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IMPACTS OF DISAGGREGATE ENERGY PRICES ON DISAGGREGATE ENERGY CO_2 EMISSIONS: EVIDENCE FROM CHINA

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This study attempts to explore the measures to reduce CO_2 emissions caused by energy consumption. This is made possible by investigating the impacts of energy price, energy consumption and their interaction on CO_2 emissions, using times series data on three sources of energy, namely fossil fuel, coal and gas, over 1984-2013 in China. Empirical analysis suggests that higher oil and coal prices do not reduce CO_2 emissions induced from oil and coal consumption respectively, but higher gas price reduces CO_2 emissions from gas consumption. The study further reveals that interactions between disaggregate fuel prices and corresponding energy consumption are negatively associated with CO_2 emissions induced from consumption of respective energy sources; this makes us believe that tax on energy consumption exceeding threshold levels would effectively hurdle further increases in CO_2 emissions induced from consumption of all three sources of energy.

Introduction

This study examines the influences of energy price and energy consumption on environmental pollution (CO2 emissions) in China. There has been a significant rise in CO2 emissions from energy consumption in the new industrialized countries compared to developed countries over the last two decades. Deterioration of environment has triggered major concerns about global warming and climate change. Hence, understanding the reasons behind environmental degradation and its relation with economic development and energy use has become common ground of research among economists. There is an extensive existing literature examining the debate about the relationship between energy consumption, income and pollution in both developed and developing countries; however,

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the lack of conclusive evidence (see Gangopadhyay and Nilakantan, 2018; Zhang et al., 2017; Zhang and Gangopadhyay, 2015; Narayan and Singh, 2007; Narayan and Smyth, 2005), continues to arouse interests among researchers and policy makers.

The main objective of this paper is to investigate the impacts of disaggregate energy consumption and energy price on CO_2 emissions in China. Further, with the inclusion of the interaction between energy consumption and energy price in explaining CO_2 emissions, we aim to examine whether tax on excessive energy consumption effectively hurdle CO2 emissions.

This study is important for the following reason. Energy prices increased multifold over the period from early 2000s to 2012; this has become a substantive concern in the world's macroeconomic environment. Despite surges in energy prices, CO_2 emissions worldwide increased contemporarily; in particular, China has overtaken the US and became the largest emitter of CO_2. The major increase in CO_2 emissions in China was attributed to fast increasing coal consumption which grew at 10 percent annually from early 2000s to 2012. Coal consumption in China declined after 2012. In contrast, oil and gas consumption have persisted continuous and strong growth over time. Concurrent increases in energy prices and CO_2 emissions in China raise an important paradox which needs further investigation.

Contribution of this paper to the literature is threefold: first, to the best of our knowledge, the existing literature on China utilizes aggregate data to investigate the nexus between energy consumption, income and CO_2 emissions. However, different energy sources are heterogenous in terms of efficiency and contribution to CO_2 emissions. Natural gas has the highest thermal efficiency, followed by oil and coal (Hao et al., 2016). In producing same quantity of heat, coal combustion emits largest quality of CO_2, followed by oil and gas. Hence, an analysis of differentiating between impacts of disaggregate energy sources on CO2 emissions is important for policy makers to formulate heterogeneous policies for different energy sources.

Second, most existing studies ignore energy price in CO_2 emissions models. An analysis of impacts of both energy consumption and prices on CO_2 emissions in China is timely and imperative from policy perspective. China made a commitment in the 2015 United Nations Climate Change Conference in Paris to reduce CO_2 emissions per unit of GDP by 60 percent by year 2030. The current study is essential for framing appropriate energy tax policies to in order to achieve the goal. Ideally, a rise in energy price would encourage consumers to adopt more efficient energy mix or more energy efficient technologies (Selden et al., 1999; Stern, 2004) and hence reduce energy consumption and CO_2 emissions. However, given that China is an influential producer and consumer of energy, an increase in energy price is likely to affect CO_2 emissions through many channels. Some channels contribute to increase CO_2 emissions while others mitigate emissions. First of all, an increase in coal and oil prices would boost wealth of coal and oil producers in China, which consequently creates demand for other goods and services and heighten CO_2 emissions. Secondly, given other conditions unchanged, increases in price are associated with decreases in consumption; however, due to strong economic growth, demand for energy grows strongly and continuously over time in China. As a matter of fact, China is able to mitigate part of the losses arising from rising energy prices. Thirdly, China's capability of substituting labour with more capital input leads to significant increases in China's labour productivity, creating more demand for Chinese products from the global market; consequently, energy demand and CO_2 emissions rise even in circumstances when energy prices increase (Faria et al., 2009). Furthermore, improvements in income and export earnings create demand for energy related goods and services such as transport and vehicles; as a result, CO_2 emissions rise (Skeer and Wang, 2007). Therefore, given substitutions of energy sources and China's characteristics of being an open economy as well as an oil and coal producer, energy prices' influences on CO_2 emissions are multifold; it is essential in policy perspective to find out the overall effects of energy prices on China's CO_2 emissions.

