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Energy Transition and Economic Development in China: A National and Sectorial Analysis from a New Structural Economics Perspectives

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Abstract: New Structural Economics (NSE) predicts that structural change in energy production would follow different patterns during different development stages and across different sectors. These variations require a range of policy responses. In this paper, we investigate this assertion by modeling China's energy transition and economic development based on provincial panel data from 2000 to 2012. By using static models (Fama–MacBeth, OLS, fixed effect) and dynamic models (difference and system GMM), we find the relationship between low-carbon energy transition and economic development presents a U-shaped curve at the national level, but it is an inverted-U curve at the residential level. Furthermore, it is ambiguous in the agricultural sector and independent of economic development in the industry and service sectors. Institutional factors, natural resource endowment, environmental policy, and technological change influence China's energy transition. Our findings supports NSE application in the Chinese energy economy and diversify energy transition policy by adjusting to the local conditions.

Keywords: energy transition; economic development; EKC; energy ladder; New Structural Economics; carbon lock-in

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1. Introduction

The replacement of high-carbon energy with low-carbon energy is critical to China meeting its "Carbon Neutrality" target by 2060. Further, global energy transition is critical to keeping global warming at less than 1.5 degrees [1] and achieving UN Sustainable Development Goals. As the world's largest carbon dioxide emitter and fastest-growing developing country, China's experience may provide an energy transition pathway for other developing economies such as India to follow [2].

China's decarbonisation strategy is embedded in its rapid economic development and structural transformation from an agrarian economy to an industrialised economy and then to a service economy. At national and sectoral levels, policymakers need to understand the relationship between energy transition and economic growth. In this regard, the New Structural Economics [3] provides a view that economic structure varies at different stages of development, resulting in a diverse portfolio of fuels. To apply Lin's view of energy transition, we first analyse China's electricity mix at the national level, which is driven by a capital deepening process.

We apply a static and dynamic panel modelling approach based on China 30 provincial data from 2000 to 2012. The static model mainly relies on the Fixed Effect (FE) approach but with the Fama–MacBeth (FMB) regression, and Ordinary Least-Square (OLS) regression to check for consistency. To overcome the potential endogeneity problem, we appy the difference and system Generalised Method of Movement (GMM) to the dynamic models.

We find a U-shaped curve between energy transition and economic development at the national level. The turning point occurred at around CNY 15,350 per capita GDP (2010 prices). It indicates that China's energy transition pattern follows the Environmental Kuznets Curve (EKC) prediction and exhibits increasing returns to scale to economic development after crossing the turning point. However, the relationship in the residential sector is found to be an inverted-U curve, with the turning point occurring at around CNY 39,558. This suggests that the energy mix of households would become more carbon-intensive once per capita GDP exceeds the thresholds. Our models show that the energy transitions in the industry and service sector are independent of the level of per capita GDP. The pattern for the agricultural sector is ambiguous. We also find that natural resource endowments, energy prices and technology affect the energy transition to varying degrees. The price effect became particularly significant after 2005 when the nation launched the energy transition policy initiatives. Natural gas abundance enhanced the level of the energy transition at the national level and in the industry sector.

2. Literature Review

Grübler (2004) [4] synthesises energy transition into three dimensions: growth in consumption, change in quality, and change in structure. Such energy transitions have been happening for centuries [5–7]; for instance, a transition from wood to fossil fuels took place over 200 years ago. In the short run, a transition relies on energy availability, cost, pollution arising from its use, and improvements in efficiency arising from economic activity [8]. From the history of Western Europe, Kander, Malanima, and Warde (2014) [8] show that the share of carbon based fuel in the energy system followed an inverted U-curve from 1870 to 2010, with the peak at 80% occurring in 1940. The share of coal consumption increased at first and then decreased after 1945. Oil increased rapidly to peak in 1978 and declined after that. In contrast, the percentage of fuelwood followed a U-curve, dropping from 70% in 1840 to no more than 10% in the 1970s but increasing again to almost 30% in 2010.

Grübler (2003) [9] finds an inverted U-curve for the worldwide share of coal consumption from 1840 to 2020, with the turning point occurring around 1920. After that, the percentage of coal consumption stabilises, but coal's share relative to other energies significantly decreases [10]. These studies reveal a universal pattern of the energy transition, indicating that coal consumption increased from the Industrial Revolution and decreased after World War II. Tahvonen and Salo (2001) [11] establish a theoretical model in which the optimal transition path between renewable and non-renewable energy follows a U-shaped pattern at different economic development stages.

Among cross-country studies, Marcotullio and Schulz (2007) [12] find that industrialising countries experience more efficient energy transition in growth—starting at a lower per capita GDP and transiting faster than the United States. Grübler (2012) [13] emphasises that such energy transition is underpinned by technological change. Still, technological change may lead to self-perpetuating inertia of fossil technology use, so energy transition may be locked in by some traditional energies [14]. Whether technological change promotes energy transition or locks energy into a high-carbon energy trajectory has not yet been determined, and a better understanding of this phenomenon is needed.

The explanation of the energy transition involves three well-known evidence-based theories that provide distinct insights into energy transition: the energy ladder, the environmental Kuznets curve (EKC), and carbon lock-in theories. The 'energy ladder' theory provides a one-way trend of the energy transition with respect to economic development [15]. The second theory—the environmental Kuznets curve (EKC)—posits a quadratic relationship between environmental degradation and per capita GDP [16]. These two theories imply a causal relationship between energy transition and economic growth, but the relationship's direction is ambiguous. A third theory, called the carbon lock-in, states that the energy system may exhibit path-dependent attributes that lock it into fossil fuel consumption, driven by technological and institutional increasing returns to scale [17]. In this regard, the energy transition will be much slower than is predicted. It implies that change may be more complex and hindered by exogenous factors.

For China, Wang, Mugera Wang, Mugera [18] is the first paper to investigate the energy share changes with economic development under the framework of New Structural Economics. However, this research is confined to the electricity sector. A small number of papers touched on the energy transition issue from the urban and rural perspective [19,20], and the transitioning policies and technology evolution perspectives [21], these studies are not directly investigating the relationship between the energy share change and development. In this paper, we will fill this gap by a comprehensive analysis of this relationship.

3. Methodology

3.1. Model Specification

A full version of a static model is:

$$S_{i,t} = \beta_1 (lnGDP_{i,t})^2 + \beta_2 lnGDP_{i,t} + \boldsymbol{\gamma} \boldsymbol{lnX_{i,t}} + u_i + \varepsilon_{i,t} \quad (1)$$

The dependent variable is the energy transition measured by the share of low-carbon energy in total energy consumption. The independent variables include the linear and quadratic terms of per capita GDP, and other control variables are in vector $\boldsymbol{X}$. We consider ten types of energy: coal, diesel oil, gasoline, kerosene, fuel oil, raw oil, liquefied petroleum gas (LPG), natural gas, methane, and non-fossil primary electricity which includes nuclear, hydro, solar, and wind as a single unit. Coal and oil products are classified as high-carbon energy and other types as low-carbon energy. All energy quantities are the final consumption by end-users, measured in a heat equivalent unit, tonnes of coal equivalent (TCE). We split energy consumption into four sectors for sectoral level analysis within a province: industry, agriculture, residential and service.

It is a semi-log regression with all independent variables given in logarithms. The terms β_1, β_2 and vector γ are parameters to be estimated; i indicates provinces and t indicates the year. u_i is a province-specific factor that is time-invariant and assumed to be homoscedastic across provinces. ε_{it} is an error term that is independent and identically distributed.

The quadratic and linear terms of per capita GDP capture the potential relationship between energy transition and economic development. It measures the 'income effect' or 'growth effect' on energy transition. The signs of β_1 and β_2 indicate either a U- or an inverted U-shaped relationship. The turning point is given by $\exp^{-\frac{\beta_2}{2\beta_1}}$. The elasticity between energy transition and per capita GDP is given by $\beta_1 ln(GDP) + \beta_2$. The quadratic term allows economic growth to diminish or increase the effect on energy transition at the margin.

The vector $\boldsymbol{X}$ contains all control variables and lock-in effects. We compute the correlation matrix for all explanatory variables to see if significant multicollinearity exists. The results show that all correlation coefficients are below 0.6. We consider three types of lock-in effects: potential technology path-dependence for coal-fired generation, institutional barriers, and natural endowments. We also control for the prices of energy types and the incentive of policy intervention from local government by a proxy for environmental degradation.

