An Analysis of Fuel Demand and Carbon Emissions in China

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Abstract: Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change, targets have been set for various developed countries to reduce their carbon emissions. China's share of carbon emissions ranked the second highest in the world in 1996, only after the United States. Although China was not formally required to achieve a reduction in its carbon emissions under the protocol, pressures were mounting, especially from the United States, for China to address the issue seriously. Some recent research on China's carbon emissions has largely been carried out in the framework of computable general equilibrium models. For example, Fisher-Vanden (2003) used such models to assess the impact of market reforms on shaping the level and composition of carbon emissions; Garbaccio et al. (1999) and Zhang (1998) studied macroeconomic and sectoral effects of policies and instruments, such as, a carbon tax, on achieving predefined targets of carbon emissions. A common omission in these studies is the role of fuel price changes in determining the amount of carbon emissions. This paper first shows China's total CO2 emissions from burning all types of fossil fuels over the 50 years or so to 2001, with those from burning coal singled out for the purpose of illustrating coal as the major CO2 emitter. Then, using annual data for the period 1985-2000, the study investigates whether changes in the relative prices of various fuels reduce coal consumption. Four sectors in the Chinese economy are selected for the study, namely, the chemical industry, the metal industry, the non-metal materials industry and the residential sector, which are top energy as well as top coal consumers. Five fuels are considered, namely, coal, crude oil, electricity, natural gas and petroleum products, which accounted for nearly all of the total energy consumption in each of the four sectors. A translog demand system is estimated for each sector using the seemingly unrelated regression method. The results suggest that significant substitutions away from coal to alternative fuels take place in the residential as well as the metal sectors.

Keywords: carbon emissions; fossil fuel intensity; price elasticity.

1. INTRODUCTION

Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change, targets have been set for various developed countries to reduce their carbon emissions. China's share of carbon emissions ranked the second highest in the world in 1996, only after the United States. Although China was not formally required to achieve a reduction in its carbon emissions under the protocol, pressures were mounting, especially from the United States, for China to address the issue seriously. Some recent research on China's carbon emissions has largely been carried out in the framework of computable general equilibrium models. For example, Fisher-Vanden (2003) used such models to assess the impact of market reforms on shaping the level and composition of carbon emissions; Garbaccio et al. (1999) and Zhang (1998) studied macroeconomic and sectoral effects of policies and instruments, such as, a carbon tax, on achieving predefined targets of carbon emissions. A common omission in these studies is the role of fuel price changes in determining the amount of carbon emissions. This paper first shows China's total CO2 emissions from burning all types of fossil fuels over the 50 years or so to 2001, with those from burning coal singled out for the purpose of illustrating coal as the major CO2 emitter. Then, using annual data for the period 1985-2000, the study investigates whether changes in the relative prices of various fuels reduce coal consumption. Four sectors in the Chinese economy are selected for the study, namely, the chemical industry, the metal industry, the non-metal materials industry and the residential sector, which are top energy as well as top coal consumers. Five fuels are considered, namely, coal, crude oil, electricity, natural gas and petroleum products, which accounted for nearly all of the total energy consumption in each of the four sectors. A translog demand system is estimated for each sector using the seemingly unrelated regression method. The results suggest that significant substitutions away from coal to alternative fuels take place in the residential as well as the metal sectors.

The plan of the paper is as follows: A brief account on China CO2 emissions is given in Section 2. Section 3 discusses and constructs data used in the present study, with Section 4 depicting the estimation procedure and estimation results. Section 5 discusses implications of the estimation results, in particular, fuel price elasticity estimates, on CO2 emissions. Finally, some concluding remarks are contained in Section 6.

2. CO2 EMISSIONS IN CHINA

Being the most populous country and fastest growing economy over the past two decades in the world, China is also increasingly insatiable on energy demand. This has made it difficult for China to dramatically cut back consumption of coal, which China is rich of.

