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Cross-national Coal Market Demand from 2001 to 2022

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Abstract

Coal is an important form among primary energies with several application in the economy and plays an important geopolitical role in the modern time. Employing a combination of static and dynamic panel data techniques, we explore the determinants of coal consumption and uncover its elasticities with respect to various influencing factors. The analysise reveal significant relationships between coal demand and variables such as population, electricity generation, and competitive energy forms. Further investigation on the top 10 countries with most coal consumption using the dynamic models and additional refinements are important to bolster the robustness of the results. Ultimately, this research contributes to the energy policy discourse by offering insights that can inform strategic decision-making in the face of evolving energy landscapes.

1 Introduction

Coal market is a very important sector of the economy. Despite the effort to transition away from it in the context of ecological transition, coal consumption still represents 26 percent of total energy consumption as of 2022, just after oil and natural gas. Furthermore, its application spread wide across different industries from power generation for electricity, cement production to be used in construction, residential and industrial heat applications to the production of steel making [6]. The consumption of coal is also heavily concentrated on couple of countries, i.e. China accounts for more than half of the global coal consumption. Therefore, it would be fruitful to investigate the determinants of the coal market as well as its elasticities. Coal elasticities is the measurement of the responsiveness of coal demand based on the change of various different factors like GDP, price, or other determinant sources. The understanding of this index contributes tremendously to design energy saving program, optimize resource allocation, etc. Moreover, on the international scheme, coal elasticity plays a crucial role in international trade and geopolitical considerations.

In this paper, we will investigate the coal market of 74 countries from 2001 to 2022. The paper is structured in 4 parts: introduction, methodology data, analytical results and conclusion. Likewise, there will also be additional results reported in the end of the document in the Appendix A.

2 Literature Review

This paper was mainly inspired by the meta-analysis of price energy elasticities of Labandeira, Labeaga and Xiral [7]. Even though we don't investigate the price demand elasticity, but it nevertheless compliments on the coal demand elasticity. This term paper also takes a look at the cross demand elasticities with regard to other forms of energy that coal has to compete with. The aggregate data were used to perform these analyses. Because of the scope of this paper, the choice of approach here is based on the existence of representative consumers, i.e. a single country as one representative coal consumer. The paper on coal by International Energy Agency [6] was used to provide an overview on the current coal market and the choice for choosing explanatory variables. The analysis was performed in R, using the package *plm* for both the static and dynamic analysis of panel data [4].

3 Methodology and Data

There are many different factors that could affect the global demand of coal consumption. The usage of coal falls into the category of industrial application, like power generation, production of cement and steel, and the non-industrial one like residential heating etc. At the same time, coal has to coexist and compete with other forms of energy, both fossil fuel and renewable alike. Additionally, it is important not only take into account of the static effect, but also the dynamic effect because there are possibly serial correlation of variable across. We will propose the regression equations in different forms.

Dependent variable	Independent variables
- Coal consumption in PJ (coal_conso_pj)	- GDP in constant 2017 International USD, PPP (gdp_billion) - Population (pop) - Electricity Generation in TWh (elect_twh) - Competitive energy forms: Gas consumption in PJ (gas_conso_pj), Hydroelectricity consumption in PJ, (hydro_conso_pj) Oil consumption in PJ (oil_conso_pj), Renewable energy consumption in PJ (renewables_)

Table 1: List of variables used for the regression

3.1 Static models

3.1.1 Linear - linear baseline regression:

$$\begin{aligned} Coal_{i,t} = & \underbrace{\beta_1 GDP_{i,t} + \beta_2 Pop_{i,t} + \beta_3 Elect_{i,t} + \sum_{i=1}^{n} \eta_n ComEnergy_{i,t}}_{Baseline} \\ & + \alpha_i + \gamma_t + \mu_{i,t} \end{aligned} \tag{1}$$

With the dummy interaction term:

$$\begin{aligned} Coal_{i,t} = Baseline & + \delta_1 GDP_{i,t} \text{ Dummy} \\ & + \delta_2 Pop_{i,t} \text{ Dummy} + \delta_3 Elect_{i,t} \text{ Dummy} \\ & + \sum_{i=1}^{n} \eta_n ComEnergy_{i,t} \text{ Dummy Dummy} \\ & + \alpha_i + \gamma_t + \mu_{i,t} \end{aligned} \tag{2}$$

3.1.2 Log - log baseline regression:

$$
\begin{aligned}
logCoal_{i,t} = &\underbrace{\beta_1 log_{GDP_{i,t}} + \beta_2 logPop_{i,t} + \beta_3 log_{Elect_{i,t}} + \sum_{i=1}^{n} \eta_n log_{ComEnergy_{i,t}}}_{Baseline} \\
&+ \alpha_i + \gamma_t + \mu_{i,t}
\end{aligned} \tag{3}
$$

With the dummy interaction term:

$$
\begin{aligned}
logCoal_{i,t} = &\, Baseline + \delta_1 logGDP_{i,t} \text{ Dummy} \\
&+ \delta_2 logPop_{i,t} \text{ Dummy} + \delta_3 logElect_{i,t} \text{ Dummy} \\
&+ \sum_{i=1}^{n} \eta_n log_{ComEnergy_{i,t}} \text{ Dummy} \\
&+ \alpha_i + \gamma_t + \mu_{i,t}
\end{aligned} \tag{4}
$$

The variables used for this study are listed in Table 1. The data of energy variables were taken from BP and the Energy Institute [5]. The electricity generation used is the electricity of all forms of primary energy, the usage of electricity generation by coal would significantly reduce the number of observation, therefore we stick with the former. World GDP and population are taken from the World Bank [8]. Datas are collected from 74 countries and from the period of 2001 to 2022. Several dummies were created for important economic entities like OECD, EU, etc., and countries in the top 10 which consume the most coal in median term during the whole studied period to investigate the effect in the coal market of each dummy. α_t, γ_t and $\mu_{i,t}$ are the entity-, time-fixed effect and the clustered robust standard error respectively. We created several different dummies for each top 10 coal consumption countries and economic entities, it is 1 if it is one particular country and 0 otherwise. Here, the linear-linear estimation method and the log-log method were used. While the former one will give us the effect of how much one unit of change in the independent variable on the dependent variable, the latter method gives us the coal demand elasticity according to a particular independent variable. There are several other variables that were added to the regression functions during the analyses, but either it reduces significantly the number of observations, results are not statistically significant or the data for important countries like China is not available, i.e. the nuclear consumption, industry productions that use directly the different coal types like non-power thermal coal for cement production or metallurgical coal for steel production.