The current energy transition state may depend upon past conditions: persistence, consumption behaviour formation, partial adjustment, and so forth. Therefore, we include the lagged dependent variable in the dynamic model:

$$S_{i,t} = \beta_0 S_{i,t-1} + \beta_1 (lnGDP_{i,t})^2 + \beta_2 lnGDP_{i,t} + \boldsymbol{\gamma} \boldsymbol{lnX_{i,t}} + u_i + \varepsilon_{i,t} \quad (2)$$

where β_0 is the parameter of the first-lagged dependent variable and the rate of convergence can be expressed as $1 - \beta_0$, which implies the speed of adjustment. If $\beta_0 = 0$, the dependent variable does not depend on the previous period's state. If $\beta_0 = 1$, there is no dynamic adjustment process because the energy transition is steady-state in every period. Given the model dynamics, $\frac{\gamma}{1-\beta_0}$ captures the long-run effect of $\boldsymbol{X}$ on energy transition.

3.2. Fixed Effect

The fixed effect term u_i in Equations (1) and (2) captures all unobservable time-invariant effects across provinces. The fixed effect can reflect, amongst other factors, social norms for energy transition and fuel-consumption patterns within a province. These factors are highly variable across provinces as there are distinct features of development across provinces. The Hausman test is used to choose between the fixed effect and the random effect models. Differences within time series and between individuals have long been discussed in the literature. Generally, Panel data involve two types of variation: the differences between provinces (between variations) and the differences over time within provinces (within variation). Firstly, we proceed to the Ordinary Least-Squares (OLS) estimator, fixed-effect (FE) estimator and random-effect (RE) estimator for model choice. The rejection from the likelihood ratio test indicates that FE is superior to OLS. Breusch and Pagan Lagrangian multiplier test shows that RE estimator are better than OLS too. We finally adopt FE on basis of rejection of Hausman test between FE and RE. In this case, RE model is biased.

For robustness and comparison, we also estimate the model using the Fama–MacBeth (FMB) model and ordinary least squares (OLS). The OLS estimator is biased and inconsistent in the presence of fixed effects. The Fama–MacBeth two-step procedure [22] includes two steps: first we estimate cross-sectional regression by OLS every year; then we average coefficient estimates from the first step using Zellner's seemingly unrelated regression (SUR) estimation. This procedure allows us to include the over-year variation in coefficients. For $T \to \infty$, these averages will provide consistent estimators for the population. The standard errors are computed from the sample standard deviations of estimated coefficients, treating them as independent drawings from a common pool. The standard error calculation allows for arbitrary cross-sectional correlation and heteroscedasticity in residuals. The Fama–MacBeth procedure can provide a heteroscedasticity-consistent estimation in the absence of serial correlation. However, given the existence of a serial correlation, in this case, we adjust it via standard error estimates with a lag length of two periods.

3.3. The Generalised Method of Moments

The dynamic model might give rise to 'dynamic panel bias' because the lagged dependent variable may be positively correlated with the fixed effect so that the OLS estimator is inconsistent and overestimates the true autoregressive coefficient β_0 [23]. Given that the lagged term exists, the FE is inconsistent because the within transformed lagged dependent variable is correlated with the within transformed error. Given the finite time period T and provinces N, FE model underestimates the true autoregressive coefficient β_0 [24].

We use the generalised method of moments (GMM) to estimate the dynamic model to deal with this potential endogeneity problem. This method is particularly suitable for a dynamic model with few years and large groups. Anderson and Hsiao [25] propose difference GMM to remove the fixed effect by first-difference transforming data as follows:

$$\Delta S_{i,t} = \alpha \Delta S_{i,t-1} + \beta_1 \Delta (lnGDP_{i,t})^2 + \beta_2 \Delta lnGDP_{i,t} + \boldsymbol{\gamma \Delta lnX_{i,t}} + \Delta \varepsilon_{i,t} \tag{3}$$

GMM does not require that the error term is independent and identically distributed over provinces and years, but the consistency of estimators assumes that $\varepsilon_{i,t}$ does not exhibit autocorrelation.

Difference GMM still has potential endogeneity problems since the lagged dependent variable is still potentially endogenous with the changes of disturbance by way of $S_{i,t-1}$ in $\Delta S_{i,t-1}$ is correlated with $\varepsilon_{i,\,t-1}$ in $\Delta \varepsilon_{i,t}$. In addition, some predetermined explanatory variables may not be strictly exogenous as they are correlated with $\varepsilon_{i,\,t-1}$. Therefore, we instrument $\Delta S_{i,t-1}$ by $S_{i,t-2}$ or further lagged terms.

Note that difference GMM does not employ all the necessary moment conditions. Thus, if some independent variables are not strictly exogenous but are predetermined, difference GMM does not always guarantee efficient estimates by applying instrument variables. More important, Blundell and Bond [26] point out that the first difference GMM may suffer from finite sample biases, particularly in a situation where the dependent variable shows high persistence; that is, α is close to one. In other words, past levels convey little information about future changes. In such situations, the instruments are weak because they provide very little information on the parameters of interest. Blundell and Bond (1998) introduce the system GMM method that uses moment conditions based on both levels and first-differences equations. The significant advantage of system GMM is that it avoids losing information by differencing the fixed effect. In this paper, we employ both difference and system GMM methods for our dynamic model estimations. We estimate all models in the software Stata 15.

4. Variables and Data

The complete data source and the summary of variables are presented in Appendix A.

Per capita GDP is from the National Bureau of Statistics [27]. Per capita production data for coal, oil, and natural gas are collected from various China Energy Statistical Yearbook editions. Per capita coal-fired power generation capacity data are from the State Electricity Regulatory Commission. Population and urbanisation data are collected from the *China National Population Census* and *China Population and Employment Statistics Yearbook*. Sulphur dioxide emission data are from various versions of the *China Statistical Yearbook on the Environment*.

Energy price data are from the National Development and Reform Commission, which surveys commodity prices in 36 large cities at ten-day intervals. We used the energy price in the capital city of each province as a proxy for energy prices in each province. The yearly price data were derived by averaging all observations within one year. Other price data are collected from the *China Price Statistical Yearbooks*. All price and per capita GDP data are deflated to 2010 using the GDP deflator issued by World Bank. Source: http://data.worldbank.org.cn/indicator/NY.GDP.DEFL.ZS (accessed on 15 October 2021), base year is 2010.

The model covers the data from 2000 to 2012. The more recent years' data are not included in the model mainly due to the energy price data not being available after 2012. The provincial and sectoral level energy price data by fuels are collected by the National Development and Reform Commission and are not open to public access. We can only access the historical data by agreement with confidentiality.

Energy prices influence energy adoption. Therefore price regulation is a potential policy lock-in factor for energy transition. China's reform and economic growth is characterised by marketisation and deregulation, which has transformed a central planning economy to a market economy; the energy sector is no exception. Energy prices cannot be used as a market signal unless the industry is deregulated. The state controlled China's energy prices before the 'dual-track' pricing reforms introduced in the 1980s; after 1990, price liberalisation was accelerated, and deregulation was introduced into all types of energy [28]. In particular, the State Planning Commission deregulated electricity and coal pricing in 2001 [29], which made most energy pricing subject to market forces. Fisher-Vanden [30] reveals by partial equilibrium analysis that market reforms in China could result in a structural shift to less carbon intensity and lower carbon emissions per capita.

Resource endowment is another major factor. Provinces with large natural endowments of some forms of energy are usually reluctant to change consumption habits as abundant local energy is readily available and cost effective. This effect has been discovered in several cross-country studies [31–33]. In modelling, we control for three main types of energy resource: coal, oil and natural gas, to test this hypothesis. We assume provinces with large coal or oil endowments retain their carbonisation trajectory even when they become wealthier; and that provinces with large natural gas reserves tend to use more low-carbon energy supplies even if they are relatively underdeveloped.

To measure the amount of natural endowment, a suitable proxy is needed. Some candidates have been discussed in the literature: for instance, some economists use the export energy data [34,35] while others use the resource rent data [36]. We adopt Brunnschweiler [37] measurement of per-capita production as an indicator for several reasons. Firstly, the reserve quantity is usually static, so it does not reflect economic dynamics. Secondly, it is a part of natural assets. It does not reflect how much energy flows into the economic system. Thirdly, the production quantity reflects the energy supply's capacity, given the technology level. As Smil [7] says, energy transition, at least in short to mid-term, is restricted by the availability and convertibility of individual resources and by the pace of technological innovation and social adaptation. We consider that using production quantity here is reasonable in the short to medium term and is a better option than reserve data for measuring the endowment effect.

