The Penetration of Small Scale Cogeneration Systems in Japanese Industry from 1985 to 1998

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ABSTRACT

It is essential to analyse what factors affect investment in cogeneration (CHP), a highly effective energy efficient technology with wide job creating effects and positive environmental outcomes; additionally CHP could increase the productivity of the national energy system considerably. The intention is to (1) identify the determinants of the installation of industrial CHP as well as obstacles in a historical setting; (2) briefly outline Japanese Government policy towards CHP; (3) use data on industrial electricity consumption, energy prices, steam demand (process heat capacity) and economic activity patterns across 7 industries to empirically validate the factors affecting CHP installations.

Site information on 1500 CHP sites was gathered and combined with industrial statistics for a 14 year span during which Japanese power markets underwent deregulation. The analysis of CHP should focus at the size of industrial sites in order to identify which plants adopted or may adopt such practice. The empirical analysis relies on the panel regression used for CHP capacity. For the 7 industries the findings confirm that CHP has replaced steam capacity; that purchased (grid) power increased CHP as this magnifies power sales from the latter; that electricity to gas price changes increase energy costs and are also an incentive for CHP; and that value added effects, reflecting manufacturing activity, increase demand for energy services and thereby for CHP.

Introduction

Under current practice the production heat and power as well as cooling increase energy waste, causing energy expenditures by the national economy to remain high, misallocating human and other economic resources and maintaining strong dependence on foreign sources of oil. CHP bears the potential to decrease those effects by increasing total national energy efficiency and thereby productivity. CHP is the simultaneous production of electrical energy and hot water or steam for heating or cooling ends in industrial applications and approach 90% efficiency (Arthur D. Little, 1999), as compared to the separate production of power and heat.

This paper analyses the CHP industry through a panel data structure, in this case a cross section of industries over time, covering several heavy and light manufacturing industries. Analysis by sub industrial sector is needed in order to analyse investment in CHP systems given the major differences among industries. For instance, the iron and steel, chemicals and the paper and pulp sectors rely considerably on self-generation. These industries have sufficient recovered and waste heat from their production processes as well as available by-product fuel. In contrast, machineries and light industries hardly cogenerate or self-generate.

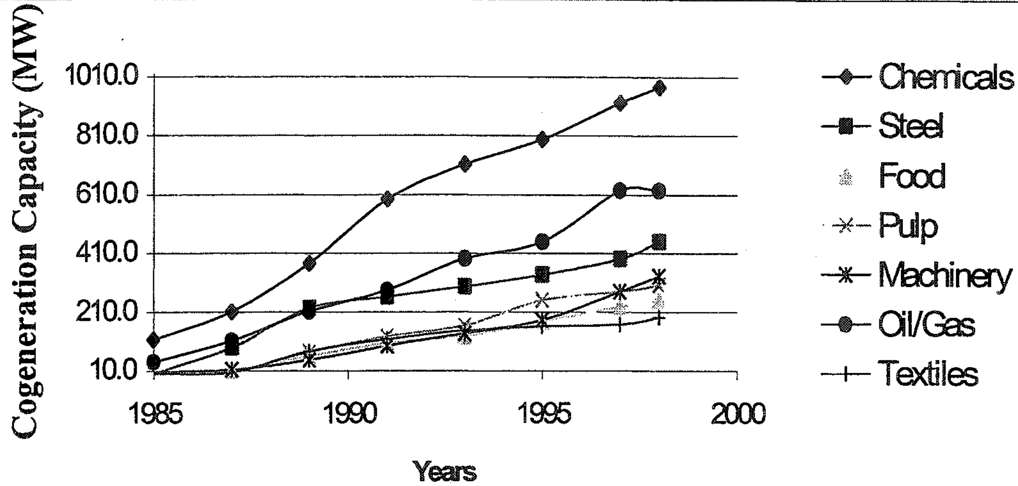

Figure 1. Cumulative Cogeneration Capacity in Selected Industries 1985-1998 (Excluding Steam Turbines and Back Pressure Turbines)

Although it would take several decades and substantial infrastructure investment, such as heat networks, before the total energy system in Japan is redesigned, some authors have suggested an option for saving energy such as energy cascading systems (involving energy sharing between the industrial and commercial sectors); model methodologies developed by (Shimazaki et al. 1997; Akisawa, Ito & Kashiwagi 1998), calibrate energy demand as determined by temperatures and then calculate how energy can be saved by integrating the systems by means of heat exchangers, CHP, and heat pumps; the driving variable is the impact of temperature differences across industries on the scope for energy efficiency and thereby CHP potentials. These models calibrate technical potentials and fail to analyse CHP in interaction with economic factors. Not one of the models discussed above have dealt with specific sub-industrial characteristics through time that affect the adoption of CHP.