The third contribution of the current study is the assessment of tax's influences on CO_2 emissions. We include in the models not only energy price but also the interactive term between energy price and energy consumption, and hypothesize a negative relationship between the interactive term and CO_2 emissions. Non-rejection of the hypothesis would imply that imposition of tax on energy consumption exceeding threshold levels (or, excessive energy consumption) effectively reduces marginal CO_2 emissions (or, hurdles excessive CO_2 emissions).

The rest of the paper is organized as follows. Section 2 proposes the models. Section 3 describes data. Section 4 presents empirical findings. And Section 5 provides conclusions and policy advices.

Models

To examine the relationships between output, disaggregate energy consumption, disaggregate energy prices, and CO_2 emissions, Bloch, Rafig and Salim (2015) propose a framework including one supply-side model and two demand-side models (henceforth, the BRS framework). In the supply-side model, the authors explain output with factors including capital stock, labor and disaggregate energy consumption; in the first demand-side model, the authors explain disaggregate energy consumption with factors including output and disaggregate energy prices; and in the second demand-side model, the authors explain CO_2 emissions with factors including output and disaggregate energy consumption. Note that the authors exclude energy prices in the CO_2 emissions model.

We amend the BRS framework by, (1) incorporating our hypotheses on the energy price-CO_2 emissions nexus in the second demand-side model, i.e., the CO_2 emissions model; (2) endogenizing energy prices as hypothesized by Apergis and Payne (2014). Our proposed framework is as follows:

$$\mathrm{Y}_t = \alpha_0^Y + \alpha_1^F \mathrm{KPC}_2 + \alpha_2^Y \mathrm{EO}_1 + \alpha_3^Y \mathrm{EC}_t + \alpha_4^Y \mathrm{EG}_t + \alpha_5^Y \mathrm{T}_t + \varepsilon_t^Y \tag{1}$$

$$CO_1 = \alpha_0^{CO} + \alpha_1^{CO} PO_1 + \alpha_2^{CO} Y_t + \alpha_3^{CO} PO_t \cdot Y_t + \varepsilon_t^{CO} \tag{2.1}$$

$$CO_t = \alpha_0^{CO} + \alpha_1^{CO} PC_t + \alpha_2^{CO} Y_t + \alpha_3^{CC} PC_t \cdot Y_t + \varepsilon_t^{CC} \tag{2.2}$$

$$CG_t = \alpha_0^{CO} + \alpha_1^{CG} PG_t + \alpha_2^{CG} Y_t + \alpha_3^{CG} PG_t \cdot Y_t + \varepsilon_t^{CG} \tag{2.3}$$

$$EO_t = \alpha_0^{EO} + \alpha_1^{EO} PO_t + \alpha_2^{EO} CO_t + \alpha_3^{EO} (PO_t \cdot CO_t) + \varepsilon_t^{EO} \tag{3.1}$$

$$EC_t = \alpha_0^{EC} + \alpha_1^{EC} PC_t + \alpha_2^{EC} CC_t + \alpha_3^{EO} (PO_t \cdot CC_t) + \varepsilon_t^{RC} \tag{3.2}$$

$$EG_t = \alpha_0^{EG} + \alpha_1^{EG} PG_t + \alpha_2^{EG} CG_t + \alpha_3^{EG} (PG_t \cdot CG_t) + \varepsilon_t^{EG} \tag{3.3}$$

$$PO_t = \alpha_0^{PO} + \alpha_1^{PO} PC_t + \alpha_2^{PO} PG_t + \alpha_3^{PO} CO_t + \varepsilon_t^{PO} \tag{4.1}$$

$$PC_t = \alpha_0^{PC} + \alpha_1^{PC} PO_t + \alpha_2^{PC} PG_t + \alpha_3^{PC} CC_t + \varepsilon_t^{PO} \tag{4.2}$$

$$PG_t = \alpha_0^{PG} + \alpha_1^{PG} PO_t + \alpha_2^{PG} PC_t + \alpha_3^{PG} CG_t + \varepsilon_t^{PG} \tag{4.3}$$

The above framework displays a multiple equations system, where Equation (1) is the supply- side model, Equations (2.1)-(2.3) are demand-side equations modelling oil, coal and gas consumption respectively, Equations (3.1)-(3.3) are demand-side equations modelling CO2 emissions from using oil, coal and gas respectively; and Equations (4.1)-(4.3) model energy prices. Notations in the above system are described as follows:

Y = per capita GDP (at constant 2010 price, \$, natural logarithm);

KPC = per capita capital stock at current price (at constant 2010 price, \$, natural logarithm). This series is estimated with the perpetual inventory method with depreciation rate of 9.6% and initial capital stock in year 1960 being 10 times investment of the same year;

T = time trend, with value 1 for year 1984, 2 for year 1985, and so on (natural logarithm);

EO = CO_2 emissions from oil consumption (% of total, natural logarithm);

EC= CO_2 emissions from coal consumption (% of total, natural logarithm);

EG = CO_2 emissions from gas consumption (% of total, natural logarithm);

CC = Electricity production from coal (% of total, natural logarithm);

CG = Electricity production from coal (% of total, natural logarithm);

PO = Price of oil (constant 2010 prices, \$, natural logarithm);

PC = Price of coal (constant 2010 prices, \$, natural logarithm);

PG = Price of gas (constant 2010 prices, \$, natural logarithm);

α = parameter to be estimated; and

ε = error term.