3.2 Dynamic models

3.2.1 Linear-Linear baseline regression

$$
\begin{aligned}
Coal_{i,t} = &\sum_{t}^{x_{coal}} \zeta_n Coal_{i,t-x_{coal}} + \sum_{t}^{x_{gdp}} \beta_1.nGDP_{i,t-x_{gdp}} + \sum_{t}^{x_{pop}} \beta_2.nPop_{i,t-x_{pop}} + \sum_{t}^{x_{ElectGen}} \beta_3.nElectGen_{i,t-x_{electgen}} \\
&\underbrace{+ \textstyle\sum_{t}^{x_{ComEnergy}} \beta_4.nComEnergy_{i,t-x_{ComEnergy}}}_{Baseline} \\
&+ \alpha_i + \gamma_t + \mu_{i,t}
\end{aligned} \tag{5}
$$

3.2.2 Log-Log baseline regression

$$logCoal_{i,t} = \sum_{t}^{x_{coal}} \zeta_n logCoal_{i,t-x_{coal}} + \sum_{t}^{x_{gdp}} \beta_1.nlogGDP_{i,t-x_{gdp}} + \sum_{t}^{x_{pop}} \beta_2.nlogPop_{i,t-x_{pop}} + \underbrace{\sum_{t}^{x_{ElectGen}} \beta_3.nlogElectGen_{i,t-x_{electgen}} + \sum_{t}^{x_{ComEnergy}} \beta_4.nlogComEnergy_{i,t-x_{ComEnergy}}}_{Baseline} + \alpha_i + \gamma_t + \mu_{i,t} \quad (6)$$

With regard to the dynamic causal effect model on panel data, the general methods of moment (GMM) using *pgmm* function from the package *plm* [4] that is based on the study of Arellano and Bond [1]. Here we introduce the lagged-value of each variable as the "normal" instruments, the number of lagged value is denoted $x_{variable}$, the number of lagged-components for each of the variables is presented in the result table 6 and 7. Beside the normal lag-instruments, GMM instruments are also specified in the *pgmm* model, in this case we use the own lagged-value of the coal consumption. Dynamic models using the GMM would take lagged values of variable into account using both normal and GMM instruments and potentially improve the model's precision according to Blundell and Bond [3]. The GMM estimators are calculated using one-step, the two-step method is not possible on this data because of the singularity of the matrix for second-step estimation in which we will not investigate further due to the scope of the term paper. As in the static models, country- and time-fixed effects (α_t, γ_t) were included in the model to take into account of the unobserved time-specific differences that affect all entities uniformly across time and the unobserved differences that are specific to each country over all time periods. Alongside the estimation results, the autocorrelation test results were presented using the Arellano-Bond test, which is a test of correlation based on the residual of the estimation. Sargan test or J test was also reported to test the validity of the over-identifying restrictions in the GMM estimation, in other word the restrictions refer to the extra equations or moments used in the GMM estimation that are not used in the direct estimation of the parameters [2]. Finally, the Wald test was represented for the jointed significance of the group of coefficient and time dummies.

4 Analytical results

4.1 Descriptive Statistics and Correlation Table

Table 2: Descriptive Statistics

	NUnique	Min	Max	Mean	P25	P50	P75
coal_conso_pj	1264	0.01	88 414.15	2428.52	62.90	248.70	976.13
gdp_billion	1268	26.87	25 684.61	1584.84	287.91	547.81	1524.70
pop	1268	0.44	1425.89	96.48	9.69	32.88	77.37
elect_twh	1266	1.62	8848.71	354.13	48.27	99.38	266.29
gas_conso_pj	1264	0.28	31 723.64	1734.79	149.03	583.23	1604.70
hydro_conso_pj	1268	0.09	12 496.28	533.63	28.50	129.46	369.92
oil_conso_pj	1268	38.30	40 370.68	2576.97	397.38	760.43	2691.04
renewables_pj	1267	0.00	13 302.66	279.91	7.02	50.53	171.29

4.2 Static Models

Table 3: Correlation between variables

	coal_conso_pj	gdp_billion	pop	elect_twh	gas_conso_pj	hydro_conso_pj	oil_conso_pj	renewables_pj
coal_conso_pj	1	0.76	0.80	0.86	0.36	0.83	0.65	0.59
gdp_billion	0.76	1	0.66	0.97	0.79	0.72	0.96	0.84
pop	0.80	0.66	1	0.68	0.27	0.65	0.53	0.46
elect_twh	0.86	0.97	0.68	1	0.73	0.82	0.92	0.82
gas_conso_pj	0.36	0.79	0.27	0.73	1	0.43	0.85	0.61
hydro_conso_pj	0.83	0.72	0.65	0.82	0.43	1	0.64	0.66
oil_conso_pj	0.65	0.96	0.53	0.92	0.85	0.64	1	0.73
renewables_pj	0.59	0.84	0.46	0.82	0.61	0.66	0.73	1

In the table 4 and table 5 the baseline regression function was presented in the respective first columns, then additional results with each dummy were additional columns hereafter. As for the countries' dummy, the results of the other 7 countries in the top 10 countries with the most coal consumption will be put in the Appendix area A.

As we can see on the baseline linear-linear function in table 4, the model explains exhaustively the coal consumption with the adjusted R-squared at 90 percent. The variables GDP, hydroelectricity and oil are not statistically significant. The insignificance of variable GDP can be explained by its highly correlated relationship with the electricity generation and the oil consumption at 0.97 and 0.96 respectively. Removing the GDP from the equation (table 9) greatly improved the significance of the population variable and has a small effect on the coefficients of other variables. Nevertheless, for the sake of the consistency of the subsequent analyses and the peculiarity of each dummy, we will keep all the original variables. With respect to the population and electricity generation, it shows the positive relationships to the coal consumption. It means that the demand for coal is very heavily based on the electricity generation; the same applies for the population. So the demand of coal here is still scaled very closely with the scope of a country as a whole. The presence of other competitive forms of energy clearly has a negative effect on the consumption of coal, in particular the gas and renewable energy consumption. This explains very well the fact that countries around the world are pushing very much for the transition towards renewable forms of energy consumption.