The industries being investigated display different demands for electricity, process heat and energy as well as profitability, for instance the iron and steel sector requires high temperature steam, while food requires low temperature steam. The influence of process heat capacity, ratio of electricity price to gas price, consumption of power, power purchased, among others, on CHP is dealt with.

The paper proceeds first with the developments in industrial plants and steam generation facilities (classified by size of the site), second with CHP capacity additions in Japanese industry and developments in large conventional electrical capacity; and third, with the legal framework affecting CHP. Finally, the model methodology and the results of two CHP investment models are discussed.

The paper attempts to answer the following questions: What is the role of energy prices, such as the electricity to gas price ratio in the rate of investment in CHP? Has there been any substitution, if any, between the old boiler technology and CHP? How have each of the 7 industries that adopted CHP reacted in respect to changes to power demand, power purchased and value added? To what degree technical and economic factors across industries affected CHP penetration rates? In short the study also attempts to analyse the decision to adopt CHP within the dynamics of each industry's behaviour.

The Evolution of CHP

CHP trends are shown in Figure 1. It should be noted that the rapid rates of expansion of CHP coincide with the introduction of interconnection guidelines for cogenerators in 1986, see Figure. 2. The chemicals sector had the largest percentage share in 1998, followed by the oil and gas sector, which includes refineries, in turn followed by the iron and steel sector including non-ferrous metals.

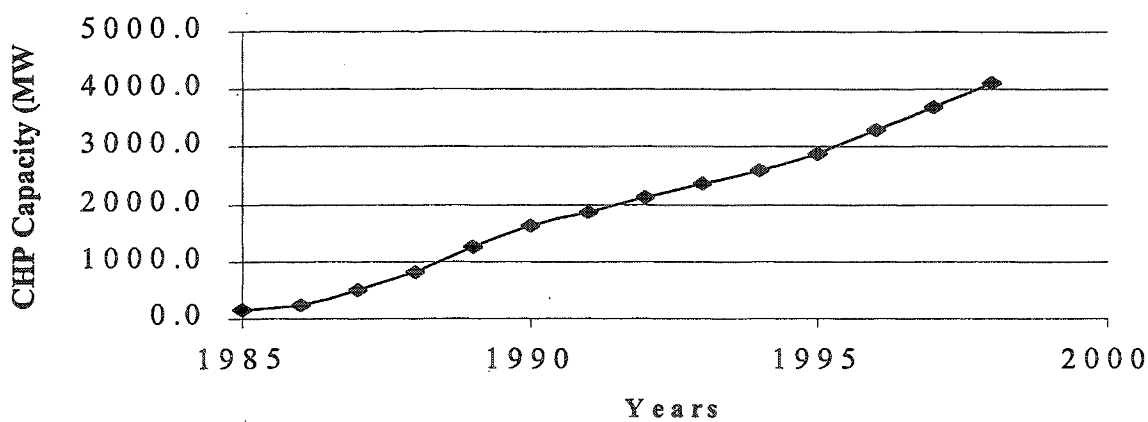

Figure 2. The Evolution of CHP (Cumulative Capacity) 1985-98.

The food sector was the fastest growing sector in 1985 through 1998 increasing its share to 8% of total installed CHP. Heavy industries such as the chemicals and refineries have seen a decline in their share from 60% and 34 % to 25% and 16% respectively in 1998.

Table 1 depicts capacity additions of various power generation technologies. Japanese industry seems to under-perform as far as installed CHP capacity when compared to the average in the OECD. Growth in CHP has outperformed the other technologies.

Most CHP capacity is installed in a fourth of the sites. The cumulative distribution depicted in Figure 3 gives an indication on the extent of the concentration of CHP capacity per number of sites. On the one hand this vintage represented only 2% of national electrical capacity. On the other hand, this vintage of CHP does not match conventional CHP which represents 4% of total power capacity. Conventional CHP is based on steam turbines and back pressure turbines. It should be noted that Figure 3 only includes modern CHP systems belonging to the non- traditional type. Time series for the traditional type are unavailable. The graph also reflects the overwhelming influence of the large industries such as chemicals, refineries, steel and pulp and paper. These industries account for most of the cumulative capacity. Around 320, 430 and 750 sites had an average CHP capacity of 9375, 1860 and 267 kW respectively, as seen in Figure 3.