Further, superscript of parameter and error term represents the dependent variable of corresponding equation; and subscript *t* represents time.

Note in the above system, prices of substitutions of energy sources are not considered in demand equations, due to high correlation between prices of energy sources.

As robustness tests of prices' influences on energy consumption as well as on CO_2 emissions, we set up another two multiple equations frameworks. First, we remove the hypothesis of endogenous energy prices and a new framework consists only Equations (1)-(3.3); Second, we set up another multiple equations framework, where the interactive terms ($POt \cdot Yt$, $PCt \cdot Yt$, $PG_t \cdot Y_t$) in demand equations (2.1)-(2.3) are replaced with squared income (Y_t^2) interactive terms ($PO_t \cdot CO_t$, $PGt \cdot CG_t$) are replaced with respective squared energy consumption ratios (CO_t^2, CC_t^2, CG_t^2) in demand equations (3.1)-(3.3). With this setup, we assume that income has quadratic impacts on energy consumption in a way that income beyond threshold level reduces marginal energy consumption, and that energy consumption has quadratic impacts on CO_2 emissions in a way that energy consumption beyond threshold level reduces marginal CO_2 emissions. Non-rejection of these hypotheses further provides incentives for policy makers to take measures to reduce excessive CO_2 emissions from excessive energy consumption.

Data

Data on prices are obtained from the Quandl website, and the rest are from World Development Indicators (WDI) database. Trends of major variables, including GDP, per capita GDP, energy prices, energy consumption as percent of total energy, and CO_2 emissions as percent of total emissions, are presented in Figures 1-4. The following observations are noted. Clear upward trends are noted in GDP and per capita GDP at 2010 prices, associated with increasing demands for energy and CO_2 emissions volume; oil price and coal price at constant 2010 prices are generally on the rise with substantial declines were seen in early 1990s and late 2000s; there was clear rise in natural gas price from late 1990s

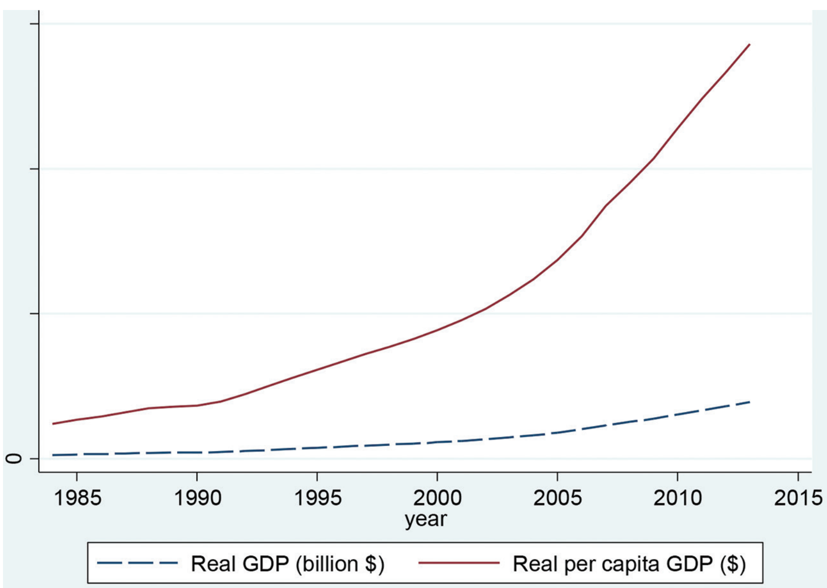

Figure 1: GDP and GDP per capita (constant 2010 prices)