Looking at the dummies of the economic entity like OECD and the EU countries, it provides a different picture than the baseline regression, the GDP has a clearly positive correlation toward the coal consumption, even though the usage of coal have been decoupled from the electricity generation demand and the population. Concerning the competitive primary energy form, they are complementary to the consumption of coal, this indicates that OECD as a whole has an increasing demand of primary energy. However, we cannot capture in further details in which application of primary energy form that OECD are using to in the scope of this study other than electricity generation; only the GDP, electricity generation, hydroelectricity and renewable energy consumption are statistically significant. For the EU as a whole, we can observe that the electricity generation of the EU has been decoupled with the coal consumption - a negative correlation. Besides that, renewable energy is a complementary good to the coal consumption, one PJ unit of renewable energy required 2.539 PJ more of coal consumption. Other variables are statistically insignificant.

Now we come to individual countries - China, USA and India which are the top 3 countries with most median coal consumption during the studied period. Firstly, China is a big player in this matter as their consumption share is more than 50 percent of the global coal consumption in 2021. Coal-fired power-generation is the backbone of China's electricity's system, the regression result demonstrates unquestionably that it has a huge impact on the coal demand, one unit of Twh in electricity generation requires 27.3 PJ in coal consumption. Its GDP has a negative correlation with the coal consumption, -6.416 at 1 percent significance. This finding contradicts the forecast of the IAE [6, p. 17]. As to the competitive primary energy forms, gas is a substitute to coal in the usage in residential heating as well as non-industrial uses [6, p. 21], the effect is quite large, one additional PJ of gas consumption results in the decrease of 5.439 PJ of coal counterpart. China's hydropower is also an important aspect of its energy generation, the correlation between coal and hydropower is negative, though it is not significant. Oil on the other hand is a complement primary energy form of coal. Secondly, the USA in other hand has been scaling down its coal consumption drastically since the early 2010s, as a result its economy has been decoupling with the coal consumption, its consumption also has contract while the consumption of renewable form of energy has taken the acceleration. The result of the USA as a dummy does not show many meaningful results compared to the reality of the coal situation in the US, which is a sign that further change to the regression specification needs to be done. On the contrary, India's coal consumption plays an important role in its generation, accounting for 73 percent of its power demand as of 2022. Along with the demand of coal in non-power sector, the demand of coal in India is projected to continuously increase[6, p. 23]. Looking at its correlation table 15 and the regression result, severe multicollinearity can be easily spotted. As a result, the regression result of India does not offer much meaningful interpretation. The correlation tables of these dummies can be found in A.

Table 5 gives the result of log-log linear estimation model, in other it is the coal demand elasticity with regard to GDP and its cross elasticity of demand. The log-log model exhibits a similar picture to the linear model. Coal consumption is very positively elastic to population and electricity generation, while being negatively elastic to gas. Leaving out the GDP does not change the model much like with the linear-linear counterpart 10. As for the dummy variables, for the OECD only the gas consumption is proven statistically significant as a complementary good to the coal consumption, for the EU as a whole it is oil. The China' regression result display a heavy negative elasticity result of the coal consumption to the population, this could be the result of the fact that the population growth in China is slowing down, at the same time its population's middle class is solidifying, making coal demand for residential heating and its power electricity increasing. China's coal consumption exerts the substitute effect toward the hydropower consumption like the linear-linear function. US' coal consumption change effect based on the change of hydropower is less than China's equivalent. However, model also suffers the same problem of its relation between coal and renewable energies. Lastly, India's regression result indicates a strong negative cross elasticity of coal to oil, and a similar relation with hydropower like China's and US's.

As we can see from the results of the static models, the result of regression results with dummies do not provide a sufficient picture of coal consumption demand, some models displays the lack of precision in the specification, at the same time it probably suffers under the endogeneity that requires additional instruments to address those issues.

Table 4: Coal energy demand: linear-linear model

	Dependent variable: coal_conso_pj					
	total	OECD	EU	China	USA	India
gdp_billion	0.195 (0.504)	−3.154** (1.507)	0.220 (0.556)	−0.648* (0.334)	−0.683 (1.001)	0.247 (0.534)
pop	13.124* (7.485)	40.585*** (13.113)	13.260 (8.687)	25.796*** (5.075)	23.072*** (8.313)	18.176 (17.981)
elect_twh	14.845*** (4.003)	27.250*** (5.224)	15.372*** (4.396)	10.244*** (1.049)	20.311*** (6.841)	14.885*** (3.991)
gas_conso_pj	−0.561*** (0.183)	−0.917*** (0.228)	−0.428** (0.199)	−0.560*** (0.096)	−0.965*** (0.366)	−0.602*** (0.196)
hydro_conso_pj	−0.962 (1.128)	−2.457** (1.032)	−1.195 (1.289)	−0.498** (0.243)	−1.256 (1.213)	−1.096 (1.289)
oil_conso_pj	−0.810 (0.542)	−0.356 (0.482)	−0.820 (0.546)	−0.183 (0.238)	−1.275*** (0.304)	−0.810 (0.536)
renewables_pj	−2.801** (1.137)	−3.714*** (0.593)	−3.082*** (1.144)	−1.095*** (0.250)	−3.215*** (0.972)	−2.817** (1.136)
oecd:gdp_billion		3.188* (1.658)				
oecd:pop		−71.195 (44.002)				
oecd:elect_twh		−19.643*** (6.070)				
oecd:gas_conso_pj		0.325 (0.304)				
oecd:hydro_conso_pj		2.037* (1.225)				
oecd:oil_conso_pj		0.139 (0.526)				
oecd:renewables_pj		2.407*** (0.784)				
eu:gdp_billion			−0.569 (0.667)			
eu:pop			−0.309 (30.248)			
eu:elect_twh			−10.750* (6.068)			
eu:gas_conso_pj			−0.082 (0.321)			
eu:hydro_conso_pj			1.093 (1.580)			
eu:oil_conso_pj			0.826 (0.641)			
eu:renewables_pj			2.539** (1.198)			
china:gdp_billion				−6.416*** (0.342)		
china:pop				7.779 (39.462)		
china:elect_twh				27.300*** (3.799)		
china:gas_conso_pj				−5.439** (2.401)		
china:hydro_conso_pj				−0.536 (0.701)		
china:oil_conso_pj				1.374*** (0.457)		
china:renewables_pj				0.130 (1.048)		
usa:gdp_billion					−1.135 (0.858)	
usa:pop					26.458 (20.969)	
usa:elect_twh					−7.835 (7.114)	
usa:gas_conso_pj					0.375 (0.386)	
usa:hydro_conso_pj					−0.110 (1.187)	
usa:oil_conso_pj					1.456*** (0.327)	
usa:renewables_pj					2.929*** (1.045)	
india:gdp_billion						−0.041 (0.621)
india:pop						−0.723 (18.837)
india:elect_twh						−3.568 (3.133)
india:gas_conso_pj						0.753*** (0.241)
india:hydro_conso_pj						0.231 (1.083)
india:oil_conso_pj						0.272 (0.583)
india:renewables_pj						0.108 (1.005)
Observations	1,268	1,268	1,268	1,268	1,268	1,268
R^2	0.907	0.953	0.914	0.975	0.924	0.908
Adjusted R^2	0.900	0.949	0.907	0.973	0.918	0.900
F Statistic	1,645.843*** (df = 7; 1179)	1,703.699*** (df = 14; 1172)	884.358*** (df = 14; 1172)	3,291.807*** (df = 14; 1172)	1,022.537*** (df = 14; 1172)	822.108*** (df = 14; 1172)
Note:						*p<0.1; **p<0.05; ***p<0.01