Energy transition may be locked in by existing fossil technologies offering an increasing scale of return [17]. Provinces with many coal-fired electricity generators will only be able to gradually replace coal with renewables. In 2015 coal-fired power generation capacity accounted for 59% of China's total electricity generation capacity, Source: https://chinaenergyportal.org/2016-detailed-electricity-statistics/ (accessed on 1 September 2019). therefore coal-fired electricity may be a major lock-in factor. Large numbers of coal-powered plants may lock a province into using coal for its electricity production. To overcome the scale effect of the economy, we use per-capita coal-fired power generation capacity (installed) as a proxy to investigate potential technology lock-in.

Another lock-in effect may be institutional lock-in. It is challenging to find an appropriate proxy variable to measure this. We propose an urbanisation variable as proxy for institutional development during the transition from agrarianism to industrialisation. A feature of China's reform and rapid growth during the past decades is internal migration from rural areas to urban centres, which is not a natural economic phenomenon but relevant to many institutional rearrangements such as the Hukou system (A Hukou is a record in a government system of household registration required by law in mainland China and Taiwan and determines where citizens can live. Because of its entrenchment of social strata, especially between rural and urban residency status, the Hukou system is often regarded as a form of caste system. https://en.wikipedia.org/wiki/Hukou_system (accessed on 20 August 2019)) reform, the social insurance system, urban infrastructure investment, and equity-based human rights. Herrerias, Aller [38] found that the energy mix in urban areas changed when electricity replaced coal, and they consider that urbanisation accounts for this, especially in the areas of Hukou reform and the New Urbanisation policy. We use the number of people living in urban areas to indicate this major institutional change: the more people in an urban area, the more sophisticated civil society becomes and, as a result, the quality of its institutions.

Urbanisation may have mixed effect on energy transition. On the one hand, a large urban population may increase energy consumption, particularly of high-carbon energy as it provides higher energy density and higher power intensity. High-carbon energy such as coal and oil can provide stable and sufficient power, given the limited space and land in a city. Any increase in urbanisation may increase high-carbon energy consumption, weakening the transition to low-carbon energy. On the other hand, a densely populated community may make more viable the widespread use of natural gas, electricity and other renewables that are suitable for grid transmission, and so would promote low-carbon energy transition. Generally, in the early stages of industrialisation, the process of urbanisation may lock energy transition into a high-carbon energy consumption trajectory; in later stages, it may increase low-carbon energy use so that sustainable development is achieved. Whether urbanisation will positively or negatively affect China's energy transition needs to be investigated.

Industrial policy and other regulatory initiatives have always played an important role in China's energy transition. We model this policy effect as a proxy of the lagged term of yearly changes in sulphur dioxide (SO_2) emission. We argue that it can measure the rigour of the environmental policy. The underlying assumption is that if an increase in SO_2 emissions was high last year, local governments would come under more pressure to adopt policy actions on energy transition this year. Sulphur dioxide is the primary pollutant from the use of coal and oil, is a significant indicator of pollution, and is strictly monitored by the Ministry of Environmental Protection and other authorities. They use it to assess the performance of the environmental governance of local governments.

5. Results

5.1. Descriptive Patterns

Figures 1 and 2 display the general pattern of energy share change against per capita GDP in the selected years at the national and sectoral levels.

From Figure 1, we can see that the level of energy transition is seen to rise over time. When per-capita GDP was below CNY 20,000, the transition curve followed an inverted U in 1995, but changed to a standard U-curve in 2006 when most provinces achieved a per-capita GDP of nearly CNY 20,000, moving towards CNY 40,000. The turning point seems to be constant at between these amounts. In 2012, most provinces lay between CNY 40,000 to 60,000, with some exceeding CNY 40,000 (Beijing, Tianjin, Shanghai, Jiangsu); the relationship between energy transition and per-capita GDP shows a linear trend, suggesting that energy transition is in line with economic growth.

The sectoral level data are presented in Figure 2. The pattern in the industrial sector is similar to the national performance. The residential sector pattern is linear and growing flattened with time. All curves in the agricultural sector have negative slopes, suggesting a negative relationship between energy transition and economic growth. The agricultural sector tends to consume high-carbon energy rather than low-carbon energy during economic growth. In the service sector the curves are almost flat, suggesting the energy transition in this sector is irrelevant to per-capita GDP. We will test all these patterns and our speculations empirically in the following sections.

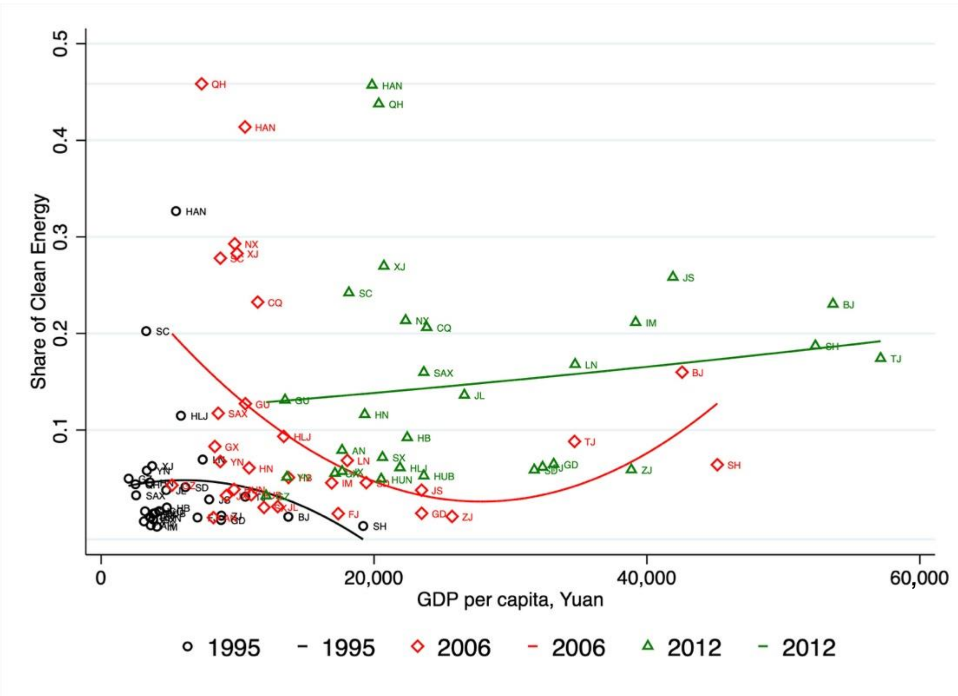

Figure 1. Relationship between the share of low-carbon energy and per-capita GDP (national level).

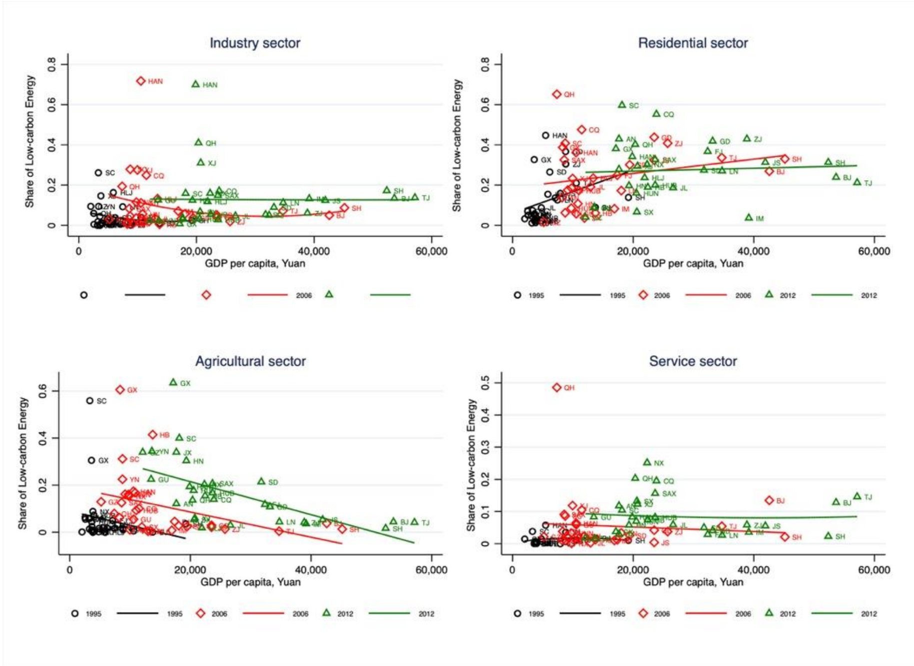

Figure 2. Relationship between the share of low-carbon energy and per capita GDP (sectoral level).

Tables 1 and 2 presents estimates of the national level static and dynamic models, respectively. Sectoral transition estimations are reported in Tables 3–6, for the industry, agricultural, service and residential sectors separately.

Table 1. Results for the national level static model.