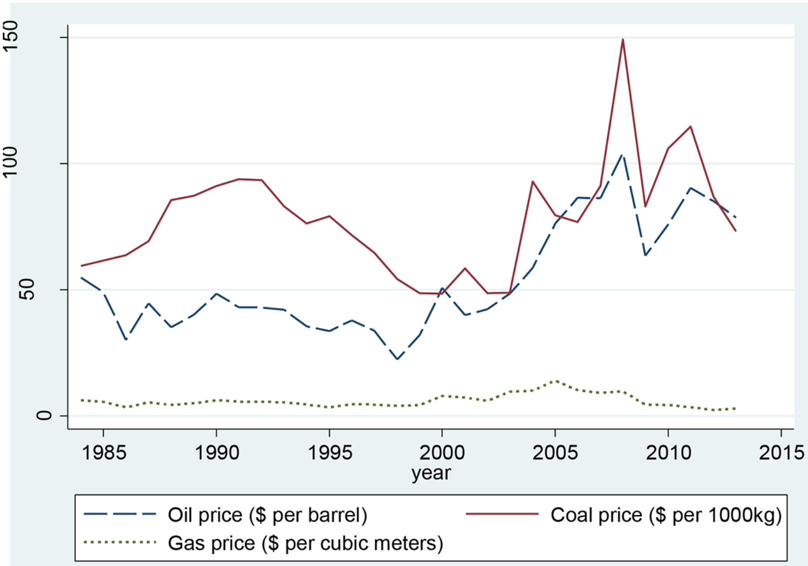

Figure 2: Energy prices by energy source

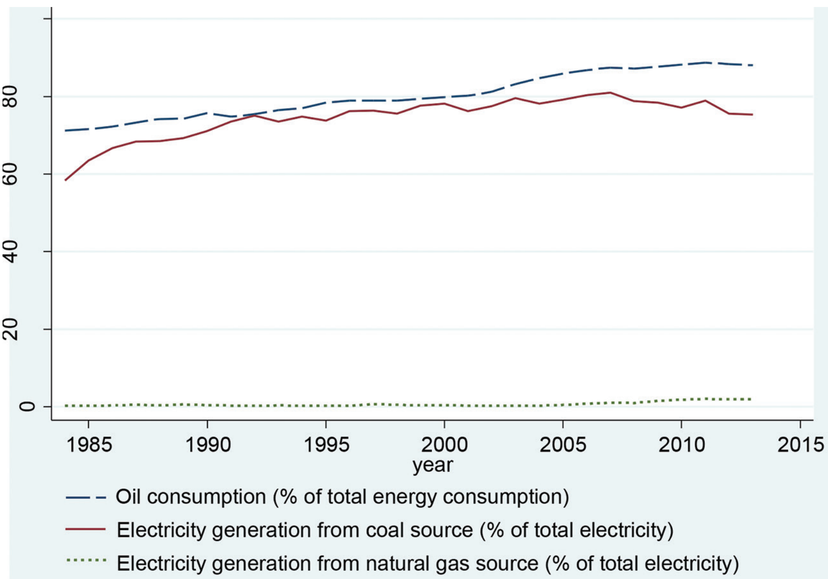

Figure 3: Energy consumption by energy source

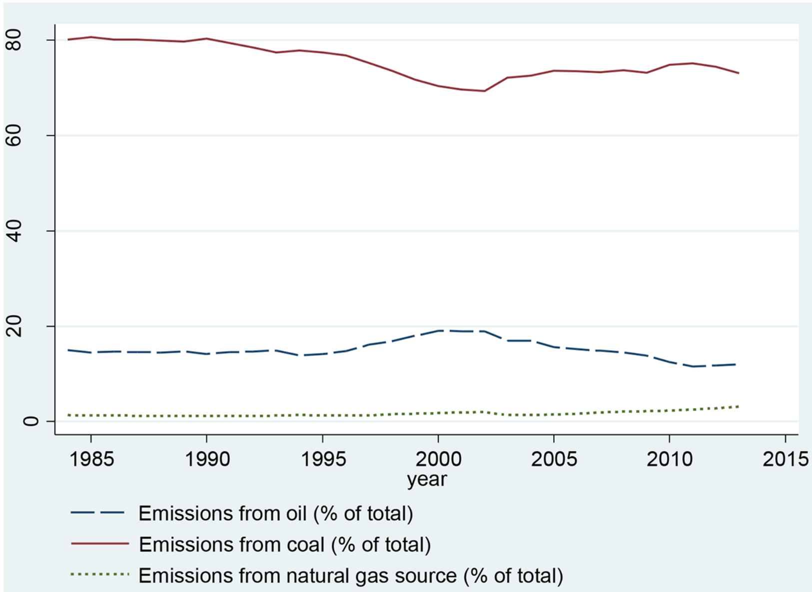

Figure 4: CO_2 emissions from energy consumption by energy source

to late 2000s, and after 2008 gas price declined significantly; oil consumption as percent of total energy increased over time; electricity generation from coal source as percent of total electricity has generally stabilized since early 1990s, given availability of substitutions such as hydropower, nuclear power and wind power; and trends of CO_2 emissions from the three sources of energy as percent of total emissions are in general consistent with energy consumption ratios. Pair wise correlation diagrams between energy prices and CO_2 emissions volume are shown in Figure 5. There are clear positive associations between