Table 5: Coal energy elasticity: log-log model

	Dependent variable: log_coal_conso_pj					
	Baseline	OECD	EU	China	USA	India
log_gdp	0.528 (0.505)	0.891 (0.585)	0.619 (0.670)	0.760 (0.514)	0.528 (0.505)	0.566 (0.517)
log_pop	1.925*** (0.685)	2.869*** (0.779)	1.100 (0.975)	1.619** (0.711)	1.940*** (0.686)	1.920*** (0.691)
log_gas_conso_pj	−0.196*** (0.061)	−0.366*** (0.079)	−0.220*** (0.072)	−0.183*** (0.055)	−0.195*** (0.060)	−0.199*** (0.062)
log_elect_twh	1.094*** (0.164)	0.725*** (0.242)	1.319*** (0.314)	1.115*** (0.168)	1.085*** (0.163)	1.096*** (0.163)
log_oil_conso_pj	0.009 (0.316)	−0.216 (0.432)	−0.360 (0.350)	−0.041 (0.315)	0.009 (0.316)	0.008 (0.316)
log_hydro_conso_pj	0.124* (0.072)	0.146** (0.073)	0.088 (0.084)	0.137** (0.068)	0.125* (0.072)	0.124* (0.072)
log_renewables_pj	0.011 (0.025)	−0.001 (0.026)	−0.001 (0.025)	0.008 (0.025)	0.010 (0.025)	0.009 (0.025)
oecd:log_gdp		−0.750 (0.634)				
oecd:log_pop		−1.458 (1.142)				
oecd:log_elect_twh		0.260 (0.394)				
oecd:log_gas_conso_pj		0.293*** (0.088)				
oecd:log_hydro_conso_pj		−0.126 (0.103)				
oecd:log_oil_conso_pj		0.731 (0.475)				
oecd:log_renewables_pj		−0.028 (0.050)				
eu:log_gdp			−1.131 (0.821)			
eu:log_pop			0.724 (1.566)			
eu:log_elect_twh			−0.713 (0.468)			
eu:log_gas_conso_pj			0.025 (0.219)			
eu:log_hydro_conso_pj			0.023 (0.103)			
eu:log_oil_conso_pj			1.255** (0.591)			
eu:log_renewables_pj			0.051 (0.053)			
china:log_gdp				0.599 (0.831)		
china:log_pop				−11.350** (4.687)		
china:log_elect_twh				0.018 (0.483)		
china:log_gas_conso_pj				0.033 (0.313)		
china:log_hydro_conso_pj				−0.553** (0.240)		
china:log_oil_conso_pj				0.220 (0.393)		
china:log_renewables_pj				−0.045 (0.106)		
usa:log_gdp					−0.962 (1.569)	
usa:log_pop					−6.355 (6.045)	
usa:log_elect_twh					0.749 (0.657)	
usa:log_gas_conso_pj					−0.739*** (0.272)	
usa:log_hydro_conso_pj					−0.333** (0.135)	
usa:log_oil_conso_pj					0.587 (0.562)	
usa:log_renewables_pj					0.644*** (0.229)	
india:log_gdp						−0.180 (0.733)
india:log_pop						2.033 (3.498)
india:log_elect_twh						0.170 (0.581)
india:log_gas_conso_pj						0.134 (0.121)
india:log_hydro_conso_pj						−0.255* (0.133)
india:log_oil_conso_pj						−1.061** (0.535)
india:log_renewables_pj						0.022 (0.272)
Observations	1,268	1,268	1,268	1,268	1,268	1,268
R^2	0.424	0.461	0.447	0.434	0.426	0.425
Adjusted R^2	0.381	0.418	0.402	0.388	0.379	0.379
F Statistic	124.001*** (df = 7; 1179)	71.683*** (df = 14; 1172)	67.726*** (df = 14; 1172)	64.116*** (df = 14; 1172)	62.004*** (df = 14; 1172)	61.930*** (df = 14; 1172)