Variable \ Model	FMB	OLS	FE	FE_before2005	FE_post2005
GDP^2	0.024 **	0.018 **	0.044 ***	−0.075 **	0.084 ***
	(0.032)	(0.030)	(0.001)	(0.033)	(0.000)
GDP	−0.417 *	−0.336 **	−0.847 ***	1.454 **	−1.634 ***
	(0.066)	(0.042)	(0.001)	(0.026)	(0.000)
coalgen	−0.064 ***	−0.052 ***	0.041 **	−0.004	0.015
	(0.000)	(0.000)	(0.029)	(0.894)	(0.568)
urban	−0.047 ***	−0.064 ***	0.030	0.009	−0.043
	(0.001)	(0.000)	(0.147)	(0.791)	(0.689)
gas	0.021 ***	0.019 ***	0.010 ***	0.004	0.007 *
	(0.000)	(0.000)	(0.006)	(0.509)	(0.055)
oil	−0.002	−0.003 **	−0.001	−0.004	0.000
	(0.280)	(0.027)	(0.863)	(0.545)	(0.964)
coal	−0.020 ***	−0.022 ***	−0.006	−0.021	0.000
	(0.000)	(0.000)	(0.397)	(0.383)	(0.995)
$P_{briquet}$	−0.031 *	−0.009	−0.014	−0.044 *	0.000
	(0.067)	(0.379)	(0.235)	(0.085)	(0.996)
$P_{steamcoal}$	0.007	0.002	0.019	−0.030	0.093 ***
	(0.457)	(0.846)	(0.321)	(0.418)	(0.000)
$P_{elecind}$	−0.061	−0.039	0.032	0.044	0.040
	(0.138)	(0.147)	(0.317)	(0.543)	(0.428)
P_{elecre}	−0.037	0.053 *	0.027	−0.050	0.102 ***
	(0.359)	(0.091)	(0.534)	(0.486)	(0.010)
P_{elecag}	−0.059	−0.006	−0.021	0.036	−0.001
	(0.128)	(0.654)	(0.173)	(0.818)	(0.921)
$P_{elecserv}$	−0.070	−0.102 ***	0.079 **	0.049	0.052
	(0.133)	(0.002)	(0.038)	(0.795)	(0.195)

Table 1. *Cont.*

Variable \ Model	FMB	OLS	FE	FE_before2005	FE_post2005
P_{petro}	0.699 *	0.233 ***	0.067	0.183	−0.144
	(0.071)	(0.009)	(0.527)	(0.367)	(0.242)
P_{diesel}	−0.164 ***	−0.040	0.037	−0.200 *	0.079 *
	(0.002)	(0.151)	(0.368)	(0.085)	(0.092)
P_{gasind}	−0.031	−0.041 **	−0.031	−0.020	−0.043
	(0.487)	(0.022)	(0.107)	(0.433)	(0.234)
P_{gasre}	−0.057	−0.059 **	0.013	0.039	0.069
	(0.266)	(0.021)	(0.690)	(0.464)	(0.520)
SO_2	0.055	0.042	0.023	0.004	0.023
	(0.486)	(0.165)	(0.346)	(0.854)	(0.388)
constant	−2.426	0.747	2.837 **	−6.557 **	8.487 ***
	(0.511)	(0.527)	(0.045)	(0.041)	(0.000)
N	330	330	330	120	210
R^2	0.919	0.814	0.404	0.415	0.309
Turning point	6062.519	9534.2395	15,356.216	16,285.513	16,146.216

Note: *p*-values in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. year dummies are eliminated to save space.

Table 2. Results for the national level dynamic model.

Variable \ Model	OLS_lag	FE_lag	Diff_GMM	Sys_GMM
lag S	0.657 ***	0.224 ***	0.379	0.267 *
	(0.000)	(0.000)	(0.371)	(0.073)
GDP^2	0.015 **	0.041 ***	0.045 *	0.016 ***
	(0.016)	(0.000)	(0.052)	(0.005)
GDP	−0.282 **	−0.781 ***	−0.868 *	−0.314 ***
	(0.018)	(0.000)	(0.056)	(0.005)
coalgen	−0.014 **	0.033 **	0.069	−0.016
	(0.026)	(0.036)	(0.197)	(0.377)
urban	−0.023 ***	0.019	0.071	0.015
	(0.001)	(0.287)	(0.755)	(0.459)
gas	0.007 ***	0.008 ***	0.011 **	0.016 ***
	(0.000)	(0.008)	(0.029)	(0.001)
oil	−0.001	0.000	0.008	−0.002
	(0.157)	(0.956)	(0.116)	(0.552)
coal	−0.009 ***	−0.006	−0.005	−0.027 ***
	(0.000)	(0.350)	(0.746)	(0.002)
$P_{briquet}$	−0.006	−0.012	−0.045 **	−0.027 *
	(0.501)	(0.223)	(0.044)	(0.068)
$P_{steamcoal}$	0.005	0.025	0.052 **	0.006
	(0.595)	(0.170)	(0.031)	(0.757)
$P_{elecind}$	−0.021	0.025	0.043	−0.087 **
	(0.232)	(0.373)	(0.542)	(0.011)
P_{elecre}	0.025	0.022	0.002	−0.046
	(0.249)	(0.552)	(0.977)	(0.240)
P_{elecag}	−0.000	−0.013	−0.024	−0.026
	(0.964)	(0.347)	(0.515)	(0.309)
$P_{elecserv}$	−0.033	0.062 *	0.091	−0.090
	(0.173)	(0.069)	(0.515)	(0.124)
P_{petro}	0.015	0.030	−0.005	0.138 ***
	(0.850)	(0.738)	(0.952)	(0.000)
P_{diesel}	−0.011	0.033	0.000	0.038
	(0.625)	(0.288)	(0.999)	(0.131)
P_{gasind}	−0.024 *	−0.027	−0.060	−0.081 ***
	(0.059)	(0.116)	(0.183)	(0.001)
P_{gasre}	−0.014	0.025	0.059	−0.005

Table 2. *Cont.*

Model / Variable	OLS_lag	FE_lag	Diff_GMM	Sys_GMM
	(0.442)	(0.364)	(0.440)	(0.885)
SO_2	0.005	0.011	0.014	0.009
	(0.789)	(0.613)	(0.760)	(0.688)
constant	1.544	2.897 **		
	(0.116)	(0.013)		
N	330	330	300	330
R^2	0.894	0.436		
AR(1) [1]			0.097	0.003
AR(2) [2]			0.737	0.753
Sargan test			0.369	0.032
Hansen test			0.268	0.340
Instruments			23	26
Adjustment factor			0.621	0.733
Turning point			17,263.092	15,345.213

Note: *p*-values in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; [1], [2]: Arellano–Bond test for AR(1) and AR(2).

Table 3. Results for the industry sector.

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	**FMB**	**Ind_OLS**	**FE_ind**	**IndOLS_lag**	**FE_ind_lag**	**Diff_ind**	**Sys_ind**
$lagS_{ind}$				0.890 ***	0.486 ***	0.637 ***	0.641 ***
				(0.000)	(0.000)	(0.002)	(0.000)
GDP^2	−0.037 ***	−0.021	0.022	−0.001	0.009	0.017	−0.001
	(0.001)	(0.202)	(0.121)	(0.782)	(0.360)	(0.247)	(0.698)
GDP	0.737 ***	0.403	−0.457	0.017	−0.178	−0.362	0.037
	(0.001)	(0.205)	(0.116)	(0.756)	(0.345)	(0.224)	(0.618)
coalgen	−0.026 **	−0.020	0.010	0.001	−0.005	0.051	−0.017
	(0.021)	(0.374)	(0.726)	(0.868)	(0.799)	(0.200)	(0.170)
urban	−0.048 ***	−0.051 **	0.048 **	−0.010 **	0.017	0.077	−0.033
	(0.000)	(0.023)	(0.016)	(0.032)	(0.214)	(0.335)	(0.219)
gas	0.027 ***	0.030 ***	0.010 *	0.004 ***	0.008 *	0.009 *	0.012 **
	(0.000)	(0.000)	(0.071)	(0.006)	(0.057)	(0.095)	(0.031)
oil	−0.005 ***	−0.006	0.002	−0.001	0.000	−0.001	−0.002
	(0.002)	(0.104)	(0.671)	(0.262)	(0.989)	(0.868)	(0.316)
coal	−0.026 ***	−0.032 **	0.008	−0.005 *	0.001	−0.014 ***	−0.009
	(0.000)	(0.013)	(0.425)	(0.064)	(0.798)	(0.005)	(0.162)
$P_{steamcoal}$	−0.016	−0.009	−0.011	0.002	−0.012	−0.014	−0.004
	(0.459)	(0.835)	(0.667)	(0.754)	(0.516)	(0.414)	(0.796)
$P_{elecind}$	−0.121 **	−0.115 **	−0.024	−0.011	−0.010	0.014	−0.019
	(0.048)	(0.019)	(0.437)	(0.337)	(0.635)	(0.491)	(0.340)
P_{petro}	0.522	0.470 *	0.098	−0.033	−0.034	−0.074 *	0.026
	(0.141)	(0.058)	(0.346)	(0.636)	(0.728)	(0.092)	(0.238)
P_{diesel}	0.100 ***	0.044	−0.061	0.002	−0.031	−0.007	−0.013
	(0.003)	(0.479)	(0.246)	(0.918)	(0.322)	(0.747)	(0.295)
P_{gasind}	−0.042 ***	−0.036	−0.024	−0.005	−0.015	−0.009	0.002
	(0.007)	(0.486)	(0.440)	(0.355)	(0.501)	(0.749)	(0.939)
SO_2	0.013	0.001	−0.010	0.008	−0.002	0.040 **	0.008
	(0.883)	(0.984)	(0.670)	(0.739)	(0.942)	(0.016)	(0.676)
constant	−8.394 **	−5.681 *	1.714	0.223	1.442		
	(0.016)	(0.052)	(0.240)	(0.667)	(0.154)		
N	330	330	330	330	330	300	330
R^2	0.847	0.760	0.264	0.947	0.419		
AR(1) [1]						0.017	0.016
AR(2) [2]						0.447	0.381

