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The mechanism of the power shortage in China: capacity shortage or capacity underutilisation?

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Abstract

This paper investigates the mechanism of the power shortage in China by estimating the capacity expansion and capacity utilisation behaviour of the power firms. The theoretical and empirical evidence is presented to show that the state planner deals with the 'coal-electricity' conflict by internalising the coal price inflation in the power generation sector. This policy may distort the market signal of the capacity utilisation and lead to the power shortage even if the capacity supply is sufficient.

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1. Introduction

Over the last three decades, China has made a great development in the power generation sector, with more than 10% average annual growth in both the capacity supply and the electricity output (Zhang, 2010). Despite of this remarkable achievement, China's power supply swings from surplus to shortage from time to time (Kroeber et al., 2008; Wu, 2011). In 2008, China experienced a great nation-wide power shortage, which is contradicted to the traditional acknowledge on the 'economic calculation problem' of the planned economy[1]. This power shortage happened when the capacity utilisation was lower than the long-run average level by around 8%. According to the past experiences, this capacity under-utilisation suggests that the capacity supply should have been sufficient in response to the market demand. Therefore, this distinguishing phenomenon in recent years motivates us to undertake this study to investigate the distortion in the capacity utilisation and also the mechanism of power shortage of the partially reformed electricity industry in China. We analyse this problem from the point of view of the capacity expansion and capacity utilisation behaviour of the power firms with the discussion of the 'coal-electricity' conflict.

2. The Capacity Expansion and Capacity Utilisation Behaviour of the Power Firms and the Derivation for the Empirical Models

First, we assume to observe an actual capacity of power firms K_t^e that equals to the optimum capacity supply of power firms $K_t^{e^*}$ at time *t*. The current capacity supply of power firms K_t^e can either grow from the previous K_{t-1}^e to the optimum capacity $K_t^{e^*}$ or to a new level diverts from the optimum level. This growing process can be described by the adjustment function as follows:

$$K_t^e = \left[\frac{K_t^{e^*}}{K_{t-1}^e}\right]^\lambda \cdot K_{t-1}^e \qquad \text{………………………………} (1.1)$$

, where λ is the growing-adjustment coefficient that is measuring the divergence of the actual capacity supply from the optimum status. When $\lambda = 1$, the capacity grows to a level where $K_t = K_t^{e^*}$. When $\lambda = 0$, K_t remains as same as the past K_{t-1}. When $0 < \lambda < 1$, the capacity grows from the past to a new level that diverts from the optimum point.

The actual output of electricity production Q_t^e is the result of the total capacity supply available for production K_t^e and the utilisation of the total available capacity supply u_t^e: $Q_t^e = u_t^e K_t^e$. So it gives us the following equation:

$$\frac{K_t^e}{K_{t-1}^e} = \left[\frac{K_t^{e^*}}{Q_{t-1}^e}\right]^\lambda \cdot {u_{t-1}^e}^\lambda \text{……………………………………} (1.2)$$

The capacity utilisation u_t^e reflects the current power demand, where a higher u_t^e implies the incumbent capacity supply may not be sufficient for the growing market demand. If the lagged capacity utilisation have a positive impact on the long-run capacity expansion $\frac{K_t^e}{K_{t-1}^e}$, it

[1] The Annual Electricity Monitoring Report of China, 2009. State Electricity Regulatory Commission of China, pp. 15-17; The Annual Industrial Report of China: The Electricity Industry, 2009. China Economic Information Network, pp. 49-50.

means that the current institutional settings can stimulate the more capacity investment in response to the current tight power supply.

Second, we look into the optimum capacity K_t^{e*} . We assume that the state promotes the capacity supply of power generation by setting up a plan electricity price for the power firms to cover the capital cost of their new investment. Then, the power firms can choose their optimum capacity investment at the point, where the additional capital cost of increasing the capital supply equals the additional revenue that it can generate (Hay & Morris 1991, pp. 438):

$$c_t^e \, dK_t^e = p_t^e \, dQ_t^e \qquad \text{……………………………. (2.1)}$$

, where c^e is the cost of capital of the power firm; p^e is the plan electricity price for the power firms to sell their outputs to the girds companies; dK^e is the additional capacity supply of the power firms; dQ^e is the additional outputs of the electricity production. We manipulate this equation and can get:

$$\frac{dQ_t^e}{dK_t^e} = \frac{c_t^e}{p_t^e} \qquad \text{………………………………. (2.2)}$$

