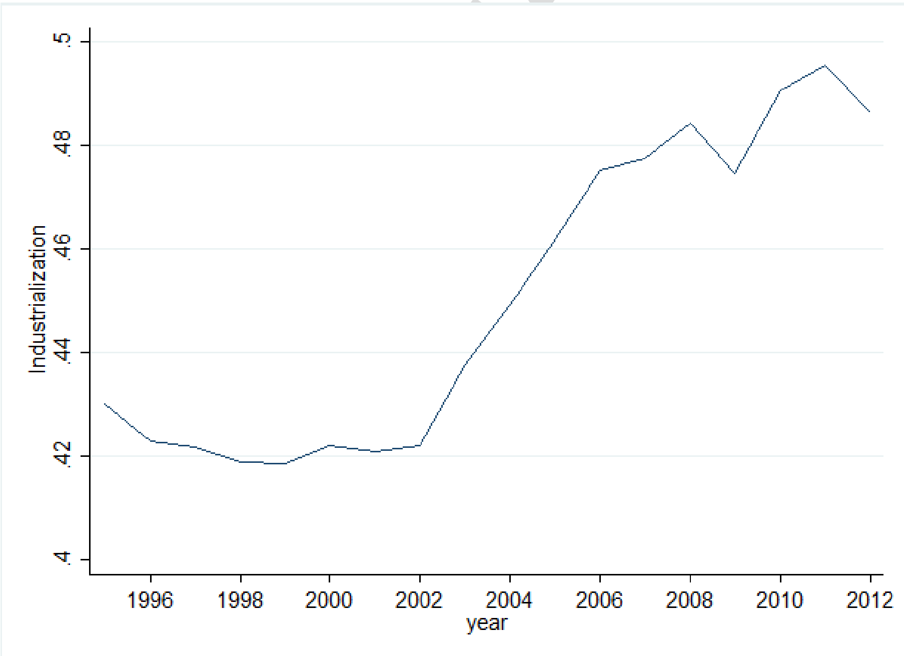
Note: Total energy intensity and income per capital are in natural logs. Observations N=540.

Figure B1: Chinese Annual Average Urbanization in 30 Provinces (1995-2012)



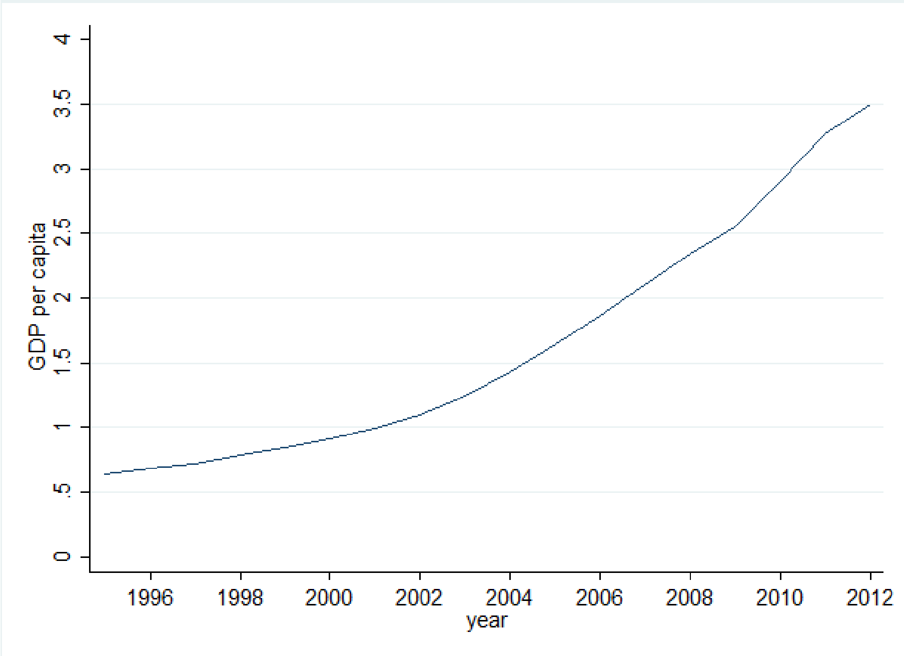
Source: China Statistical Yearbooks and China Population Statistical Yearbooks 1996-2013

Figure B2: Chinese Annual Average Industrialization in 30 Provinces (1995-2012)



Source: China Statistical Yearbooks 1996-2013 (Units: Secondary industry added value/GDP)

Figure B3. Chinese Annual Average Income per capita in 30 Provinces (1995-2012)



Source: China Statistical Yearbooks 1996-2013 (Units: 10,000 RMB/person in 2005 prices)

[1] Appendix A presents the definitions for the specific terms that are used in this paper (energy intensity, urbanization and industrialization).

[2] The huge movement of people from rural to urban areas underpinned the Chinese economic transformation but caused an appreciable increase in the share of city residents without urban *hukou*. Due to limited access to public services internal migrants have a lower average propensity to consume. The lower consumption of non-*hukou* households tends to impede progress towards a consumption-led growth model.[58]

[3]An alternative to the AMG approach is to use the Common Correlated Effects (CCEMG) estimator developed by Pesaran (2006)[59] and used by Sadorsky (2013) which also takes into account both parameter heterogeneity and common factors. This CCEMG has a general multifactor error structure and assumes that the unobservable common factor can be substituted by the cross-sectional average of the independent and the dependent observations. Compared to the AMG approach, the CCEMG estimator is relatively data-intensive since the degrees of freedom are reduced considerably after the inclusion of the averages as proxies for the unobservable common factor in each region regression. In relatively short province time-series this could lead to loss of precision in the province estimates. With panel data, N is regarded as infinite asymptotically and T is finite. Since it is a relatively short panel the CCEMG approach is unreliable and hence the CCEMG results are not reported in this paper although they are available from the authors upon request.

[4] Data source: http://data.worldbank.org/indicator/EG.USE.COMM.GD.PP.KD.

[5] The variables measures as percentages i.e. industrialization, Urban1 and Urban2 have not been logged although in Zhang and Lin (2012), Sadorsky (2013) and Ma (2015) the variables measures in percentages were then logged. Hence, the coefficients are comparable with these previous studies only after multiplying by the corresponding mean value. For example, the coefficients for Urban1 in Table 6 range from 0.875 to 1.126. It implies that a one percentage point increase in Urban1 leads to an increase in energy intensity of between 0.875 to 1.126 percentage points. With the mean value at 0.425 from Table 2, one percentage point increase in Urban1 is equal to 1/0.425=2.353 percentage increase. Hence, the equivalent coefficient from previous studies' should be 0.875/2.353=0.372 to 1.126/2.353=0.479 which are highly consistent with the results that are found in this paper. Summing up, the coefficients for industrialization, Urban1 and Urban2 in the paper need to be multiplied by its mean value to be comparable with previous studies, which are 0.386, 0.425 and 0.336 from Table 2 respectively.

[6] See Elliott *et al.* (2015)[60] for a discussion of the China energy distribution network.