Table 3. *Cont.*

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	FMB	Ind_OLS	FE_ind	IndOLS_lag	FE_ind_lag	Diff_ind	Sys_ind
Sargan test						0.246	0.125
Hansen test						0.296	0.130
instruments						25	28
Adjustment factor						0.36	0.36
Turning point	21,547.938						

Note: *p*-values in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. [1], [2]: Arellano–Bond test for AR(1) and AR(2). Instruments of models 6 and model 7 include the second to the fifth lagged of lag S_{ind}, the first to the fifth lagged of ln(coalgen) and ln(urban), unless collapsed.

Table 4. Results for the agricultural sector.

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	FMB	OLS	FE	OLS_lag	FE_lag	Diff_GMM	Sys_GMM
$lagS_{ag}$				0.921 ***	0.673 ***	0.809 ***	0.837 ***
				(0.000)	(0.000)	(0.000)	(0.000)
GDP^2	0.053 ***	−0.022	−0.034 ***	0.004	−0.002	0.011	−0.004
	(0.003)	(0.134)	(0.000)	(0.238)	(0.790)	(0.531)	(0.338)
GDP	−1.169 ***	0.333	0.652 ***	−0.089	0.057	−0.179	0.041
	(0.002)	(0.247)	(0.000)	(0.152)	(0.733)	(0.596)	(0.540)
coalgen	−0.071 ***	−0.066 ***	0.013	0.000	0.019	0.064	0.025
	(0.001)	(0.004)	(0.134)	(0.976)	(0.118)	(0.398)	(0.303)
gas	0.033 **	0.008	0.010	0.001	0.005	−0.095	−0.016
	(0.020)	(0.681)	(0.546)	(0.540)	(0.738)	(0.530)	(0.477)
oil	−0.006 ***	−0.007	−0.008	−0.001	−0.005	−0.008	−0.003
	(0.006)	(0.320)	(0.156)	(0.279)	(0.303)	(0.257)	(0.378)
coal	−0.020 ***	−0.020 **	0.008 **	−0.002 ***	−0.000	−0.004	−0.004
	(0.000)	(0.014)	(0.012)	(0.004)	(0.969)	(0.204)	(0.350)
$P_{steamcoal}$	−0.003	−0.001	−0.002	0.000	−0.001	0.004	0.001
	(0.551)	(0.882)	(0.687)	(0.800)	(0.789)	(0.779)	(0.887)
$P_{briquet}$	0.090 ***	0.093 **	0.042 **	0.014 *	0.008	−0.007	0.037
	(0.000)	(0.030)	(0.019)	(0.055)	(0.633)	(0.856)	(0.144)
P_{elecag}	−0.105 ***	−0.065	0.006	−0.010	−0.003	−0.024	−0.015
	(0.002)	(0.179)	(0.779)	(0.102)	(0.863)	(0.245)	(0.426)
P_{petro}	0.017	−0.001	−0.042 **	0.008	−0.015	0.017	0.030
	(0.566)	(0.989)	(0.031)	(0.193)	(0.173)	(0.793)	(0.276)
P_{diesel}	−0.364 ***	−0.265 ***	−0.025 *	−0.024	−0.046	0.024	−0.007
	(0.006)	(0.007)	(0.099)	(0.186)	(0.175)	(0.377)	(0.740)
SO_2	−0.142 **	−0.116 *	−0.030	−0.008	0.007	−0.008	−0.021
	(0.016)	(0.061)	(0.198)	(0.614)	(0.660)	(0.684)	(0.288)
constant	9.511 ***	1.336	−3.144 ***	0.719 *	−0.068		
	(0.001)	(0.457)	(0.001)	(0.050)	(0.943)		
N	330	330	330	330	330	300	330
R^2	0.712	0.617		0.955	0.693		
AR(1) [1]						0.013	0.006
AR(2) [2]						0.953	0.778
Sargan test						0.267	0.240
Hansen test						0.136	0.185
instruments						20	23
Adjustment factor						0.19	0.16
Turning point			14,952.158				

Note: *p*-values in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. [1], [2]: Arellano–Bond test for AR(1) and AR(2). Year dummies are eliminated to save space. Instruments of model 6 and 7 include the fourth to the sixed lagged lag S_{ag}, the fifth to the seventh lagged of ln(coalgen) and ln(urban), unless collapsed.

Table 5. Results for the service sector.

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	**FMB**	**OLS**	**FE**	**OLS_lag**	**FE_lag**	**Diff_GMM**	**Sys_GMM**
$lagS_{serv}$				0.846 ***	0.731 ***	0.779 ***	0.817 ***
				(0.000)	(0.000)	(0.000)	(0.000)
GDP^2	0.027 *	0.013	0.007	0.001	0.005	−0.000	0.003
	(0.057)	(0.243)	(0.470)	(0.669)	(0.398)	(0.977)	(0.416)
GDP	−0.504 *	−0.262	−0.079	−0.026	−0.054	0.003	−0.067
	(0.068)	(0.245)	(0.658)	(0.671)	(0.561)	(0.989)	(0.439)
urban	−0.026 ***	−0.030 *	−0.029	−0.003 *	0.008	0.109	0.010
	(0.005)	(0.051)	(0.197)	(0.100)	(0.591)	(0.647)	(0.707)
gas	0.007 **	0.007	−0.001	0.000	−0.002	−0.002	0.001
	(0.022)	(0.144)	(0.810)	(0.651)	(0.525)	(0.542)	(0.789)
oil	0.003 **	0.003	0.002	0.001 **	0.000	0.002	0.001
	(0.023)	(0.155)	(0.487)	(0.020)	(0.676)	(0.433)	(0.353)
coal	−0.009 ***	−0.006	−0.001	−0.001	−0.003	0.007	−0.003
	(0.001)	(0.233)	(0.894)	(0.375)	(0.589)	(0.504)	(0.596)
$P_{steamcoal}$	0.024 *	0.015	0.019	−0.000	0.016	−0.003	−0.004
	(0.073)	(0.595)	(0.386)	(0.963)	(0.230)	(0.824)	(0.680)
$P_{briquet}$	0.016 ***	0.021	−0.019	0.001	−0.007	−0.007	−0.006
	(0.006)	(0.118)	(0.405)	(0.893)	(0.455)	(0.612)	(0.564)
$P_{elecserv}$	0.005	0.005	0.107	−0.010	−0.006	−0.061	−0.030
	(0.847)	(0.898)	(0.221)	(0.345)	(0.798)	(0.217)	(0.553)
P_{petro}	−0.117	−0.052	0.150	0.036	−0.000	−0.013	0.032
	(0.578)	(0.743)	(0.189)	(0.194)	(0.989)	(0.835)	(0.206)
P_{diesel}	−0.070	−0.072	−0.058	−0.023	0.018	0.024	0.005
	(0.139)	(0.148)	(0.636)	(0.178)	(0.224)	(0.463)	(0.716)
P_{gasind}	−0.079 ***	−0.064 **	−0.039	−0.015 *	−0.009	0.015	−0.011
	(0.000)	(0.040)	(0.342)	(0.057)	(0.630)	(0.473)	(0.380)
constant	3.982	2.384	−0.361	0.054	−0.120		
	(0.141)	(0.276)	(0.707)	(0.876)	(0.760)		
N	368	368	368	339	339	310	339
R^2	0.615	0.450	0.239	0.843	0.572		
AR(1) [1]						0.045	0.034
AR(2) [2]						0.619	0.720
Sargan test						0.342	0.229
Hansen test						0.487	0.664
instruments						18	20
Adjustment factor						0.22	0.18

Note: *p*-values in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. [1], [2]: Arellano–Bond test for AR(1) and AR(2). Instruments of model 6 include the sixth to eighth lagged of lag S_{serv}, and the first to the fourth lagged of ln(urban); instruments of model 7 include the fifth to seventh lagged of lag S_{serv}, and lagged of ln(urban), unless collapsed.