By taking the derivative of the Cobb-Douglas production with respect to K^e, it can give us the following equation:

$$\frac{dQ_t^e}{dK_t^e} = \alpha A {K_t^e}^{\alpha-1} {L_t^e}^{\beta} = \alpha \frac{Q_t^e}{K_t^e} \qquad \text{………………………………… (2.3)}$$

, where α is the elasticity of output with respect to capital supply. If we assume that there is no significant change in the electricity production techniques, then α can be seen as a constant. We link the equation (2.2) and (2.3) together and it gives us:

$$\frac{c_t^e}{p_t^e} = \alpha \frac{Q_t^e}{K_t^e} \qquad \text{…… …………………...... (2.4)}$$

Therefore, the desired optimum capital supply of the power firms K_t^{e*} can be seen as the function of the electricity output Q_t^e and the relative electricity price to the capital cost of the additional investment $\frac{p_t^e}{c_t^e}$:

$$K_t^{e*} = \alpha \frac{Q_t^e p_t^e}{c_t^e} \qquad \text{……………………………………… (2.5)}$$

Third, we look into the electricity output Q_t^e. In line with the view by Kornai (1992) in terms of the centrally planned economy, we assume that the state planner intervenes in the coal price setting to maximise the total energy output to satisfy the market energy demand. The total energy output Q_t is the sum of the coal output Q_t^c and the electricity output Q_t^e:

$$Q_t = Q_t^c + Q_t^e \qquad \text{…………………………….. (3.1)}$$

Since the coal supply is partially-liberalised, it's expected that a higher average coal price p_t^c can stimulate the coal firms to produce more coal output Q_t^c. Since the electricity production is a very important driver of the coal consumption, it links electricity output Q_t^e with the coal output Q_t^c. So it gives $Q_t^c = Q_t^c(Q_t^e, p_t^c)$, where it has the property of $\frac{dQ_t^c}{dp_t^c} > 0$ and $\frac{dQ_t^c}{dQ_t^e} > 0$.

Although the electricity price is still controlled by the state, the power firms have the autonomy to decide their own investment strategy. The higher plan on-grid electricity price can stimulate the power firms to expand their capacity supply and then the total output of electricity. So it gives $Q_t^e = Q_t^e(p_t^e)$, where $\frac{dQ_t^e}{dp_t^e} > 0$.

Therefore, the equation (3.1) can be transformed into:

$$Q_t = Q_t^c[Q_t^e(p_t^e), p_t^c] + Q_t^e(p_t^e) \quad \text{………………….. (3.1)}$$

Since the coal is a 'strategic resource' for the electricity production in China, the state planner attempts to promote the coal output to sustain the sufficient electricity output. So, it has the property of $\frac{dQ_t^c}{dQ_t^e} > 0$. However, the relationship between the input coal price and the electricity output depends on the state planner's policy. If the state planner attempts to supress the coal price to stimulate more electricity output, this relationship is negative. So, it has the property of $\frac{dQ_t^e}{dp_t^c} < 0$. If the state planner attempts to pass coal price inflation to downstream industries through the power firms, then this relationship can be positive, where $\frac{dQ_t^e}{dp_t^c} > 0$. Therefore, the equation (3.1) can be augmented as:

$$Q_t = Q_t^c[Q_t^e(p_t^e, p_t^c), p_t^c] + Q_t^e[Q_t^c(p_t^c), p_t^e, p_t^c] \quad \text{.................….. (3.2)}$$

The opposite effect of the coal price inflation on the coal output and electricity output represents the so-called 'coal-electricity conflict'. In order to balance this conflict, the state intervenes in the coal price setting to arrive at an average coal price p_t^c to maximise the total output of the coal output and electricity output:

$$\frac{dQ_t}{dp_t^c} = \frac{\partial Q_t^c}{\partial Q_t^e}\frac{dQ_t^e}{dp_t^c} + \frac{\partial Q_t^c}{\partial p_t^c} + \frac{\partial Q_t^e}{\partial Q_t^c}\frac{dQ_t^c}{dp_t^c} + \frac{\partial Q_t^e}{\partial p_t^e}\frac{dp_t^e}{dp_t^c} + \frac{\partial Q_t^e}{\partial p_t^c} = 0$$