Note: *p<0.1; **p<0.05; ***p<0.01

4.3 Dynamic Models

Table 6: Two-way Effects One-step System GMM linear model

Dependent variable: coal_conso_pj				
Coefficients	Estimate	Std. Error	z-value	$\Pr(>\lvert z\rvert)$
lag(coal_conso_pj, 1:2)1	1.429 819	0.075 547	18.9262	$< 2.2e^{-16}$ ***
lag(coal_conso_pj, 1:2)2	−0.421 727	0.081 882	−5.1504	$2.599e^{-07}$ ***
lag(gdp_billion, 0:2)0	−0.505 755	0.634 866	−0.7966	0.4256643
lag(gdp_billion, 0:2)1	−1.390 700	0.528 184	−2.6330	0.0084638 **
lag(gdp_billion, 0:2)2	1.884 839	0.645 301	2.9209	0.0034906 **
lag(pop, 0)	0.535 374	0.302 078	1.7723	0.0763443 .
lag(elect_twh, 0:2)0	9.464 816	0.742 775	12.7425	$< 2.2e^{-16}$ ***
lag(elect_twh, 0:2)1	−6.911 690	2.073 495	−3.3334	0.0008581 ***
lag(elect_twh, 0:2)2	−2.922 391	1.664 122	−1.7561	0.0790687 .
lag(gas_conso_pj, 0:2)0	−0.379 900	0.140 992	−2.6945	0.0070498 **
lag(gas_conso_pj, 0:2)1	0.335 345	0.233 500	1.4362	0.1509542
lag(gas_conso_pj, 0:2)2	0.049 744	0.111 421	0.4464	0.6552733
lag(hydro_conso_pj, 0:2)0	−1.275 916	0.547 747	−2.3294	0.0198385 *
lag(hydro_conso_pj, 0:2)1	1.444 744	0.723 601	1.9966	0.0458682 *
lag(hydro_conso_pj, 0:2)2	−0.185 950	0.213 781	−0.8698	0.3844017
lag(oil_conso_pj, 0:2)0	0.145 726	0.151 483	0.9620	0.3360535
lag(oil_conso_pj, 0:2)1	0.010 479	0.165 669	0.0633	0.9495672
lag(oil_conso_pj, 0:2)2	−0.108 608	0.205 271	−0.5291	0.5967382
lag(renewables_pj, 0:1)0	−1.027 393	0.496 385	−2.0697	0.0384758 *
lag(renewables_pj, 0:1)1	1.145 359	0.565 929	2.0239	0.0429849 *

Unbalanced Panel: n = 61, T = 7-22, N = 1268
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Sargan test: chisq(245) = 37.85123 (p-value = 1)
Autocorrelation test (1): normal = -1.010379 (p-value = 0.31231)
Autocorrelation test (2): normal = 0.02540992 (p-value = 0.97973)
Wald test for coefficients: chisq(20) = 404902800 (p-value = $< 2.22e^{-16}$)
Wald test for time dummies: chisq(19) = 51.67418 (p-value = $7.4013e^{-05}$)

Table 6 and 7 present the results of dynamic model using two-way effects, time- and entity-fixed effect, by estimating the GMM estimators in one step because of the large data set of this data frame, that we have confidence that making inferences using the asymptotic variance matrix is a more dependable approach according to Blundell and Bond [3]. The result of the linear table 6 makes sense of the influence of coal consumption from previous years onto the current one. The variable GDP with its lagged-components now have meaningful effects on the consumption of coal, though its effect on the first lag is negative and the effect on the second lag is positive, the interpretation for this phenomenon can be that an increase in immediate GDP stress the economy to go to other source of energy, which can be more cost-efficient or readily available at the moment to fill up the demand to power the economy, but starting from the second period the coal demand starts to catch up. Electricity generation still plays an important place in the picture of the coal demand. Its results on the immediate, first and second lag reveal the opposite picture to the GDP's; on the one hand a surge in demand for electricity generation spikes the demand for coal consumption, in the other hand a similar surge of electricity generation demand from the lag period results in decrease in the current coal consumption, a possible interpretation is that the coal consumption used quickly catch up to satisfy the demand of electricity. Gas consumption exhibits the same negative correlation like in the static model. Hydroelectricity consumption and renewable energy and their lagged-variables have similar effects on the coal consumption, their change in immediate demand make the demand for coal decrease while on the lagged-period, coal behaves like complementary good for the demand of primary energy. The results of the model suggest that the overidentification restrictions (Sargan test) are valid, and there is no significant autocorrelation present in the residuals. The Wald tests indicate that the coefficients

Table 7: Two-way Effects One-step System GMM Log Model

Dependent variable: log_coal_conso_pj				
Coefficients	Estimate	Std. Error	z-value	Pr(> $\|z\|$)
lag(log_coal_conso_pj, 1:2)1	0.845 482	0.162 548	5.2014	1.978e-07 ***
lag(log_coal_conso_pj, 1:2)2	0.160 962	0.147 634	1.0903	0.2755924
lag(log_gdp, 0:1)0	0.309 289	0.425 647	0.7266	0.4674513
lag(log_gdp, 0:1)1	−0.316 761	0.437 591	−0.7239	0.4691437
lag(log_pop, 0:1)0	2.340 546	1.166 463	2.0065	0.0447995 *
lag(log_pop, 0:1)1	−2.319 020	1.177 210	−1.9699	0.0488465 *
lag(log_elect_twh, 0:1)0	0.664 558	0.181 621	3.6590	0.0002532 ***
lag(log_elect_twh, 0:1)1	−0.670 416	0.195 969	−3.4210	0.0006239 ***
lag(log_gas_conso_pj, 0:1)0	−0.059 545	0.037 202	−1.6006	0.1094705
lag(log_gas_conso_pj, 0:1)1	0.049 010	0.029 628	1.6542	0.0980920 .
lag(log_hydro_conso_pj, 0:1)0	−0.038 932	0.033 933	−1.1473	0.2512393
lag(log_hydro_conso_pj, 0:1)1	0.042 430	0.034 985	1.2128	0.2251948
lag(log_oil_conso_pj, 0:1)0	0.029 317	0.106 534	0.2752	0.7831691
lag(log_oil_conso_pj, 0:1)1	−0.024 533	0.098 135	−0.2500	0.8025903
lag(log_renewables_pj, 0:1)0	−0.045 458	0.020 193	−2.2511	0.0243766 *
lag(log_renewables_pj, 0:1)1	0.036 135	0.017 206	2.1002	0.0357111 *

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Sargan test: chisq(241) = 61 (p-value = 1)
Autocorrelation test (1): normal = -1.618783 (p-value = 0.10549)
Autocorrelation test (2): normal = 0.1400111 (p-value = 0.88865)
Wald test for coefficients: chisq(16) = 236546.3 (p-value = $< 2.22e^{-16}$)
Wald test for time dummies: chisq(19) = 76.03327 (p-value = $8.8871e^{-09}$)

are jointly significant, implying the model's effectiveness in capturing relationships between variables, while the time dummy variables also exhibit statistical significance in explaining the variation in the data.