With the successful controlling production and consumption of ozone-depleting substance, burning fossil fuels has been the major source of CO2 emissions in China (World Bank 2001). Of the four primary energy types used in China, coal, oil, natural gas and hydro-power, the consumption of coal still accounted for 66 per cent of total energy consumption in 2001. Emission factors, measured as tons of carbon dioxide emission per ton of fuel in standard coal equivalent, for the four types of fuel are 0.651, 0.543, 0.404 and 0, respectively (the Energy Research Institute of the State Planning Commission of China, 1991).

Applying the emission factors to China's energy data, one is able to obtain total CO2 emissions due to the consumption of the three fossil fuels. As coal is the dominating source of energy, CO2 emissions from using oil and natural gas is small enough to be neglected.

Figure 1.
CO2 Emission in China (million tons)

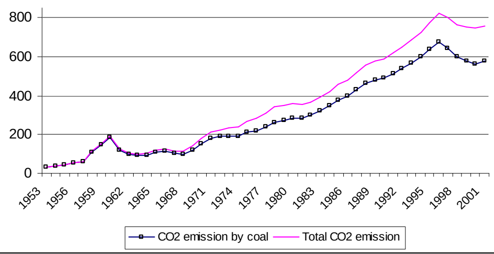

Figure 1 shows the time paths of the total CO2 emissions as well as the CO2 emissions due to coal-firing alone. It is clear that coal had been responsible for almost all of the CO2 emissions in China prior to the early 1970s, and has remained as a predominant contributor afterwards. The total CO2 emissions had risen steadily since the early 1960s until 1996, when a decline was recorded. Over the period 1978-1996, China's CO2 emissions had increased by about 480 million tons, compared with 306 million tons for the 30 years of the pre-reform period.

Demand for coal has been toned down since 1996 and remained negative growth ever since. This can be attributable to various initiatives on the part of the Chinese government to address environmental issues. As noted in World Bank (2001), "China's long-held policy in energy conservation has made a real and significant contribution to reducing global CO2 loading relative to growth in either GDP or energy consumption. Fuel diversification has also reduced the carbon intensity of China's energy mix."

3 DATA

The purpose of this paper is to investigate the role of fuel prices in achieving substitutions away from coal to alternative fuels, that is, fuel diversification. Therefore, the data requirements are completely dominated by the availability of fuel prices at industry level. It was found that fuel prices by industry are not available from published sources from both the Chinese government and various international organisations.

Although fuel prices are not directly available from public sources, the State Statistical Bureau of China does publish yearly the physical quantities of fuel consumption by industry and fuel type. The corresponding expenditure on such fuels by each industry, using China's published input-output tables, can be approximated by the monetary input of the fuels into the particular industry. Due to the infrequency of input-output tables, fuel prices acquired in this way are only for the year when the input-output table is available. To obtain a time series of them needs to index the prices using relevant price indices. Available relevant price indices from China are ex-factory price indices by industry, encompassing three industries in the energy sector, namely, electricity, coal and petroleum.

In the present study, the 1987 input-output table is employed to obtain fuel expenditures by four different sectors, namely, Chemical Industry (CHEM), Metal Industry (META), Non-metal Material Industry (NMMT) and Residential (RSDN). The reason to select the four sectors (CMNR) is because they consume more than half of the total energy in the economy. The five fuels included are coal, crude oil (Oil), electricity (Elec), natural gas (NG) and petroleum products (Petro), which accounted for nearly all of the total energy consumption in each of the four sectors. Table 1 shows their combined share in the total energy consumption by fuel type. The calculation of shares was based on physical quantities, with Coal, Oil and Petro measured in tons, Elec in kilowatt hours, and NG in cubic meters. Elec includes both hydro-power, which is CO2 emission free, and that generated by coal-burning as data on the two components for the sectors are unavailable. Thus, all of the five fuels considered contribute to CO2 emissions.

For the number one CO2 emitter, Coal, as the table shows, the four sectors together accounted for 40 per cent or more of total consumption for a half of the years under study. For NG and Elec, they have been the major consumers for all of the sample years.