We manipulate it and get: $-\left[\frac{\partial Q_t^e}{\partial p_t^c}\frac{p_t^c}{Q_t^e}\right]\frac{Q_t^e}{p_t^c} = \frac{\partial Q_t^c}{\partial Q_t^e}\frac{dQ_t^e}{dp_t^c} + \frac{\partial Q_t^c}{\partial p_t^c} + \frac{\partial Q_t^e}{\partial Q_t^c}\frac{dQ_t^c}{dp_t^c} + \frac{\partial Q_t^e}{\partial p_t^e}\frac{dp_t^e}{dp_t^c}$

Then the electricity output becomes:

$$Q_t^e = \frac{\sigma}{\varepsilon} p_t^c \quad \text{…………………………………. (3.3)}$$

, where $\varepsilon = \frac{\partial Q_t^e}{\partial p_t^c}\frac{p_t^c}{Q_t^e}$, $\sigma = \rho - \frac{\partial Q_t^c}{\partial Q_t^e}\frac{dQ_t^e}{dp_t^c}$ and $\rho = -\left[\frac{\partial Q_t^c}{\partial p_t^c} + \frac{\partial Q_t^e}{\partial Q_t^c}\frac{dQ_t^c}{dp_t^c} + \frac{\partial Q_t^e}{\partial p_t^e}\frac{dp_t^e}{dp_t^c}\right]$

ε is the price elasticity of the electricity output with respect to the coal price, which reflects how the state planner intervenes in the coal price settings to balance the conflict between the coal supply and the electricity supply. If the elasticity is highly negative, the state planner chooses to suppress the coal price inflation to stimulate more electricity output, which implies a positive σ in equation (3.3). The positive sign of σ may appear if the absolute value of ρ is smaller than the combined effect of the marginal coal output and the reduced coal price to stimulate the electricity output ($\frac{dQ_t^e}{dp_t^c} < 0$). When the marginal output of the coal with respect to the electricity is high and positive, the relationship between the electricity output and the coal price can be negative. In this case, it means that the coal output relies heavily on the electricity output so that a lower coal price can stimulate the power firms to produce more electricity and then demand for more coal output. So, in the long run, this policy will have a

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long-run effect on stimulating more capacity investment K_t^e into the power generation sector and also a short-run effect on encouraging higher utilisation u_t^e of the incumbent capacity supply. However, the state may also choose to stimulate more coal output by passing the coal price inflation on to the power firms. In this case, the coal production doesn't heavily rely on the electricity production so that a high coal price can still be sustained. The high coal price may lead to the losses of the power firms and discourage the electricity output. In order to encourage the electricity production, the state planner can choose to set up a plan electricity price for the power firms to pass though their fuel inflation to the downstream industries. If the state planner chooses to fully absorb the coal price inflation into the on-grid electricity price, then the electricity price can be very responsive to the coal price ($\frac{dp_t^e}{dp_t^c} \geq 1$). This solution for the coal-electricity conflicts will protect the economic benefits for the coal suppliers and power firms at the expense of the welfare of the downstream energy consumers. In this case, the elasticity ε can be positive, where the relationship between the electricity production and coal price can be positively. By taking consideration of the public interest, the state planner may choose to internalise the coal price inflation in the power generation sector by controlling the electricity price inflation, then the electricity price will be less responsive to the coal price, where $0 < \frac{dp_t^e}{dp_t^c} \leq 1$. In this case, the elasticity ε turns to be weakly negative, since the marginal fuel cost may exceed the electricity price so that the cost inefficient small-sized power firms may face losses and then shut down. The value of the elasticity depends on the degree of internalising the coal price inflation in the power generation sector.