On the log model in the table 7, the coefficient of three variables population, electricity generation and renewable energy are significant, making their coal elasticity indexes interpretable. In addition to that, the first lag component of coal consumption logarithmic is a valid instrument for this model. The Sargan test results indicate that the instrumental variables used in the model are valid and not exhibiting endogeneity issues. Autocorrelation tests suggest that there is no significant first-order autocorrelation in the model's residuals, and the second-order autocorrelation is also not significant. The Wald test for coefficients reveals joint significance of the model's coefficients, indicating its ability to capture meaningful relationships among the variables. Additionally, the Wald test for time dummy variables is significant, suggesting that these dummies effectively contribute to explaining the variation in the data. The result was recorded using only 1 lag of variables, as the result with 2 lags does not offer much improvement on the model (unreported in the paper).

Down below is the table of short-run and long-run effect of statistically significant variables for both the linear and the log model, the coefficient on the log model here is the elasticity index.

Table 8: Short-run and long-run effects of independent variables

Independent Variables	Short Run	Long Run
Lagged coal consumption	N/A	1.008092
GDP	N/A	0.494139
Electricity generation	9.464816	-0.369265
Gas consumption	-0.379900	N/A
Hydroelectricity consumption	-1.275916	0.168828
Renewable energy	-1.027393	0.117966
Lagged coal consumption (log)	N/A	0.845482
Population (log)	2.340546	0.021526
Electricity generation (log)	0.664558	-0.005858
Renewable energy (log)	-0.045458	-0.009323

5 Conclusion

The research paper titled ”Coal Market Demand from 2001 to 2022” investigates the determinants and elasticities of coal market demand across different countries. The study employs panel data analysis and dynamic causal effect modeling using the general method of moments (GMM) to examine the relationship between coal consumption and various independent variables. The findings reveal that electricity generation, population, and competitive energy forms play significant roles in influencing coal consumption. Specifically, increases in electricity generation and population are associated with higher coal demand. On the other hand, the consumption of competitive energy sources like gas and renewable energy is negatively correlated with coal consumption. The paper also explores the effects of economic entities like OECD and the EU, as well as the top coal-consuming countries like China, the USA, and India. The results with interaction term using linear model highlight the complex interactions between different factors and their impacts on coal consumption, though it does not offer a complete picture due to misspecification and potential presence of endogeneity. Fortunately, the dynamic models addressed the problem of endogeneity by employing GMM with various lagged variables and provide insights into the short-run and long-run effects of various variables on coal demand. Further investigation using the dynamic models to take a deeper look into the dummy could result in potential insights. Additional testing like test for stationarity, normality and heteroskedasticity for the given baseline regression could be done to ensure a good base for the study, alongside with other robustness check like exploring alternative dynamic model specifications and sensitivity check to solidify the results of the study.

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A Additional Results

Table 9: Coal energy demand linear model (without GDP)

	Dependent variable:
	coal_conso_pj total lin lin
pop	15.668***
	(2.044)
elect_twh	15.042***
	(4.247)
gas_conso_pj	−0.530**
	(0.206)
hydro_conso_pj	−0.885
	(0.933)
oil_conso_pj	−0.802
	(0.529)
renewables_pj	−2.719***
	(0.996)
Observations	1,268
R^2	0.907
Adjusted R^2	0.900
F Statistic	1,918.934*** (df = 6; 1180)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 10: Coal energy elasticity (without GDP)

	Dependent variable:
	log_coal_conso_pj total
log_pop	2.096***
	(0.606)
log_gas_conso_pj	−0.187***
	(0.063)
log_elect_twh	1.184***
	(0.163)
log_oil_conso_pj	0.235
	(0.178)
log_hydro_conso_pj	0.143*
	(0.073)
log_renewables_pj	0.018
	(0.022)
Observations	1,268
R^2	0.418
Adjusted R^2	0.376
F Statistic	141.527*** (df = 6; 1180)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 11: Correlation between variables of OECD

	coal_conso_pj	gdp_billion	pop	elect_twh	gas_conso_pj	hydro_conso_pj	oil_conso_pj	renewables_pj
coal_conso_pj	1	0.90	0.87	0.94	0.89	0.49	0.95	0.63
gdp_billion	0.90	1	0.96	0.98	0.98	0.54	0.97	0.87
pop	0.87	0.96	1	0.93	0.92	0.50	0.93	0.78
elect_twh	0.94	0.98	0.93	1	0.98	0.61	0.99	0.81
gas_conso_pj	0.89	0.98	0.92	0.98	1	0.59	0.97	0.86
hydro_conso_pj	0.49	0.54	0.50	0.61	0.59	1	0.58	0.43
oil_conso_pj	0.95	0.97	0.93	0.99	0.97	0.58	1	0.77
renewables_pj	0.63	0.87	0.78	0.81	0.86	0.43	0.77	1

Table 12: Correlation between variables of EU

	coal_conso_pj	gdp_billion	pop	elect_twh	gas_conso_pj	hydro_conso_pj	oil_conso_pj	renewables_pj
coal_conso_pj	1	0.67	0.71	0.66	0.63	0.03	0.65	0.54
gdp_billion	0.67	1	0.97	0.97	0.94	0.48	0.96	0.79
pop	0.71	0.97	1	0.94	0.91	0.47	0.94	0.72
elect_twh	0.66	0.97	0.94	1	0.85	0.57	0.94	0.71
gas_conso_pj	0.63	0.94	0.91	0.85	1	0.35	0.93	0.68
hydro_conso_pj	0.03	0.48	0.47	0.57	0.35	1	0.45	0.28
oil_conso_pj	0.65	0.96	0.94	0.94	0.93	0.45	1	0.66
renewables_pj	0.54	0.79	0.72	0.71	0.68	0.28	0.66	1