Coal and Elec price series were obtained by indexing the 1987 Coal and Elec prices with Coal and Elec ex-factory price indices, respectively. Because of lack of relevant price indices, Oil, Petro and NG price series were obtained by indexing their 1987 prices with Petroleum ex-factory price indices, respectively, assuming that Oil and NG followed Petro in price movements. In addition, it was also assumed that the four sectors experienced the same price movement for the same fuel since the same indices were applied to all them.

Table 1. CMNR's Shares in Total Energy Consumption by Fuel Type

Year	Coal	Oil	Elec	NG	Petro
1985	45.9	13.3	38.9	42.5	24.4
1986	45.7	13.3	39.2	45.1	25.7
1987	45.2	13.7	39.8	47.7	24.7
1988	44.9	13.0	40.1	52.3	22.3
1989	43.4	13.4	40.3	52.0	23.1
1990	39.9	15.5	40.9	54.8	23.7
1991	41.2	15.4	40.5	56.4	23.2
1992	39.9	14.5	40.4	54.8	20.5
1993	39.8	13.0	42.7	55.5	20.4
1994	39.4	11.4	43.8	55.0	21.0
1995	40.0	10.9	43.9	53.2	19.0
1996	38.9	11.9	44.8	61.3	19.2
1997	36.7	11.9	43.9	55.6	16.5
1998	34.4	12.2	43.6	55.5	16.5
1999	33.6	11.6	43.7	53.4	15.3
2000	31.9	11.6	44.1	52.5	15.1

Table 2. Sectoral Expenditures on Fuels for Selected Years (% of total)

Year	CHEM				
	Coal	NG	Elec	Oil	Petro
1985	17.4	9.7	46.7	16.7	9.4
1990	19.3	8.4	44.8	19.9	7.6
1995	16.9	11.3	46.5	17.8	7.5
2000	7.5	14.5	44.6	26.4	7.0
	META				
1985	39.9	1.8	55.1	1.1	2.1
1990	40.2	2.5	54.8	0.3	2.2
1995	35.8	1.3	60.0	0.1	2.9
2000	22.1	0.8	74.3	0.2	2.6
	NMMT				
1985	45.1	1.0	52.6	0.4	0.9
1990	42.5	1.1	55.1	0.4	0.9
1995	32.2	1.0	64.4	1.3	1.1
2000	18.4	1.3	77.4	1.4	1.5
	RSDN				
1985	69.7	0.1	30.1	0.0	0.1
1990	51.9	0.3	47.7	0.0	0.1
1995	30.9	0.3	68.6	0.0	0.1
2000	11.0	0.5	88.3	0.0	0.2

Table 2 shows that expenditure on Coal has been declining over the years across all of the sectors. Against this backdrop has been the steady rise of Elec expenditure for all the sectors except CHEM whereby NG and Oil rose considerably.

4. ESTIMATION AND EMPIRICAL RESULTS

An energy demand system, in the form of the homothetic translog expenditure shares function, was estimated for each of the sectors. Coefficient estimates of the translog demand system allow the estimation of the partial Allen-Uzawa substitution elasticities, own and cross price elasticities for the fuels (Magnus and Woodland (1987), Hall (1983), Berndt and Wood (1975)). Concretely, the demand system is specified as follows,

$$s_j^i = b_j^i + \sum_{l=1}^{k} b_{lj}^i \ln p_l + u_j^i \qquad (1)$$

where i denotes sector i (CHEM, META, NMMT, RSDN), j and l denote fuel type (Coal, Oil, Elec, NG, Petro), b s are coefficients to be estimated, and s and p are fuel expenditure share and fuel price, respectively.