Table 1. Capacity of Electric Power Generation in 1985-1998 by Technology Type (MW)

	1985	1998	Annual growth. % change
Nuclear	16,077	45,083	8
Thermal	96,613	132,925	2
Hydro	33,195	43,888	2
Subtotal	15,4329	222,393	3
Self-Generation			
Hydro	1142	1494	2
Thermal	13,762	26,129	5
Nuclear	165	165	flat growth
CHP (small systems)	186	3744.5	24

Source: EDMC (2000)

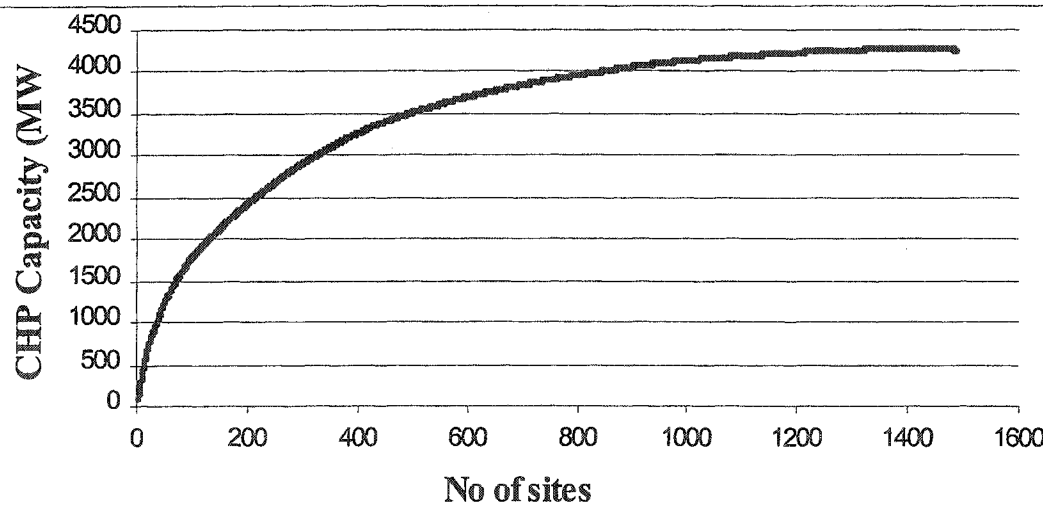

Figure 3. Distribution of CHP Capacity

The Role of Policy and Subsidy Allocation in CHP and IPP'S

Energy policy towards CHP technologies has evolved as follows:

- In 1986 guidelines for interconnection of CHP systems were introduced;
- In 1988 tax concessions favouring CHP were introduced;
- IPP (independent power producers) were introduced in 1998;
- In 1995 the electric utility law came into effect, the intent is to allow new IPP'S to sell their power to the largest electric power companies. Some 6.4 GW of generation capacity were awarded to IPP's by electric power companies between 1986-1998, according to Nishimura (1998). The same author claims the following:
- Amendment of the law to stimulate retail competition between the major electric power companies (EPCO's) and IPP's to satisfy loads larger than 2 MW customer category

- From 2000 onwards it will be obligatory for the large (EPCO's), if planning acquisitions of thermal generation capacity, to engage into competitive bidding, including their own projects.
- Subsidies for the purchase of CHP systems amount to 15-30% and 15% of initial capital costs for the service and industrial sectors respectively. Although it is known that one large gas company offering CHP equipment provide additional discounts with the aim of gaining market share. Also uncertainty over nuclear power may boost the prospects for CHP in Japan.

Recent Trends in Steam Generation

As a steam producing technology CHP competes head to head with conventional boiler technology, to provide process heat for industrial needs. In what follows an analysis is made of developments in process heat boiler capacity during the 1985-1998 period in Japanese industry. The link between firm size and CHP ought to signal at what size (range) the typical firm is adopting CHP; future size reductions in CHP systems could involve even more industrial sites with lower heat and power demands (and smaller workforce). Any forecast on CHP would focus on this distribution.

Sites sized within 30-49 workers have retired boiler capacity the least; in contrast the 50-199-worker class of sites decreased capacity the most. Given the size of the CHP systems considered (average of 5731 kW and 1226 kW for gas turbines and diesel engines respectively), sites with an average process heat capacity in the 5-12 t/h range are the most likely groups to have adopted CHP, please see Table 2. The argument can be made that industries that showed a decline in conventional boiler capacity mirror increases in CHP capacity; therefore the larger the boiler capacity retirements (conventional type) in a given industry, other things equal, the larger the additions of CHP systems during the 1985-1998 period.

Table 2 depicts steam production according to firm size for two years. Virtually every single plant site category shows a decline in, steam capacity, t/h, between 1985-1998. According to the OECD (1999) firms between a 100-999 employees have managed to survive the two oil shocks and have outperformed the others, specially the category (300-999 workers), as far as value added, employment and labour productivity between 1986 and 1995. Thus it may be that industrial sites of sizes between 100-999 workers may have replaced boilers for CHP technology. Only 13% of industrial sites with process heat needs possess modern CHP systems, hence there is further scope for CHP. An econometric model incorporating the impact of boiler retirements and manufacturing value added and other variables on CHP growth is introduced below.