Table 6. Results for the residential sector.

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	**FMB**	**OLS**	**FE**	**OLS_lag**	**FE_lag**	**Diff_GMM**	**Sys_GMM**
$lagS_{serv}$				0.934 ***	0.666 ***	0.720 ***	0.666 ***
				(0.000)	(0.000)	(0.004)	(0.001)
GDP^2	0.027	−0.017	−0.033	−0.002	−0.013	0.007	−0.010 **
	(0.321)	(0.460)	(0.114)	(0.748)	(0.310)	(0.786)	(0.041)
GDP	−0.512	0.359	0.644	0.039	0.295	−0.085	0.221 **
	(0.341)	(0.419)	(0.105)	(0.757)	(0.206)	(0.862)	(0.034)
urban	0.025 *	0.013	0.003	0.001	−0.000	−0.105	−0.020
	(0.063)	(0.627)	(0.960)	(0.742)	(0.995)	(0.604)	(0.474)
gas	0.027 ***	0.028 ***	0.009	0.001	−0.004	0.001	0.007
	(0.000)	(0.003)	(0.337)	(0.659)	(0.474)	(0.785)	(0.301)

Table 6. *Cont.*

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	**FMB**	**OLS**	**FE**	**OLS_lag**	**FE_lag**	**Diff_GMM**	**Sys_GMM**
oil	0.003	−0.002	−0.023 **	−0.001	−0.010 ***	−0.006 *	−0.002
	(0.504)	(0.733)	(0.014)	(0.490)	(0.001)	(0.058)	(0.491)
gas	−0.052 ***	−0.045 ***	−0.010	−0.002	−0.015	−0.014	−0.014
	(0.000)	(0.000)	(0.497)	(0.308)	(0.214)	(0.394)	(0.236)
$P_{briquet}$	0.017	0.030	−0.014	0.005	−0.009	−0.024	0.017
	(0.477)	(0.475)	(0.632)	(0.456)	(0.516)	(0.259)	(0.375)
P_{elecre}	−0.043	0.020	0.248 *	0.025	0.130 **	0.070	0.040
	(0.409)	(0.885)	(0.050)	(0.407)	(0.036)	(0.344)	(0.325)
P_{diesel}	−0.311 *	−0.132	0.005	−0.020	−0.009	−0.040	−0.036 **
	(0.062)	(0.424)	(0.965)	(0.346)	(0.876)	(0.230)	(0.028)
P_{petor}	0.331	0.151	−0.105	−0.059	0.014	−0.019	−0.085
	(0.310)	(0.769)	(0.598)	(0.280)	(0.902)	(0.852)	(0.111)
P_{gasre}	−0.084 ***	−0.062	−0.015	−0.024 **	0.014	0.056	0.010
	(0.002)	(0.444)	(0.867)	(0.039)	(0.771)	(0.430)	(0.726)
constant	2.091	−2.053	−1.936	0.501	−1.427		
	(0.608)	(0.703)	(0.516)	(0.558)	(0.372)		
N	389	389	389	359	359	329	359
R^2	0.552	0.458	0.251	0.917	0.563		
AR(1) [1]						0.023	0.018
AR(2) [2]						0.181	0.303
Sargan test						0.144	0.212
Hansen test						0.108	0.213
instruments						16	18
Adjustment factor						0.28	0.33
Turning point							39,558.94

Note: *p*-values in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. [1], [2]: Arellano–Bond test for AR(1) and AR(2). Instruments of model 6 and model 7 include the second to the third lagged of lag S_{serv} and the second to fifth lagged of ln(urban).

5.2. National Level Results

A significant U curve relationship is found at the national level between energy transition and per capita GDP, as shown in Table 1. Except for the sub-period before 2005, all the other models' coefficients for per capita GDP quadratic terms are significantly positive. The coefficients for per capita GDP linear terms are significantly negative. The energy transition pattern shifted from 2005 when the National Energy Transition Initiatives launched. However, the turning points are different across the models. Given that the Fama–MacBeth and OLS are biased estimations, the FE models are more robust, and they suggest that the turning point is around CNY 15,000–16,000.

The FE models for the two sub-periods before and after 2005 provide different significance levels. The natural gas endowment effect changes from insignificant to positively significant. After 2005, a one per cent increase in natural gas production will increase the low-carbon energy share by 0.007 per cent. It could be a result of the natural gas stimulation policy.

The price effects also became more significant after 2005. The price response is measured as the share elasticities. A one per cent increase in the steam coal price will result in a 0.093 per cent increase in the low-carbon energy share. A one per cent increase in residential electricity price will increase the low-carbon energy share by 0.102 per cent. One per cent increase in diesel price will increase low-carbon energy share by 0.079 per cent, ceteris paribus. These results indicate that price fluctuations effectively promotes the energy transition. The deregulation policy reform that decentralises the energy market would be valid to assist China in getting into a low-carbon and sustainable development trajectory [39].

Focusing on the FE model of the whole period, we find that the coefficient of natural gas production to energy transition is significantly positive (0.010), slightly higher than in the post-2005 model (0.007). It implies a more substantial effect of natural gas resource endowment in the long run. The coefficient of coal-fired electricity generation capacity is significantly positive (0.041), suggesting that a one per cent increase in coal-fired power generation would increase energy transition by 0.041 per cent, rather than hindering the transition. When households directly burn coal for heating or cooking at the early stages of development, burning coal and electricity are substitutes. Hence, electricity, even from coal, could significantly reduce direct coal consumption in a less-developed society. In Table 1, we report the national level dynamic model results. The models suggest a U-curve between energy transition and per capita GDP with the turning points at about CNY 17,263 or 15,345, indicated by the dynamic and system GMM models. Sargan and Hansen's tests show that both the difference and system GMM models are appropriate for the selected instruments. As the system GMM model contains more information on the level equation for inference, we are prone to adopt the turning point suggested by the system GMM model (CNY 15,345). This number is close to the turning point indicated by the static FE model in Table 1. (CNY 15,356.216).

Apparently, from the system GMM model, the energy transition performs some pattern of self-persistence with a coefficient of 0.267, and the speed of adjustment is 0.733. We can also observe a significant natural resource endowment effect and price effect. In the long run, (the long-run coefficient of dynamic GMM model is given by $\gamma/(1-\beta_0)$, as illustrated in Equation (2)) a one per cent increase in natural gas production will increase low-carbon energy share by 0.022 per cent; a one per cent increase in petroleum price will increase low-carbon energy share by 0.188 per cent, ceteris paribus. On the contrary, a long-run effect of a one per cent increase in industrial electricity price or industry natural gas price will significantly decrease energy transition by 0.119 and 0.111 per cent, respectively. Apart from these, we find the national energy mix would be locked into the coal-electricity power generation capacity by the long-run coefficient of 0.022 per cent.

Instruments for model 3 include the second lagged to fourth lagged of lag S and the first and second lagged of ln(urban) and ln(coalgen). Instruments for model 4 include the first to third lagged of lag S and the first and second lagged of ln(urban) and ln(coalgen).

5.3. Industry Sector Results

Table 2 reports results for the industry sector. Columns (1) to (3) are for the static models, and columns (4) to (7) are for the dynamic models. We can see that except for the FMB in column (1), the quadratic and linear terms of per capita GDP are all insignificant. The lagged terms of the energy transition are all highly significant, and the magnitudes are relatively high. It suggests a significant self-perpetuating energy transition process independent of GDP per capita in the industry sector.

In this case, FMB estimates are inappropriate as errors are likely to be correlated over time and across provinces, and GMM can correct the estimates [40]. According to the difference and system GMM model in columns (6) and (7), the energy transition can be stimulated by 0.009 and 0.012 per cent, respectively, if the natural gas abundance increased by one per cent, indicating a significant natural resource endowment effect. In the difference GMM model, we can also find that the coal reserve endowment may lock in the energy transition at the margin of −0.014. A one per cent increase in coal production will decrease energy transition by 0.04 per cent in the long run.