The Allen-Uzawa substitution elasticity for fuels j and l for sector i is

$$\sigma_{lj}^i = \begin{cases} 1 + (b_{jj}^i - s_j^i)/(s_j^i s_j^i) \text{ when } l = j \\ 1 + b_{lj}^i/(s_l^i s_j^i) \text{ when } l \neq j \end{cases} \qquad (2)$$

and the corresponding price elasticity is

$$\eta_{lj}^i = \sigma_{lj}^i s_j^i \qquad (3)$$

Because of the add-up condition, namely, $\sum_j s_j^i = 1$, equation (1) is estimated for all but one fuel for each sector. The coefficients of the equation for the omitted fuel can be deduced from estimated coefficients for the other fuels in the light of the add-up condition as well as parameter restrictions imposed by economic theory.

Due to space limitation, the estimates of the b s will not be presented. Tables 3 to 6 present the substitution and price elasticities in three selected years for the four sectors, respectively.

Tables 3 to 6 present the substitution, own and cross price elasticities for Coal across the four sectors. Since a negative Allen-Uzawa substitution elasticity indicates complementarity between the two fuels, it is seen that Coal has been complementary to most of the other fuels in all the sectors. Coal has been complementary to Elec across the board and to all the other fuels in both the non-metal material and residential sectors.

Table 3. Estimates of $\sigma_{l\,coal}^{CHEM}$ and $\eta_{l\,coal}^{CHEM}$

	$\sigma_{l\,coal}^{CHEM}$				
	l				
	Coal	NG	Elec	Oil	Petro
1990	-0.14	0.20	-0.12	0.34	-0.48
1991	0.17	0.37	0.18	-0.26	0.26
1992	0.18	0.11	0.22	-0.19	0.31
1993	0.17	0.23	0.30	-0.23	0.24
1994	0.16	0.51	0.32	-0.24	0.05
1995	0.36	0.32	-0.23	0.16	-0.72
1996	0.15	0.99	0.27	-0.32	0.03
1997	0.13	1.98	0.14	-0.46	0.01
1998	0.13	2.47	0.05	-0.46	-0.06
1999	0.10	5.43	-0.05	-0.84	-0.18
2000	4.30	-0.19	-1.88	-0.28	-3.13
	$\eta_{l\,coal}^{CHEM}$				
1990	-0.03	0.04	-0.02	0.07	-0.09
1991	0.06	0.03	-0.04	0.04	-0.11
1992	0.02	0.04	-0.03	0.06	-0.13
1993	0.04	0.05	-0.04	0.04	-0.11
1994	0.08	0.05	-0.04	0.01	-0.09
1995	0.06	0.05	-0.04	0.03	-0.12
1996	0.15	0.04	-0.05	0.00	-0.14
1997	0.26	0.02	-0.06	0.00	-0.20
1998	0.31	0.01	-0.06	-0.01	-0.26
1999	0.56	-0.01	-0.09	-0.02	-0.25
2000	1.08	-0.01	-0.14	-0.02	-0.24

As Coal could not be substituted for the other fuels in the chemical and metal sectors, discussion of cross price elasticity became meaningful only for the two sectors.

NG and Petro were substitutes for Coal in the chemical and metal sectors, respectively, for the whole sample period. Oil remained a substitute for Coal for the second half of the 1980s in the chemical sector. However, the increases in the consumption of NG and Oil were in general smaller than 0.1 per cent when there was 1 per cent increase in Coal prices. This compares with about a 0.5 per cent increase in Petro consumption in response to a 1 per cent increase in Coal prices in the metal sector.

The own price elasticities of Coal were positive for all the sectors except for RESD, indicating it was a Giffen good for the three sectors. Although the own price elasticity of Coal became positive in RESD for the last two years in the sample, this was largely caused by the small share of Coal expenditure in the total fuel expenditure. The large magnitudes of elasticity estimates for NG were a result of the combination of small NG expenditure shares and a relatively large coefficient estimate, $b_{NG\,NG}^{RSDN}$, (Magnus and Woodland (1987)).