We substitute the equation (3.3) into (2.5) and get:

$$K_t^{e*} = \alpha \frac{\frac{\sigma}{\varepsilon} p_t^c p_t^e}{c_t^e} \text{ .... } (4.1)$$

Or in a non-linear form the above can be transformed into:

$$K_t^{e*} = \frac{{p_t^c}^{\sigma/\varepsilon} {p_t^e}^{\alpha}}{c_t^e} \text{ .... } (4.2)$$

We substitute the equation (4.2) back to (1.2) and get:

$$\left[\frac{K_t^e}{K_{t-1}^e}\right] = {p_t^e}^{\alpha\lambda} \cdot \left[\frac{p_t^c}{p_{t-1}^c}\right]^{\alpha\lambda(\sigma/\varepsilon)} \cdot {c_t^e}^{-\alpha\lambda} \cdot {u_{t-1}^e}^{\lambda} \text{ .... } (5.1)$$

, where $\frac{K_t}{K_{t-1}}$ represents the capacity expansion and can be denoted as ΔK_t ; $\frac{p_t^c}{p_{t-1}^c}$ represents the coal price inflation and can be denoted as Δp_t^c. Again, we add up other control variables on the capacity expansion and test their effect on stimulating the power firms to increase their long-run supply capabilities:

$$\Delta K_t = {p_t^e}^{\alpha\lambda} \cdot {p_t^g}^{\psi} \, {\Delta p_t^c}^{\alpha\lambda(\sigma/\varepsilon)} \cdot {c_t^e}^{-\alpha\lambda} \cdot {w_t^e}^{\kappa} \cdot {u_{t-1}^e}^{\lambda} \cdot {l_t^e}^{\xi} \cdot {s_t}^{\tau} \cdot {g_t}^{\phi}$$

, where p_t^g represents the end electricity price of the grids selling the electricity to the end users; w_t^e represents the wage; l_t^e represents the population; s_t represents the industrial value-added percentage out of the real GDP; g_t is the real GDP that represents the market demand for energy. Since it may take two years on average to complete the construction of a new power plant, we lag the explanatory variables for two years. By taking the natural logarithm, the equation (5.1) can be transformed into the linear form as below:

$$ln\Delta K_t = \hat{\alpha} + \hat{\beta} lnp_{t-2}^e + \hat{\psi} lnp_{t-2}^g + \hat{\zeta} ln\Delta p_{t-2}^c + \hat{\eta} lnc_{t-2}^e + \hat{\kappa} lnw_{t-2}^e + \hat{\lambda} lnu_{t-2}^e + \hat{\xi} lnl_{t-2}^e + \hat{\tau} lns_{t-2} + \hat{\phi} lng_{t-2} + \mu_t \quad \ldots\ldots (6)$$

, where $\hat{\alpha}$ is the constant; $\hat{\beta} = \alpha\lambda$; $\hat{\zeta} = \alpha\lambda(\sigma/\varepsilon)$; $\hat{\eta} = -\alpha\lambda$. Again, the cost of capital can be divided into two components, i.e. the depreciation rate d_t^e and the interest rate i_t^e. Therefore, Model 6 can be extended to:

$$ln\Delta K_t = \hat{\alpha} + \hat{\beta} lnp_{t-2}^e + \hat{\psi} lnp_{t-2}^g + \hat{\zeta} ln\Delta p_{t-2}^c + \hat{\eta}_1 lnd_{t-2}^e + \hat{\eta}_2 lni_{t-2}^e + \hat{\kappa} lnw_{t-2}^e + \hat{\lambda} lnu_{t-2}^e + \hat{\xi} lnl_{t-2}^e + \hat{\tau} lns_{t-2} + \hat{\phi} lng_{t-2} + \mu_t \quad \ldots\ldots (7)$$

Moreover, we test the capacity utilisation u_t^e with the same set of the explanatory variables as well. Since the capacity utilisation represents the short-run supply with the incumbent capacity, we take one year's lag for the explanatory variables as the instrument to avoid the endogenous problem. So, we have Model 8:

$$ln\Delta u_t = \hat{\alpha} + \hat{\beta} lnp_{t-1}^e + \hat{\psi} lnp_{t-1}^g + \hat{\zeta} ln\Delta p_t^c + \hat{\eta} lnc_t^e + \hat{\kappa} lnw_{t-1}^e + \hat{\lambda} lnK_{t-1}^e + \hat{\xi} lnl_t^e + \hat{\tau} lns_t + \mu_t \quad \ldots\ldots (8)$$