The price effect of petroleum is significant. A one per cent increase in petroleum price will decrease low-carbon energy share by 0.2 in the long run. It implies that a petroleum price increase would not result in a substitution between oil and natural gas; on the contrary, it reversely shifts the energy consumption to coal. It could be because coal is easier to access than natural gas in terms of availability, infrastructure and price. We also observe a significant policy effect by the different GMM models. If the government implements stricter environmental regulations on the factories, it will increase energy transition by 0.11 per cent in the long run.

In the static model, we find that urbanisation and natural gas endowments significantly increase energy transition by 0.048 and 0.01 per cent, respectively, if they increase 1% at the margin.

5.4. Agricultural Sector Results

Table 4 reports the agricultural sector results. In the dynamic model, we find a significant self-perpetuating energy transition process similar to the industry sector results. The coefficient of the lagged term of the energy transition is 0.837, and all the other variables are insignificant. In the static model, we find an inverted U-curve relationship between energy transition and per capita GDP in the static FE model in column (3).

In contrast, a U-curve relationship is found in the FMB model. We advocate the FE result here. Given the heterogeneity of provinces, the standard error estimate from FMB would be too small to be correct in terms of the significance level. The installed coal-fired electricity generation would increase the energy transition in agriculture by a margin of 0.008 per cent, resulting from shifting burning coal to electricity in the rural area. An increase in petroleum and diesel price will decrease the energy transition instead of increasing low-carbon energy consumption such as natural gas, which indicates a potentially reverse energy transition to coal. It could reflect increased agricultural intensification through the use of heated greenhouses. When the oil products become expensive, farmers may use coal to substitute oil consumption as other low-carbon energies are more expensive, or they cannot access natural gas or electricity in remote areas.

The turning point of FE is CNY 14,952, which is very close to the turning points found by the national level model though the patterns are opposite. It is debatable in the literature whether the energy transition in the agricultural sector is an inverted U relationship regarding per capita GDP or it is a solely self-perpetuating phenomenon. For example, Démurger and Fournier [41] argue that fuelwood in rural areas is an 'inferior good' and will decrease as per capita income increases. The increasing opportunity cost of collecting fuelwood for the wealthier families. On the other hand, use a CGE model to find that fuelwood is a normal good in rural Beijing and will increase as income increases. Overall, the energy transition in the agricultural sector is more complex.

5.5. Service Sector Results

Table 5 reports the results for the service sector. There is no significant relationship between energy transition and per capita GDP across all the models except for the FMB model, which suggests the energy transition of the service sector is independent of per capita GDP. The lagged terms of the energy transition are significant in all dynamic models, meaning there is a considerable self-evolution of the energy transition in the service sector.

5.6. Residential Sector Results

Results for the residential sector are reported in Table 6. The system GMM model suggests an inverted U-curve relationship between energy transition and per capita GDP, as the quadratic terms of per capita GDP are negative (−0.010) and the linear terms are positive (0.221). It indicates that the low-carbon energy proposition would increase as per capita GDP increases but would eventually decrease in the long run as economic development increases. The turning point is CNY 39,558.94 suggested by the system GMM model.

The difference GMM model suggests that oil production has a −0.021 (as we have explained in Equation (2), the long-run effect can be computed by the coefficients of control variables divided by the adjustment factor) per cent point effect on energy transition in the long run. It is a natural resource endowment lock-in indicating the and that more oil endowments would decrease energy transition in the long run. The FE result shows that such an oil endowment effect would be −0.023 per cent in the static model, which is similar to the differenced GMM model.

On the price effect, the system GMM model suggests that diesel oil price has a −0.108 per cent point effect on energy transition in the long run. On the other hand, the FE model indicates that the marginal effect of the petroleum price on energy transition is −0.023 per cent. These findings hint that increasing oil product prices does not decrease diesel or petroleum consumption in residential sectors. It could be explained by the correlation between the improvement of living standards increase vehicle ownership. The increase in fuel prices is a consequence of an increase in vehicle ownership rather than a cause of energy transition. It is consistent with other developing countries such as Botswana [41]. Such evidence shows that most households prioritise high-carbon energy consumption rather than shifting to low-carbon fuel use. It could be the underlying reason for the inverted-U curve between the energy transition and per capita GDP in the residential sector. Some factors beyond energy price may influence their energy adoption decisions, including household characteristics, the reliability of fuel distribution networks and local policies. It has implications for urban development policy design: urban expansion induced by economic development may work against energy transition contrary to policymakers' expectations for a transition to low carbon use in the energy mix.

6. Policy Implication and Conclusions

The overwhelming conclusion of this paper aligns with Justin Lin's New Structural Economics prediction in the Chinese energy economy—the energy transition pattern is not uniform but varies according to different levels, sectors, and economic development stages. In this regard, the structure of endowments and comparative advantages determine the energy transition path. The energy transition is intrinsically associated with the stages of economic development. It is not appropriate for policymakers to treat different stages of development or different sectors as the same situation when they are thinking about energy transition policies. Otherwise, the 'carbon rush' would Qi, Shi [42].

Given the U-curve relationship between energy transition and economic development at the national level, with the turning point at around CNY 15,350 at the 2010 constant price, we conclude that all 30 provinces have crossed the turning point so far. Therefore, China's energy mix would generally continuously de-carbonise with a further increase in GDP per capita. It sheds light on China's future energy transition to low-carbon development. It is also consistent with Tahvonen and Salo's theoretical model and the Environmental Kuznets Curve theory.

On the other hand, the patterns at the sectoral level are diverse. We account for an inverted U-curve between energy transition and economic development in the residential sector to increase the use of fuelled vehicles. It suggests several potential policy options. First, in the metropolitan area, the government should further develop public transportation to reduce the use of private cars as much as possible. Second, electric car subsidy policies need to be encouraged to replace fuelled vehicles gradually—for example, the subsidy to increase the incentives to adopt electric vehicles and car battery innovations. Third, the government may also promote green infrastructure such as solar power generation in the urban areas.

We find that the price effect is significantly helpful for promoting energy transition at the national and sectoral levels. It suggests that deepening energy market liberalisation would be necessary for facilitating energy transition. After 2005, the price effects became more significant. It also verifies the effectiveness of nationwide energy transition initiatives such as the Five-year Plan.

The coal-fired power plants would be a problem for future energy transition policy decision-making as they could hinder the energy transition to decarbonisation. Hence, the industrial policy such as capping and reduction of coal-fired generation and stimulating of renewable electricity generation, would remove the technological lock-in effect.

The limitation of this research is that we cannot investigate how the endowment structure would affect the speed of energy transition. It would be a promising direction for future research.

In the future energy transition policy design and planning, the principles of New Structural Economics would apply. The central and local governments would adjust the policies to their local conditions and facilitate their comparative advantages of energy sectors. Our research also provides another stream to study energy transition within the New Structural Economics framework.

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Appendix A

Table A1. Summary of variables.

	Variable	Label	Unit	Obs	Mean	Std. Dev.	Min	Max
Dependent variables	S	Share of low-carbon energy consumption at national level	%	390	0.106	0.110	9×10^{-5}	0.565
	S_{ind}	Share of low-carbon energy consumption in industrial sector	%	390	0.101	0.125	0.000168	0.718
	S_{ag}	Share of low-carbon energy consumption in agricultural sector	%	390	0.126	0.147	4.17×10^{-5}	0.790
	S_{serv}	Share of low-carbon energy consumption in service sector	%	368	0.0543	0.0680	5.84×10^{-5}	0.494
	S_{re}	Share of low-carbon energy consumption in residential sector	%	389	0.241	0.147	0.0150	0.664
Independent variables	GDP	GDP *per capita*	CNY	390	16291	11,200	2662	57,132
	coalgen	Coal generation capacity *per capita*	W	390	423.7	370.8	58.17	2567
	urban	Urban population	10^4	390	1912	1259	181	7141
	gas	Natural gas production *per capita*	10^4 tce	390	94.24	215.9	0	1145
	oil	Oil production *per capita*	10^4 tce	390	0.212	0.420	0	2.566
	coal	Coal production *per capita*	10^4 tce	390	2.466	4.986	0	41.84
	$P_{briquet}$	Briquet price	CNY/100 kg	390	35.90	17.52	8.500	99
	$P_{steamcoal}$	Steam coal price	CNY/ton	390	366.5	181.3	74.10	879.9
	$P_{elecind}$	Industry electricity price	CNY/kWh	390	0.622	0.147	0.160	0.930
	P_{elecre}	Residential electricity price	CNY/kWh	390	0.500	0.0704	0.319	0.879
	P_{elecag}	Agricultural electricity price	CNY/kWh	390	0.418	0.108	0.145	0.748
	$P_{elecserv}$	Service electricity price	CNY/kWh	390	0.790	0.110	0.502	1.043
	P_{petro}	93# petroleum price	CNY/ton	390	6190	2273	2898	11,247
	P_{diesel}	0# diesel price	CNY/ton	390	5306	1914	2548	9052
	P_{gasind}	Industry natural gas price	CNY/ton	390	2.304	0.779	0.730	4.600
	P_{gasre}	Residential natural gas price	CNY/m^3	390	2.041	0.540	0.920	3.740
	SO_2	SO_2 emission	10^4 ton	390	73.75	45.11	2	200.3

Note: there are no multicollinearity problem among the variables by test.