Table 4. Estimates of $\sigma_{l\ coal}^{META}$ and $\eta_{l\ coal}^{META}$

	$\sigma_{l\ coal}^{META}$				
	l				
	Coal	NG	Elec	Oil	Petro
1990	0.55	-2.49	-0.44	-6.42	1.44
1991	0.74	-3.33	-0.48	-11.71	1.46
1992	0.66	-7.85	-0.43	-26.02	1.45
1993	0.65	-4.84	-0.45	-3.15	1.41
1994	0.92	-9.40	-0.57	0.18	1.42
1995	0.78	-6.72	-0.47	-33.38	1.38
1996	0.80	-7.24	-0.47	-17.12	1.46
1997	1.03	-12.78	-0.51	-45.98	1.53
1998	1.61	-14.32	-0.64	-25.71	1.68
1999	2.14	-27.55	-0.73	-21.35	1.81
2000	3.22	-18.04	-0.93	-16.12	1.67
	$\eta_{l\ coal}^{META}$				
1990	0.22	-1.00	-0.18	-2.58	0.58
1991	0.27	-1.21	-0.17	-4.26	0.53
1992	0.25	-2.96	-0.16	-9.82	0.55
1993	0.25	-1.84	-0.17	-1.20	0.53
1994	0.31	-3.18	-0.19	0.06	0.48
1995	0.28	-2.41	-0.17	-11.96	0.49
1996	0.28	-2.57	-0.17	-6.07	0.52
1997	0.34	-4.17	-0.17	-15.00	0.50
1998	0.45	-4.03	-0.18	-7.23	0.47
1999	0.55	-7.03	-0.19	-5.45	0.46
2000	0.71	-3.99	-0.21	-3.56	0.37

5. IMPLICATIONS ON CO2 EMISSION

As Coal is the main CO2 emitter, a reduction in Coal consumption will lead to abatement in CO2 emissions, *ceteris paribus*. The elasticity estimates relating to Coal demand in the various sectors in Section 4 have provided information on how the alternative fuels might have been substituted for Coal. This bears implications on the role of fuel prices in abating CO2 emission.

As shown in Table 2, Coal consumption has been diminishing over the sample period in all the sectors. The elasticity estimates contained in Tables 3 to 6 suggest that the relative price changes of the fuels have generally played a part in reducing Coal consumption. Particularly, substitution of Coal took place in CHEM by NG and Oil, in META by Petro, and in RSDN by Elec.

Table 5. Estimates of $\sigma_{l\ coal}^{NMMT}$ and $\eta_{l\ coal}^{NMMT}$

	$\sigma_{l\ coal}^{NMMT}$				
	l				
	Coal	NG	Elec	Oil	Petro
1990	0.31	-12.24	-0.21	-4.81	-1.80
1991	0.43	-11.77	-0.25	-6.23	-1.81
1992	0.45	-17.04	-0.25	-8.38	-2.20
1993	0.47	-13.70	-0.27	-2.95	-1.79
1994	0.87	-20.53	-0.36	-11.89	-2.41
1995	0.78	-18.37	-0.37	-1.49	-1.88
1996	0.73	-14.24	-0.35	-1.91	-2.07
1997	1.01	-16.36	-0.42	-2.06	-2.67
1998	1.77	-19.27	-0.57	-3.22	-3.33
1999	2.41	-31.29	-0.68	-3.76	-3.11
2000	4.42	-25.69	-0.99	-2.98	-2.69
	$\eta_{l\ coal}^{NMMT}$				
1990	0.13	-5.20	-0.09	-2.04	-0.76
1991	0.16	-4.53	-0.10	-2.39	-0.70
1992	0.17	-6.46	-0.09	-3.18	-0.83
1993	0.18	-5.11	-0.10	-1.10	-0.67
1994	0.27	-6.40	-0.11	-3.71	-0.75
1995	0.25	-5.92	-0.12	-0.48	-0.60
1996	0.24	-4.68	-0.12	-0.63	-0.68
1997	0.30	-4.89	-0.12	-0.62	-0.80
1998	0.44	-4.84	-0.14	-0.81	-0.84
1999	0.55	-7.10	-0.15	-0.85	-0.71
2000	0.81	-4.73	-0.18	-0.55	-0.50

However, the substitutability between Coal and NG and Oil in CHEM was weak for the corresponding cross price elasticities were relatively small, compared with those between Coal and Petro, and Coal and Elec in META and RSDN, respectively. Although there was only one Coal substitute in both META and RSDN, Coal substitutions in the two sectors were much more significant than that in CHEM. This was because META and RSDN consumed more Coal than CHEM and the substitutions were much more elastic to Coal price rises.