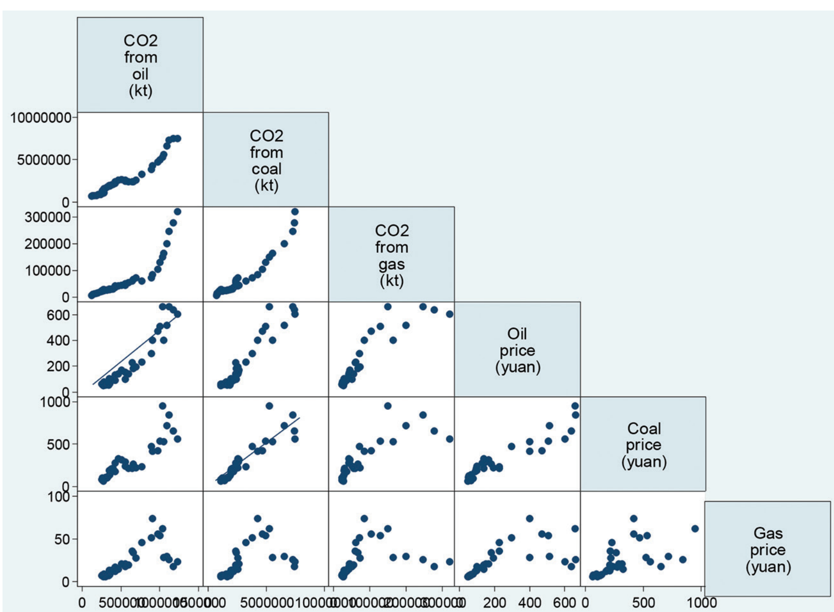

Figure 5: Scatter diagrams between energy price and CO2 emissions by energy source

energy price and CO_2 emissions volume in the cases of oil and coal, and such association is not evident in the case of natural gas.

Summary statistics and coefficients of pair wise correlation between major variables are respectively presented in Table 1 and Table 2. From Table 2 we see high correlations amongst variables such as *EG*, *CO*, *CC*, *CG* and *PO*, hence combination of these variables in corresponding equations should be chosen with care in order to avoid multicollinearity problem.

Table 1: Summary statistics

Series	Mean	Standard deviation	Minimum	Maximum
CO_2 emissions from oil consumption (% of total)	15.08	1.96	11.57	19.07
CO_2 emissions from coal consumption (% of total)	75.63	3.50	69.36	80.64
CO_2 emissions from gas consumption (% of total)	1.63	0.52	1.12	3.13
Oil consumption (% of total energy consumption)	80.29	5.79	71.16	88.73
Electricity production from coal sources (% of total)	74.55	5.26	58.29	80.95
Electricity production from gas sources (% of total)	0.69	0.58	0.24	2.04
GDP per capita (constant 2010 price, $)	2122	1570	481	5722
Capital stock per capita (constant 2010 price, $)	4362	3757	818	13910
Oil price (constant 2010 price, $)	50.96	18.71	22.37	104.10
Coal price (constant 2010 price, $)	76.93	20.96	48.48	149.28
Gas price (constant 2010 price, $)	6.54	2.44	3.41	14.08

Note: Data on prices are obtained from the Quandl website, and the rest are from World Development Indicators (WDI).

Table 2: Correlation Matrix

	Y	KPC	EO	EC	EG	CO	CC	CG	PO	PC	PG
Y	1.0000										
KPC	0.9992	1.0000									
EO	-0.2346	-0.2492	1.0000								
EC	-0.7318	-0.7230	-0.4669	1.0000							
EG	0.8634	0.8736	-0.3236	-0.6181	1.0000						
CO	0.9886	0.9866	-0.2274	-0.7039	0.7969	1.0000					
CC	0.7775	0.7576	0.1393	-0.7511	0.4547	0.8011	1.0000				
CG	0.7425	0.7520	-0.6375	-0.2211	0.7672	0.7198	0.3898	1.0000			
PO	0.6825	0.6950	-0.4550	-0.2581	0.6337	0.7141	0.3264	0.6555	1.0000		
PC	0.2750	0.2745	-0.6629	0.2877	0.1572	0.3311	0.1579	0.5099	0.5567	1.0000	
PG	0.0331	0.0255	0.5295	-0.2850	-0.2301	0.1288	0.2522	-0.3029	0.2973	0.0095	1.0000

Findings

In this section two issues in time series regression analysis are addressed: (1) Regression results are non-spurious. This requires cointegration of variables that are integrated of order one. (2) Endogeneity of regressors is addressed by using the three- stage least squares estimator.

Integration and cointegration tests

Integration and cointegration tests are necessary in order to avoid risk of obtaining spurious regression results. Unit root test allowing for the presence of two structural breaks, described by Clemente, Montanes and Reyes (1998), is used to test the null hypothesis that a time series contains unit root. Integration tests for variables at level and in first differences are based on tests with maximum 2 lags. Since all test statistics for integration tests of variables at level are greater than critical statistics at the 5 percent significance level, the null hypothesis of non-stationary time series is not rejected for all variables at level. Integration tests for variables in first differences reject the null hypothesis of non-stationarity at the 5 percent significance level, since all test statistics are smaller than critical values at the 5 percent significance level. These conclude that all quantitative variables are integrated of order 1, with the presence of up to two structural breaks. Optional breakpoints are hypothesized and tested in the Clemente, Montanes and Reyes (1998) unit root tests. A *p*-value of less than 0.05 is taken as the evidence to reject the null hypothesis that a year is not a structural break at the 5 percent significance level. Dummy variables, which are included in the final regression model for each country, are decided based on unit root test of estimated errors obtained in ordinary least squares estimation.