Similarly, we divided the cost of capital into the depreciation rate and interest rate and then we have Model 9:

$$ln\Delta u_t = \hat{\alpha} + \hat{\beta} lnp_{t-1}^e + \hat{\psi} lnp_{t-1}^g + \hat{\zeta} ln\Delta p_t^c + \hat{\eta}_1 lnd_t^e + \hat{\eta}_2 lni_t^e + \hat{\kappa} lnw_{t-1}^e + \hat{\lambda} lnK_{t-1}^e + \hat{\xi} lnl_t^e + \hat{\tau} lns_t + \mu_t \quad \ldots\ldots (9)$$

3. Empirical Results of the Capacity Expansion and Capacity Utilisation Model

The results of the empirical test on Model 6, 7, 8 and 9 are shown in Table 1 in the appendix[2].

(INSERT TABLE 1 HERE)

As shown in Table 1, the on-grid price of selling the electricity from the power firms to the grids has significantly positive impact on the capacity utilisation. It indicates that the higher on-grid price can stimulate the power firms to produce more output of electricity, which confirms our analysis in the above section. Unfortunately, we don't find the same effect in terms of the capacity expansion. The reason might be that the on-grid price includes the capacity tariff and the volume tariff, where the former one covers the capital cost of the power firms. So the capacity investment may be responsive to the capacity tariff rather than the on-grid price. This result is consistent with the findings of Zhao et al. (2012).

The end electricity price doesn't have any significant impact on either the capacity supply in the long-run or the capacity utilisation in the short-run. It indicates that the changes in the end

[2] The industrial non-financial data, including the installed capacity, the power consumption and the average annual operation hours of the generators, are collected from the Chinese Electric Power Yearbook 2007-2012, covering the period from 2006 to 2011. The electricity prices are collected from the Electricity Monitoring Annual Report 2006-2011, covering the period from 2006 to 2011. The industrial financial data are collected from China Industry Economy Statistical Yearbook 2007-2012, covering the same period. The combination of the two annual datasets provides a seven year's balanced panel of the aggregate data of 30 provinces except Tibet and Taiwan with 210 observations in total for estimating both the capacity expansion model and the capacity utilisation model.

electricity price cannot be fully transmitted back to the power firms through the plan on-grid price, since the state-owned monopolistic grids intervene in the deals between the power firms and power users. But through the dis-link of the two electricity prices, this intervention of the monopolistic grids in the electricity trade effectively reduces the volatile impact of the on-grid price on the downstream power demand.

The fuel price inflation is negatively related to both the long-run capacity supply and the short-run capacity utilisation. But the coefficient is only -0.104 in Model 6 and -0.082 in Model 9 respectively. It indicates that the state planner allows the coal price inflation and attempts to internalise it in the power generation sector by restricting the on-grid electricity price. This policy discourages further investment into the power generation sector, since the power firms fear that the coal price inflation may not be fully absorbed by the on-grid electricity price. Besides, this policy may immediately push some inefficient small-sized power firms out of the production schedule, since they are facing the losses due to the marginal fuel cost exceeding the capped plan price of selling the electricity to the grids. So, this "coal-price-inflation-internalising" policy may lead to the short-run power shortage even though the long-run capacity supply is sufficient.

The cost of capital is found to be negatively related to the capacity expansion rather than the capacity utilisation. It indicates that the high capital cost relative to the electricity price is a barrier to entry that can deter the power firms from making the long-run capacity investment decision. It implies that the "rate-of-return" pricing policy is important to promote the growth of the capacity supply in the power generation sector. But the capacity cost will not take any short-run effect on the utilisation rate of the incumbent capacity, since the capacity investment is a sunk cost incurred by the power firm's past decision.

The lagged capacity utilisation is found to be positively related to the capacity investment decision. It indicates that under the current institutional settings the power firms can respond to the market demand shocks by investing more capacity supply when the electricity supply tends to be tight. This is also confirmed by the positive effect of the real GDP, where an increase in capacity supply by 0.41% occurs in response to 1% increase in the real GDP. Unfortunately, we don't find any significant impact of the industrial value-added percentage out of the GDP on either the capacity expansion or the capacity utilisation. It implies that the recent global economic downturn has seriously stricken the industrial outputs and the industry-driven energy consumption pattern in China.