Table A2. Test for autocorrelation, heteroscedasticity and cross-sectional independence.

Test	National Model	Industry Sector Model	Agricultural Sector Model	Service Sector Model	Residential Sector Model
Wooldridge test for autocorrelation	0.1234	0.0001	0.0000	0.0003	0.0000
Modified Wald for groupwise heteroskedasticity	0.0000	0.0000	0.0000	0.0000	0.0000
Pesaran test for cross sectional independence	0.4271	0.6539	0.0000	0.2172	0.6898
Standard error	White	Roger	Driscoll-Kraay	Rogers	Rogers

p-Value.

References

1. IPCC. *Spectial Report: Global Warming of 1.5 °C*; IPCC: Geneva, Switzerland, 2018.
2. Sheehan, P.; Cheng, E.; English, A.; Sun, F. China's response to the air pollution shock. *Nat. Clim. Chang.* **2014**, *4*, 306. [CrossRef]
3. Lin, J.Y. New structural economics: A framework for rethinking development. *World Bank Res. Obs.* **2011**, *26*, 193–221. Available online: https://openknowledge.worldbank.org/handle/10986/2232 (accessed on 10 January 2018).
4. Grübler, A. Transitions in energy use. *Encycl. Energy* **2004**, *6*, 163–177.
5. Gales, B.; Kander, A.; Malanima, P.; Rubio, M. North versus South: Energy transition and energy intensity in Europe over 200 years. *Eur. Rev. Econ. Hist.* **2007**, *11*, 219–253. [CrossRef]
6. Smil, V. *Energy Transitions: History, Requirements, Prospects*; ABC-CLIO: Santa Barbara, CA, USA, 2010.
7. Solomon, B.D.; Krishna, K. The coming sustainable energy transition: History, strategies, and outlook. *Energy Policy* **2011**, *39*, 7422–7431. [CrossRef]
8. Kander, A.; Malanima, P.; Warde, P. *Power to the People: Energy in Europe over the Last Five Centuries: Energy in Europe over the Last Five Centuries*; Princeton University Press: Princeton, NJ, USA, 2014.
9. Grübler, A. *Technology and Global Change*; Cambridge University Press: Cambridge, UK, 2003.
10. Grübler, A.; Nakićenović, N.; Victor, D.G. Dynamics of energy technologies and global change. *Energy Policy* **1999**, *27*, 247–280. [CrossRef]
11. Tahvonen, O.; Salo, S. Economic growth and transitions between renewable and nonrenewable energy resources. *Eur. Econ. Rev.* **2001**, *45*, 1379–1398. [CrossRef]
12. Marcotullio, P.J.; Schulz, N.B. Comparison of energy transitions in the United States and developing and industrializing economies. *World Dev.* **2007**, *35*, 1650–1683. [CrossRef]
13. Grübler, A. Energy transitions research: Insights and cautionary tales. *Energy Policy* **2012**, *50*, 8–16. [CrossRef]
14. Arthur, W.B. Competing technologies, increasing returns, and lock-in by historical events. *Econ. J.* **1989**, *99*, 116–131. [CrossRef]
15. Hosier, R. Energy Ladder in Developing Nations. In *Encyclopedia of Energy*; Elsevier Science & Technology: Amsterdam, The Netherlands, 2004; Volume 2, pp. 423–435.
16. Stern, D.; Common, M.S.; Barbier, E.B. Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. *World Dev.* **1996**, *24*, 1151–1160. [CrossRef]
17. Unruh, G. Understanding carbon lock-in. *Energy Policy* **2000**, *28*, 817–830. [CrossRef]
18. Wang, D.; Mugera, A.; White, B. Directed Technical Change, Capital Intensity Increase and Energy Transition: Evidence from China. *Energy J.* **2019**, *40*, 277–296. [CrossRef]
19. Zhang, P.; Zhang, L.; Tian, X.; Hao, Y.; Wang, C. Urban energy transition in China: Insights from trends, socioeconomic drivers, and environmental impacts of Beijing. *Energy Policy* **2018**, *117*, 173–183. [CrossRef]
20. Ma, W.; Zhou, X.; Renwick, A. Impact of off-farm income on household energy expenditures in China: Implications for rural energy transition. *Energy Policy* **2019**, *127*, 248–258. [CrossRef]
21. Bai, C.; Feng, C.; Du, K.; Wang, Y.; Gong, Y. Understanding spatial-temporal evolution of renewable energy technology innovation in China: Evidence from convergence analysis. *Energy Policy* **2020**, *143*, 111570. [CrossRef]
22. Fama, E.F.; MacBeth, J.D. Risk, Return, and Equilibrium: Empirical Tests. *J. Political Econ.* **1973**, *81*, 607–636. [CrossRef]
23. Nickell, S. Biases in Dynamic Models with Fixed Effects. *Econometrica* **1981**, *49*, 1417–1426. [CrossRef]
24. Verbeek, M. *A Guide to Modern Econometrics*, 4th ed.; A John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2012.
25. Anderson, T.W.; Hsiao, C. Estimation of Dynamic Models with Error Components. *J. Am. Stat. Assoc.* **1981**, *76*, 598–606. [CrossRef]
26. Blundell, R.; Bond, S. Initial conditions and moment restrictions in dynamic panel data models. *J. Econom.* **1998**, *87*, 115–143. [CrossRef]

27. NBS. *China Price Statistical Yearbook*; China Statistics Press: Beijing, China, 2012.
28. Wu, Y. Deregulation and growth in China's energy sector: A review of recent development. *Energy Policy* **2003**, *31*, 1417–1425. [CrossRef]
29. SPC. The State Planning Commission Informed about Release and Deregulate the Price of Goods and Services. Available online: http://www.people.com.cn/GB/jinji/31/179/20010711/509143.html (accessed on 1 January 2020).
30. Fisher-Vanden, K. The effects of market reforms on structural change: Implications for energy use and carbon emissions in China. *Energy J.* **2003**, *24*, 27–62. [CrossRef]
31. Burke, P.J. Income, resources, and electricity mix. *Energy Econ.* **2010**, *32*, 616–626. [CrossRef]
32. Burke, P.J. The national–level energy ladder and its carbon implications. *Environ. Dev. Econ.* **2013**, *18*, 484–503. [CrossRef]
33. Burke, P.J. Climbing the electricity ladder generates carbon Kuznets curve downturns*. *Aust. J. Agric. Resour. Econ.* **2012**, *56*, 260–279. [CrossRef]
34. Sachs, J.; Warner, A. Natural Resource Abundance and Economic Growth. *NBER Work. Pap.* **1995**. [CrossRef]
35. Davis, G.A. Learning to love the Dutch disease: Evidence from the mineral economies. *World Dev.* **1995**, *23*, 1765–1779. [CrossRef]
36. Stijns, J.P. Natural resource abundance and human capital accumulation. *World Dev.* **2006**, *34*, 1060–1083. [CrossRef]
37. Brunnschweiler, C.N. Cursing the Blessings? Natural Resource Abundance, Institutions, and Economic Growth. *World Dev.* **2008**, *36*, 399–419.
38. Herrerias, M.; Aller, C.; Ordonez, J. Residential energy consumption: A convergence analysis across Chinese regions. *Energy Econ.* **2017**, *62*, 371–381. [CrossRef]
39. Guo, Q.K.; Lau, C.K.M.; Li, K.; Song, L. National Energy Market Integration: A study of energy price convergence in China. In *China's Domestic Transformation in a Global Context*; Song, L., Cai, F., Johnston, L., Eds.; ANU Press: Canberra, Australia, 2015; pp. 111–135.
40. Cochrane, J.H. Fama-MacBeth Procedure. In *Asset Pricing*; Princeton University Press: Princeton, NJ, USA, 2001; p. 231.
41. Démurger, S.; Fournier, M. Rural poverty and fuelwood consumption: Evidence from Labagoumen Township (China). *SSRN* **2007**. [CrossRef]
42. Qi, R.; Shi, C.; Wang, M.Y. Carbon emission rush in response to the carbon reduction policy in China. *China Inf.* **2022**. [CrossRef]