The same unit root test is further used to test estimated errors from each ordinary least squares regression $\hat{\varepsilon}_{t.}$ Since observed test statistics are respectively smaller than the 5 percent critical values in the Clemente, Montanes and Reyes (1998) unit root tests (see Table 2), respective combinations of quantitative variables in Equations (1) produce stationary error terms in all time-series regressions. This suggests that estimation of Equation (1) would yield non-spurious regression results for each country under study.

Table 3: Clemente, Montanes and Reyes (1998) two-break unit root tests

Variable	Optimal breakpoint 1 (*p*-value)	Optimal breakpoint 2 (*p*-value)	Observed t-stat (H_0: *rho* – 1 = 0)	5% critical value
Y	1993 (0.000)	2004 (0.000)	–2.711	–5.490
KPC	1995 (0.000)	2005(0.000)	–2.597	–5.490
EO	1998 (0.001)	2006 (0.000)	–3.375	–5.490
EC	1994 (0.000)	2000 (0.171)	–3.680	–5.490
EG	1995 (0.001)	2008 (0.000)	–3.563	–5.490
CO	1991 (0.000)	2004 (0.000)	–2.743	–5.490
CC	1986 (0.000)	1993 (0.000)	–3.503	–5.490
CG	1987 (0.005)	2006 (0.000)	–4.383	–5.490
PO	1996 (0.080)	2003 (0.000)	–4.255	–5.490
PC	1997 (0.002)	2005 (0.000)	–4.118	–5.490
PG	2001 (0.000)	2008 (0.000)	–3.670	–5.490
ε^{Y}	1985 (0.004)	1992 (0.684)	–5.656	–5.490
ε^{EO}	1994 (0.000)	2009 (0.000)	–5.879	–5.490
ε^{EC}	1999 (0.109)	2002 (0.106)	–5.668	–5.490
ε^{EG}	1999 (0.037)	2004 (0.144)	–5.746	–5.490
ε^{CO}	1983 (0.777)	1988 (0.183)	–5.524	–5.490
ε^{CC}	1996 (0.000)	2005 (0.000)	–5.511	–5.490
ε^{CG}	1993 (0.000)	2005 (0.000)	–5.548	–5.490
ε^{PO}	1987 (0.001)	2000 (0.048)	–5.536	–5.490
ε^{PC}	1987 (0.000)	1996 (0.001)	–5.592	–5.490
ε^{PG}	1998 (0.029)	2010 (0.000)	–5.813	–5.490

Note: Numbers before parentheses are optimal breakpoints; numbers in parentheses are *p*-values; ε with superscripts are estimated errors from corresponding Equations (1)-(4.3).

Table 4: Estimation of the multiple equations system

Dependent variable	Income	CO_2 emissions			Energy consumption			Energy prices		
	Y	EO	EC	EG	CO	CC	CG	PO	PC	PG
Explanatory variables	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)
Constant	16.4	–44.98	–12.70	.621	3.088	–.341	–2.628	–11.49	3.840	–1.319
	(4.56)***	(–3.23)***	(–2.55)**	(6.70)***	(13.39)***	(–0.27)	(–1.00)	(–4.76)***	(1.43)	(–2.10)**
Y					.167	.596	.308			
					(2.94)***	(3.55)***	(0.92)			
KPC	.597									
	(7.84)***									
EO	–.688									
	(–4.15)***									
EC	–2.826									
	(–3.86)***									
EG	–.192									
	(–3.90)***									
PO		13.52			.171				.713	.897
		(3.95)***			(5.51)***				(3.66)***	(6.28)***
PC			4.627			.963		.798		–.162
			(3.88)***			(3.24)***		(5.74)***		(–1.17)
PG				–.240			.506	.316	–.198	
				(–4.20)***			(0.32)	(3.50)***	(–1.89)**	
CO		10.88						2.604		
		(3.43)						(4.51)***		
CC			3.852						–.447	
			(3.36)						(–0.77)	
CG				.390						–.351
				(3.29)						(–4.82)***
PO · CO		–3.091								
		(–3.97)								

PC · CC			–1.050							
PG · CG				-2.36 (-3.39)***						
PO ·Y					-.021 (-2.80)***					
PC ·Y						-.125 (-3.27)***				
PG ·Y							-.126 (-0.63)			
T	.013 (1.76)*									
D1986						.057 (2.26)**				
D1987							.159 (0.98)			
D1993						.042 (2.51)**				
D1995	.054 (3.99)***			.170 (3.72)***						
D1998		.231 (5.97)***								
D2001										.191 (2.14)**
D2003					.019 (3.72)***					
D2005										-.582 (-4.60)***
D2006	.083 (4.76)***			.375 (4.12)***			1.138 (6.62)***			
RMSE	.0186	.0724	.0207	.1137	.0086	.0288	.2648	.2321	.2287	.2000
R squares	0.9994	0.6739	0.7922	0.8360	0.9850	0.8461	0.8474	0.6289	0.2675	0.7550

Note: Equations are estimated simultaneously with three-stage least squares estimator; (*)(**)(***) represent significance at the 10%, 5% and 1% levels respectively; last eight variables are dummy variables; RMSE is root mean squared error.