Table 13: Correlation between variables of China

	coal_conso_pj	gdp_billion	pop	elect_twh	gas_conso_pj	hydro_conso_pj	oil_conso_pj	renewables_pj
coal_conso_pj	1	0.86	0.91	0.89	0.80	0.89	0.89	0.64
gdp_billion	0.86	1	0.99	1.00	0.99	0.98	0.99	0.91
pop	0.91	0.99	1	0.99	0.95	0.99	0.99	0.83
elect_twh	0.89	1.00	0.99	1	0.99	0.98	0.99	0.91
gas_conso_pj	0.80	0.99	0.95	0.99	1	0.95	0.97	0.95
hydro_conso_pj	0.89	0.98	0.99	0.98	0.95	1	0.99	0.83
oil_conso_pj	0.89	0.99	0.99	0.99	0.97	0.99	1	0.86
renewables_pj	0.64	0.91	0.83	0.91	0.95	0.83	0.86	1

Table 14: Correlation between variables of USA

	coal_conso_pj	gdp_billion	pop	elect_twh	gas_conso_pj	hydro_conso_pj	oil_conso_pj	renewables_pj
coal_conso_pj	1	−0.93	−0.93	−0.48	−0.97	0.19	0.61	−0.97
gdp_billion	−0.93	1	0.98	0.75	0.95	−0.17	−0.53	0.98
pop	−0.93	0.98	1	0.70	0.93	−0.12	−0.68	0.97
elect_twh	−0.48	0.75	0.70	1	0.59	0.00	−0.23	0.63
gas_conso_pj	−0.97	0.95	0.93	0.59	1	−0.24	−0.55	0.98
hydro_conso_pj	0.19	−0.17	−0.12	0.00	−0.24	1	0.08	−0.21
oil_conso_pj	0.61	−0.53	−0.68	−0.23	−0.55	0.08	1	−0.61
renewables_pj	−0.97	0.98	0.97	0.63	0.98	−0.21	−0.61	1

Table 15: Correlation between variables of India

	coal_conso_pj	gdp_billion	pop	elect_twh	gas_conso_pj	hydro_conso_pj	oil_conso_pj	renewables_pj
coal_conso_pj	1	0.99	0.99	0.99	0.87	0.89	0.98	0.93
gdp_billion	0.99	1	0.99	1.00	0.84	0.89	0.99	0.96
pop	0.99	0.99	1	0.98	0.90	0.92	0.98	0.93
elect_twh	0.99	1.00	0.98	1	0.83	0.89	0.99	0.97
gas_conso_pj	0.87	0.84	0.90	0.83	1	0.82	0.85	0.77
hydro_conso_pj	0.89	0.89	0.92	0.89	0.82	1	0.87	0.86
oil_conso_pj	0.98	0.99	0.98	0.99	0.85	0.87	1	0.93
renewables_pj	0.93	0.96	0.93	0.97	0.77	0.86	0.93	1

Table 16: Coal energy demand linear-linear (rest)

	Dependent variable: coal_conso_pj						
	Japan	Russian Federation	South Africa	Germany	South Korea	Poland	Australia
gdp_billion	0.129 (0.531)	0.446 (0.538)	0.195 (0.505)	0.190 (0.499)	0.215 (0.527)	0.183 (0.506)	0.198 (0.505)
pop	13.246* (7.544)	8.615 (8.045)	13.120* (7.503)	13.289* (7.798)	12.566 (7.978)	13.352* (7.569)	13.152* (7.498)
elect_twh	14.801*** (4.280)	14.678*** (3.953)	14.846*** (4.004)	15.313*** (4.291)	14.935*** (4.042)	14.873*** (4.023)	14.866*** (4.030)
gas_conso_pj	−0.542*** (0.198)	−0.562*** (0.190)	−0.561*** (0.183)	−0.470*** (0.180)	−0.558*** (0.185)	−0.559*** (0.183)	−0.562*** (0.185)
hydro_conso_pj	−1.056 (1.130)	−1.184 (1.218)	−0.962 (1.130)	−1.106 (1.210)	−1.024 (1.172)	−0.957 (1.124)	−0.964 (1.132)
oil_conso_pj	−0.699 (0.602)	−0.779 (0.529)	−0.811 (0.542)	−0.835 (0.537)	−0.814 (0.546)	−0.814 (0.546)	−0.816 (0.548)
renewables_pj	−2.772** (1.202)	−2.950** (1.155)	−2.801** (1.138)	−3.015*** (1.125)	−2.827** (1.162)	−2.799** (1.137)	−2.806** (1.139)
japan:gdp_billion	0.883** (0.434)						
japan:pop	59.143 (213.766)						
japan:elect_twh	−13.712** (5.581)						
japan:gas_conso_pj	0.728*** (0.218)						
japan:hydro_conso_pj	1.436 (1.381)						
japan:oil_conso_pj	0.803 (0.563)						
japan:renewables_pj	3.095*** (0.520)						
russia:gdp_billion		−0.940 (0.631)					
russia:pop		9.978 (63.780)					
russia:elect_twh		−16.286*** (4.553)					
russia:gas_conso_pj		0.702*** (0.206)					
russia:hydro_conso_pj		0.175 (1.070)					
russia:oil_conso_pj		0.795 (0.595)					
russia:renewables_pj		−1.187 (2.110)					
safrica:gdp_billion			4.093*** (1.190)				
safrica:pop			−62.289** (24.402)				
safrica:elect_twh			−2.747 (7.308)				
safrica:gas_conso_pj			−2.990 (2.730)				
safrica:hydro_conso_pj			−13.259*** (1.846)				
safrica:oil_conso_pj			−1.518** (0.670)				
safrica:renewables_pj			1.406 (1.219)				
germany:gdp_billion				−0.205 (0.457)			
germany:pop				306.566** (142.731)			
germany:elect_twh				−2.434 (3.927)			
germany:gas_conso_pj				−0.641*** (0.237)			
germany:hydro_conso_pj				5.277** (2.276)			
germany:oil_conso_pj				0.739 (0.623)			
germany:renewables_pj				2.041* (1.045)			
skorea:gdp_billion					−3.644** (1.737)		
skorea:pop					396.818*** (150.950)		
skorea:elect_twh					−0.474 (3.846)		
skorea:gas_conso_pj					0.273 (0.276)		
skorea:hydro_conso_pj					−2.815* (1.642)		
skorea:oil_conso_pj					0.617 (0.616)		
skorea:renewables_pj					0.998 (1.530)		
poland:gdp_billion						−1.670 (0.824)	
poland:pop						−279.270 (200.152)	
poland:elect_twh						−8.552 (7.001)	
poland:gas_conso_pj						−0.544 (0.910)	
poland:hydro_conso_pj						9.231 (5.791)	
poland:oil_conso_pj						1.376*** (0.383)	
poland:renewables_pj						3.502 (1.201)	
australia:gdp_billion							1.705 (5.582)
australia:pop							−153.749 (374.607)
australia:elect_twh							−5.973 (7.931)
australia:gas_conso_pj							0.210 (0.212)
australia:hydro_conso_pj							−0.800 (0.654)
australia:oil_conso_pj							0.131 (1.069)
australia:renewables_pj							1.303 (1.316)
Observations	1,268	1,268	1,268	1,268	1,268	1,268	1,268
R^2	0.911	0.909	0.907	0.912	0.907	0.907	0.907
Adjusted R^2	0.904	0.902	0.900	0.905	0.900	0.900	0.900
F Statistic	854.995*** (df = 14; 1172)	840.549*** (df = 14; 1172)	818.558*** (df = 14; 1172)	870.647*** (df = 14; 1172)	821.144*** (df = 14; 1172)	818.528*** (df = 14; 1172)	819.047*** (df = 14; 1172)