It is worthwhile noting that in the residential sector Coal and Elec remained to be substitutes until 1998 when the proportion of Coal expenditure fell below 20 per cent for the first time over the 16 years to 2000. Given the traditional use of Coal in Chinese energy consumption, Coal expenditure shares for the years preceding 1985 were expected much higher than 20 per cent. This suggests that under current technologies there were very limited rooms for households to further replace Coal with Elec.

Table 6. Estimates of $\sigma_{l\ coal}^{RSDN}$ and $\eta_{l\ coal}^{RSDN}$

	$\sigma_{l\ coal}^{RSDN}$				
	l				
	Coal	NG	Elec	Oil	Petro
1990	-0.43	-126.95	0.32	0.00	-3.73
1991	-0.45	-144.97	0.32	0.00	-4.51
1992	-0.55	-136.58	0.31	0.00	-5.15
1993	-0.65	-152.31	0.29	0.00	-4.04
1994	-0.81	-166.74	0.23	0.00	-4.98
1995	-0.84	-185.93	0.20	0.00	-5.10
1996	-0.86	-227.51	0.19	0.00	-5.29
1997	-0.85	-287.95	0.06	0.00	-6.57
1998	-0.13	-402.10	-0.25	0.00	-9.99
1999	0.93	-456.38	-0.46	0.00	-10.20
2000	2.93	-346.67	-0.75	0.00	-9.16
	$\eta_{l\ coal}^{RSDN}$				
1990	-0.22	-65.91	0.16	0.00	-1.93
1991	-0.23	-73.55	0.16	0.00	-2.29
1992	-0.25	-62.28	0.14	0.00	-2.35
1993	-0.27	-62.00	0.12	0.00	-1.65
1994	-0.27	-54.98	0.08	0.00	-1.64
1995	-0.26	-57.46	0.06	0.00	-1.57
1996	-0.26	-67.86	0.06	0.00	-1.58
1997	-0.20	-68.06	0.01	0.00	-1.55
1998	-0.02	-65.54	-0.04	0.00	-1.63
1999	0.13	-61.19	-0.06	0.00	-1.37
2000	0.32	-38.03	-0.08	0.00	-1.01

Against the backdrop of a reduction of Coal consumption was the trend of electrification in fuel consumption for all of the sectors. This was evidenced by the rising share of electricity expenditure. However, the reduction of CO2 emission from such electrification is unknown since there was no data on the consumption of hydro-power in the total electricity consumption.

6. CONCLUDING REMARKS

Identifying Coal being the largest CO2 emission, this paper investigated how Coal might have been replaced by the alternative fuels. Substitution away from Coal necessarily results in less CO2 emission than if no substitution of Coal takes place. Four top energy-consuming as well as coal-consuming sectors were selected to study the substitution possibilities between Coal and four other fuels, namely, natural gas, electricity, crude oil and petroleum products. A translog demand system was estimated for each of the four sectors using annual data from 1985 to 2000. As fuel prices data are unavailable at the sectoral level, they were estimated using fuel expenditure data from the 1987 input-output table and fuel physical quantity data from China Statistical Yearbook. It is found that substitution of Coal took place in three of the four sectors over the sample period. The most significant substitutions were in the metal and residential sectors, with petroleum products being the coal substitute for the former and electricity for the latter. The findings suggest that changes in the relative prices of the fuels led to substitution away from Coal to less CO2-intensive fuels and therefore an overall reduction of CO2 emission.

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