4. Conclusion

The state intervenes in coal price setting between the coal suppliers and the power firms to maximise the total output of the coal supply and the electricity supply. The state allows the coal price inflation to stimulate the coal production and internalises the coal price inflation in the power generation sector to compromise the public interests. This 'coal-price-inflation-internalising' policy to deal with the 'coal-electricity' conflict may influence the power firm's behaviour of producing the electricity and lead to the power shortage of capacity underutilisation.

Under the 'free-investment' policy, the power firms can decide their capacity investment in response to the capacity utilisation that measures the tightness of the electricity supply. It indicates that the power shortage of insufficient capacity is temporary, since new investment can be promptly attracted to supply more electricity output. This beats the conventional wisdom that the planned economy will always lead to severe chronic capacity shortages and rationing.

However, the ‘coal-price-inflation-internalising’ policy adopted by the state planner intensifies the so-called ‘coal-electricity’ conflict. Since coal price inflation is partially absorbed in the electricity price, the cost inefficient power firms can be immediately driven out of the production schedule and the small-sized investment may also be deterred. The ‘coal-electricity’ conflict not only leads to the short-run under-utilisation of the incumbent capacity supply, but also distorts the market signal of the capacity utilisation for the long-run investment decision.

Apparently, the power shortages in China are mixed by the capacity shortage and the capacity under-utilisation. The power shortage due to capacity under-utilisation can only be solved when the state planner adopts proper policy to address the ‘coal-electricity’ conflict.

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Appendix

Table 1. Estimated results of Model 6-9

		$ln\Delta K_t$			$ln\Delta u_t$	
		Model 6	Model 7		Model 8	Model 9
On-grid electricity price	lnp^e_{t-2}	0.317 (1.14)	0.378 (1.35)	lnp^e_{t-1}	**0.325**** **(2.50)**	**0.281**** **(2.07)**
End electricity price	lnp^g_{t-2}	-0.0875 (-0.23)	-0.0908 (-0.24)	lnp^g_{t-1}	-0.207 (-1.24)	-0.184 (-1.09)
Fuel price inflation	$ln\Delta p^c_{t-2}$	**-0.104*** **(-1.85)**	-0.0892 (-1.58)	$ln\Delta p^c_t$	-0.0701 (-1.54)	**-0.082** **(-1.75)**
Cost of capital	lnc^e_{t-2}	**-0.496**** **(-2.44)**		lnc^e_t	-0.0948 (-0.53)	
Depreciation rate	lnd^e_{t-2}		**-0.399**** **(-1.99)**	lnd^e_t		-0.153 (-0.82)
Interest rate	lni^e_{t-2}		**-1.768*** **(-1.92)**	lni^e_t		0.583 (0.84)
Wages	lnw^e_{t-2}	-0.0127 (-0.10)	-0.005 (-0.04)	lnw^e_{t-1}	-0.0469 (-0.75)	-0.0596 (-0.94)
Capacity Utilisation	lnu^e_{t-2}	**1.215***** **(3.44)**	**1.255***** **(3.57)**			
Capacity Supply				lnK^e_{t-1}	**-0.141**** **(-2.10)**	**-0.125*** **(-1.80)**
Population	lnl^e_{t-2}	0.343 (0.30)	0.464 (0.41)	lnl^e_t	-0.261 (-0.33)	-0.328 (-0.42)
Industrial Value-Added %	lns_{t-2}	-0.277 (-0.91)	-0.285 (-0.94)	lns_t	0.0327 (0.18)	0.026 (0.11)
Real GDP	lng_{t-2}	**0.418*** **(2.05)**	**0.413** **(2.03)**			
Constant		-1.644 (-0.90)	-1.934 (-1.05)		-0.600 (-1.04)	-0.517 (-0.89)
Observations		121	121		169	169
Mean VIF		2.54	2.45		2.41	2.34

Note: T-statistics in parentheses, * p<0.1, ** p<0.05, ***p<0.01; Both the individual and time dummies are added and the fixed effects estimation is performed for all models.