Note: Standard errors in parentheses. *p ¡ 0.1, **p ¡ 0.05, ***p ¡ 0.01

Table 17: Coal energy demand log-log (rest)

	Dependent variable: log_coal_conso_pj						
	Japan	Russian Federation	South Africa	Germany	South Korea	Poland	Australia
log_gdp	0.508 (0.511)	0.553 (0.516)	0.547 (0.511)	0.526 (0.507)	0.518 (0.503)	0.499 (0.509)	0.513 (0.509)
log_pop	2.133*** (0.652)	1.948*** (0.699)	1.840*** (0.698)	1.964*** (0.687)	1.953*** (0.681)	1.987*** (0.699)	1.990*** (0.703)
log_elect_twh	1.076*** (0.159)	1.097*** (0.164)	1.123*** (0.166)	1.093*** (0.164)	1.083*** (0.164)	1.117*** (0.167)	1.075*** (0.160)
log_gas_conso_pj	−0.206*** (0.066)	−0.197*** (0.061)	−0.200*** (0.064)	−0.196*** (0.061)	−0.197*** (0.062)	−0.198*** (0.062)	−0.195*** (0.060)
log_hydro_conso_pj	0.128* (0.073)	0.122* (0.073)	0.130* (0.076)	0.126* (0.073)	0.131* (0.073)	0.126* (0.073)	0.126* (0.072)
log_oil_conso_pj	0.092 (0.311)	−0.015 (0.321)	−0.014 (0.319)	0.016 (0.317)	0.017 (0.317)	−0.009 (0.317)	0.032 (0.322)
log_renewables_pj	0.017 (0.025)	0.011 (0.025)	0.009 (0.025)	0.012 (0.025)	0.009 (0.025)	0.012 (0.025)	0.011 (0.025)
japan:log_gdp	−2.241* (1.291)						
japan:log_pop	−9.033 (5.789)						
japan:log_elect_twh	0.816 (0.909)						
japan:log_gas_conso_pj	0.810*** (0.247)						
japan:log_hydro_conso_pj	−0.142 (0.123)						
japan:log_oil_conso_pj	−0.182 (0.361)						
japan:log_renewables_pj	0.576*** (0.177)						
russia:log_gdp		−0.418 (0.728)					
russia:log_pop		4.918 (3.419)					
russia:log_elect_twh		0.570 (1.307)					
russia:log_gas_conso_pj		−0.513 (0.612)					
russia:log_hydro_conso_pj		0.058 (0.172)					
russia:log_oil_conso_pj		0.391 (0.590)					
russia:log_renewables_pj		0.082** (0.042)					
safrica:log_gdp			−0.413 (0.623)				
safrica:log_pop			2.713** (1.126)				
safrica:log_elect_twh			−0.281 (0.444)				
safrica:log_gas_conso_pj			0.248*** (0.085)				
safrica:log_hydro_conso_pj			−0.179** (0.082)				
safrica:log_oil_conso_pj			−1.256*** (0.384)				
safrica:log_renewables_pj			−0.011 (0.042)				
germany:log_gdp				−0.273 (0.566)			
germany:log_pop				10.291** (3.206)			
germany:log_elect_twh				0.850* (0.451)			
germany:log_gas_conso_pj				−0.868*** (0.197)			
germany:log_hydro_conso_pj				0.116 (0.122)			
germany:log_oil_conso_pj				−0.983*** (0.330)			
germany:log_renewables_pj				−0.026 (0.070)			
skorea:log_gdp					−2.209** (1.003)		
skorea:log_pop					2.168 (2.345)		
skorea:log_elect_twh					0.031 (0.964)		
skorea:log_gas_conso_pj					0.302 (0.222)		
skorea:log_hydro_conso_pj					-0.087 (0.087)		
skorea:log_oil_conso_pj					0.302 (0.409)		
skorea:log_renewables_pj					0.232*** (0.064)		
poland:log_gdp						0.847 (0.553)	
poland:log_pop						1.965 (3.705)	
poland:log_elect_twh						−0.495* (0.300)	
poland:log_gas_conso_pj						0.549** (0.225)	
poland:log_hydro_conso_pj						0.094 (0.081)	
poland:log_oil_conso_pj						−0.341 (0.365)	
poland:log_renewables_pj						−0.088* (0.051)	
australia:log_gdp							1.776 (2.321)
australia:log_pop							−2.813 (2.796)
australia:log_elect_twh							0.285 (0.661)
australia:log_gas_conso_pj							−0.128 (0.258)
australia:log_hydro_conso_pj							−0.216** (0.103)
australia:log_oil_conso_pj							−1.057** (0.502)
australia:log_renewables_pj							−0.031 (0.131)
Observations	1,268	1,268	1,268	1,268	1,268	1,268	1,268
R^2	0.444	0.425	0.428	0.426	0.426	0.425	0.425
Adjusted R^2	0.399	0.379	0.382	0.379	0.380	0.379	0.379
F Statistic (df = 14; 1172)	66.783***	61.924***	62.634***	62.082***	62.164***	61.915***	61.938***

Note: Standard errors in parentheses. *p ¡ 0.1, **p ¡ 0.05, ***p ¡ 0.01