Table 5: Robustness analysis: Estimation of the multiple equations system

Dependent variable	*Income Y*	*CO_2 emissions*			*Energy consumption*		
		EO	*EC*	*EG*	*CO*	*CC*	*CG*
Explanatory variables	*Coef. (z stat)*	*Coef. (z stat)*	*Coef. (z stat)*	*Coef. (z stat)*	*Coef. (z stat)*	*Coef. (z stat)*	*Coef. (z stat)*
Constant	15.59***	-38.19***	-9.902**	.606***	3.332***	1.388	-4.177
	(4.00)	(-2.78)	(-2.11)	(6.46)	(13.07)	(1.13)	(-1.49)
Y					.139***	.374**	.438
					(3.99)	(2.34)	(1.22)
KPC	.517***						
	(5.91)						
EO	-.656***						
	(-3.66)						
EC	-2.542***						
	(-3.20)						
EG	-.189***						
	(-3.45)						
PO		11.864***			.109*		
		(3.52)			(1.71)		
PC			3.959***			.562***	
			(3.54)			(1.99)	
PG				-.226***			1.677
				(-3.90)			(0.98)
CO		9.35***					
		(2.99)					
CC			3.214***				
			(2.98)				
CG				.434***			
				(3.48)			
PO · CO		-2.717***					
		(-3.55)					
PC · CC			-.898***				
			(-3.49)				
PG · CG				-.253***			
				(-3.42)			
PO · Y					-.014*		
					(-1.70)		
PC · Y						-.074***	
						(-2.04)	
PG · Y							-.253
							(-1.18)
T	.023***						

	(2.60)						
D1986						.084***	
						(3.29)	
D1987							.360**
							(1.91)
D1993						.039**	
						(2.28)	

Note: Equations are estimated simultaneously with three-stage least squares estimator; (*)(**)(***) represent significance at the 10%, 5% and 1% levels respectively; last eight variables are dummy variables; RMSE is root mean squared error.

Table 6: Robustness analysis: Estimation of the multiple equations system

Dependent variable	Income *Y*	CO_2 emissions *EO*	*EC*	*EG*	Energy consumption *CO*	*CC*	*CG*
Explanatory variables	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)	Coef. (z stat)
Constant	17.49***	-449.7***	-25.17***	.311***	2.836***	-1.668***	28.23***
	(4.15)	(-6.96)	(-2.99)	(3.25)	(20.27)	(-3.56)	(3.47)
Y					.323***	1.513***	-8.214***
					(8.94)	(12.28)	(-3.58)
KPC	.484***						
	(5.08)						
EO	-.731***						
	(-3.82)						
EC	-2.883***						
	(-3.32)						
EG	-.212***						
	(-3.49)						
PO		.143***			.016***		
		(2.72)			(3.34)		
PC			.048***			.012	
			(3.92)			(1.18)	
PG				.017			-.260**
				(0.30)			(-2.30)
CO		208.8***					
		(7.07)					
CC			14.31***				
			(3.60)				
CG				.297***			
				(2.95)			
Y^2					.016***	.095***	.570***
					(-6.67)	(-12.01)	(3.61)
CO^2		-24.13***					
		(-7.12)					
CC^2			-1.744***				
			(-3.73)				

CG^2				.164*** (2.93)			
T	.025*** (2.56)						
D1986						.039*** (3.12)	
D1987							.749*** (3.75)
D1993						-0.51*** (-4.62)	
D1995	.048*** (2.98)			.177*** (4.03)			
D1998		.304*** (8.83)					
D2003					.023*** (4.97)		
D2006	.083*** (3.96)			.139 (1.34)			.605*** (2.65)
RMSE	.0194	0.529	.0209	.1174	.0056	.0142	.2315
R squares	0.9993	0.8264	0.7886	0.8252	0.9936	0.9623	0.8833

Note: Equations are estimated simultaneously with three-stage least squares estimator; (*)(**)(***) represent significance at the 10%, 5% and 1% levels respectively; last eight variables are dummy variables; RMSE is root mean squared error.

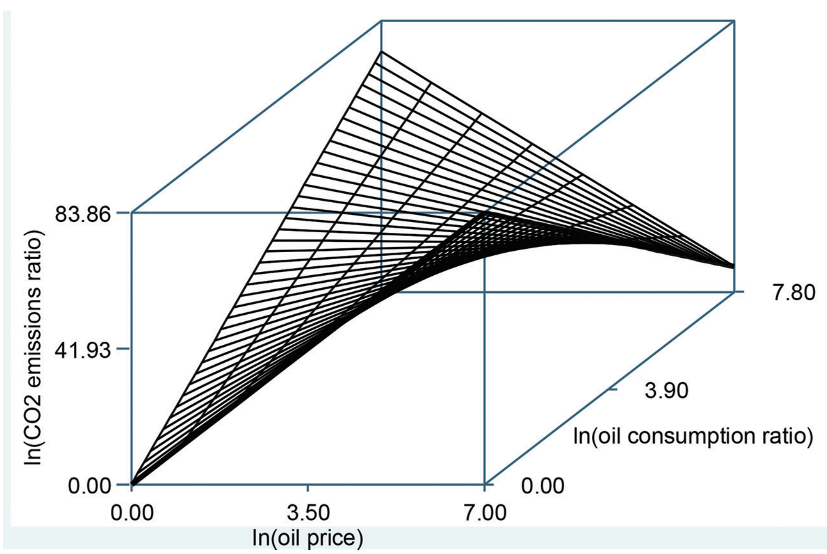

Figure 6: Simultaneous impacts of oil price and oil consumption on CO2 emissions

The multiple equations system is estimated by the three-stage least squares estimator. It is found that:

1. CO_2 emissions from consumption of all three sources of energy reduce income in China. This is associated with lower production efficiency caused by pollution, which is in line with the argument of Choi (2013);
2. Oil and coal prices are positively associated with CO_2 emissions, while natural gas price is negatively associated with CO_2 emissions. This suggests that tax on general consumption of oil and coal (i.e., addition to energy price) doesn't help reduce CO_2 emissions caused by using oil and coal.
3. A positive association between price and CO_2 emissions in China is attributed to the increasing demand for Chinese products in the world market resulting from its relative comparative advantages. China has better capacity to substitute labor for machines and thus improve its relative comparative advantage in the light of rising fuel prices. Improved relative comparative advantage provides more demand for Chinese products in the international market, which, in turn translates into more manufactured goods produced in China. Increased production of manufactured goods leads to consumption of more coal and oil, which consequently creates more emissions. Secondly, China is an emerging economy and has experienced rapid economic growth and growth-associated energy consumption during the period of rising fuel prices. Massive improvement in income in China has become the main force of energy consumption. There is significant increase in domestic energy related consumption such as tourism and white goods. The increase in demand for Chinese goods in the international market and rapid increase in domestic consumption consequently contribute to observed increase in CO_2 emissions despite of rise in prices of coal and oil;
4. Energy consumption is positively associated with CO_2 emissions in all three sources of energy. This calls for the innovation of clean energy, given the trend of increases in demand for energy is irrevocable;
5. Interaction between energy price and energy consumption reduces CO_2 emissions induced from consumption of all three sources of energy, indicating that tax on the portion of consumption of individual energy sources exceeding threshold levels effectively would reduce CO_2 emissions. The results suggest that impact of fuel tax on emissions is non-linear and fuel tax policy that focuses on reducing emissions should be formulated carefully. While a tax on low level of energy consumption is likely to increase emissions, however, tax on consumption above a threshold level will reduce emissions. This finding is not unexpected. Taxing basic coal and oil consumption can encourage consumers to substitute coal and oil with cheaper but more carbon emitting energy sources. However, coal and oil tax levied on large energy consumers will encourage them to explore more efficient energy sources.
6. In the cases of oil and coal, energy price and income are positively associated with energy consumption, while the interaction between price and income is negatively associated with energy consumption. Such associations are not significant in the case of gas. This further reinforces results discussed in the above.

7. In the robustness analysis, we found that the hypothesis of income's quadratic effects on energy consumption is not rejected, consistent with findings from Jalil and Mahmud (2009); however, this finding doesn't mean that income's non-linear impacts can only take the quadratic form. The performance of income squared suggests that income beyond certain level reduces income's marginal effect on energy consumption. This is phenomenon we observed; but what is the mechanism to such phenomenon? We propose that, marginal energy consumption is reduced if government imposes energy consumption tax on those with high income.

Other macroeconomic indicators such as openness, urbanization and transport development are not included in this framework due to high correlation between any of these indicators with variables currently included.

As further robustness analyses, we also try different forms of variables, for instance, energy consumption per capita in place of energy consumption ratio, CO_2 emissions per capita in place of CO_2 emissions ratio, values at current prices in place of values at constant prices, and values in US dollar in place of values in local currency yuan. Quantitative analyses using different forms of variables yield similar results.

Conclusions and Policy Advice

We examine the impacts of disaggregate fuel prices on CO_2 emission in China using times series data over the period 1984-2013 in a simultaneous equation framework. Our findings can be summarized as follows: (1) CO_2 emissions are harmful to economic development; (2) energy consumption positively contributes to CO_2 emissions; (3) coal and oil prices are positively associated with CO_2 emissions; (4) tax, proxied by addition in energy prices, on the portion of fuel consumption above a threshold level reduces CO_2 emissions.

Our findings have some important policy implication. The policy makers should design a progressive tax structure on fuel consumption. While low oil and fuel prices should be maintained on low level of fuel consumption, however, a fuel tax should be charged on fuel consumption above a certain threshold level. For instance, higher fuel tax should be levied for households owning multiple motor vehicles. A tax on coal and oil consumption above a threshold level will encourage consumers to consume more efficient energy source, while no tax on energy consumption below a threshold level will encourage low income earners to consume coal and oil as opposed to more carbon-producing fuel.

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