Data

Most of the data supporting the econometric estimation is published in EDMC & IEEJ (2000), except for CHP data which is found in two sources: MITI (1999) and the Cogeneration Research Centre (2000). Based on the available data it was decided to investigate 7 industries in combination, which are the most energy intensive and thus highly likely to adopt CHP. Process heat has declined during 1985 through 1995. Industry overall retired process heat capacity in the period reflecting partially the growth of CHP. CHP capacity is represented in terms of electrical capacity due to data constraints.

Table 2. Steam Generation for Process Heat in Japanese Industry in 1995

Factories classified per Workforce size	No. factories	Capacity	Average process heat per-site	Capacity retired[1]	CHP (000 kl)[2]
30-49	2,548	13,171	5	-638	24
50-99	3,599	21,846	6	-3,609	243
100-199	2,581	23,516	9	-2,769	692
200-299	1,029	12,500	12.	-1,896	540
300-499	820	13,018	16	-1,712	971
500-999	623	12,916	21	-1,803	1611
1000 and >	453	19,918	44	-1,485	1186
Total	11,653	116,885		-13,912	5268

Source: MITI (1997)
1 boiler capacity retired in 1985-1995; [2] Primary energy consumption of CHP

Data on CHP installations for pulp and paper, chemicals, iron and steel, oil and gas products, food and machineries and textiles was used based on approximately 1500 CHP sites. All CHP systems are based on gas turbines and diesel engine technology.

Model Methodology for the Analysis of CHP Growth

Cross sectional econometric work by (Rose and McDonald 1991; Dismukes and Kleit 1999) examined the cogeneration decision but no work so far has analysed sub industrial sectors across time, not to mention incorporating specific features across each of the industries that cogenerate.

Dismukes and Kleit (1999) have analysed the issue of CHP decisions using a binary model specification and found that the probabilities of on-site generation increase as power demand increases. For example some of the coefficients calculated provide useful insights on the impact of gas prices, buyback, fuel switching ability, electricity prices, steam capacity and temperature as well as plant hours and the related behaviour of industrial electricity demand on CHP. In a second model, in the ordered choice equation, based on a sample of industrial plants in the Louisiana region in the US, CHP was assumed to be determined by the same explanatory variables just mentioned, however, the objective was to model a broader series of on-site generation choices by industrial firms. Panel techniques have also been applied in the analysis of boiler stock in a case study in Switzerland (Carlevaro and Bertholet 2000)

Each CHP industrial group is changing its characteristics over time, while new plants are added and others retired. To understand the dynamics of CHP an empirical model and results are presented below. In the analysis of CHP, it is believed that there are 3 underlying substitution processes. The first is the impact on CHP of purchased power, equation 3; the second is the substitution of CHP for total power consumption, equation 4, and the third is the substitution of CHP for process heat capacity, again equations 3 and 4. These three processes may have taken place simultaneously during the 1985-1998 period. This model relies on panel data structures enabling to model differences in the investment in CHP technologies by the various industries considered, however these differences are unobserved and can be captured by differences in intercepts and slopes.

Under the fixed effects model (FE), if accepted, it implies that different intercepts are held constant for each industry as they adopt CHP technologies. The regressors are assumed to be correlated with the intercepts. If random effects apply (RE) the regressors and the intercept are uncorrelated. The pooled model, neglects panel structures, assumes that the long run elasticities of CHP capacity with respect to price ratio of electricity to gas, process heat capacity as well as value added, have equal impact across industries. A static model, based on panel data structure, to capture influences in CHP capacity is built as follows:

$$y_{it} = \alpha_i + \beta\ x_{it} + u_{it} \qquad (1)$$

where α_i industry effects which is taken to be constant over time and specific to the individual cross sectional unit i . β could be assumed to be constant across cogenerators in industry if $\beta_i = \beta_j$ or β_i. if $\beta_i \neq \beta_j$ slopes differ across cogenerators. The FE approach assumes α_i to be a group specific constant term in the regression model. If $\alpha_i \neq \alpha_i$ heterogeneous intercepts apply. The RE approach specifies α_i is a group specific disturbance similar to u_{it}, it assumes individual effects are uncorrelated with the regressors, unlike the fixed effects model. The intercept can be treated as random or fixed. However a Hausman test for model selection is useful in selecting whether the intercept is random or fixed. In the analysis of cogenerators one can view them as a set of influences outside the regression specific to that CHP capacity of industry *i.*

The changing intercept model can aid the analysis of CHP decisions as follows:

$$Let\ CHP_{it} = \mu + \beta_1\ x_{1it} \ldots + \beta_k\ x_{kit} + \mu_{it} \qquad (2)$$

where CHP is the logarithm of CHP capacity and $x_1 \ldots x_k$ are the logarithms of respective inputs. It is usually assumed that the effects of omitted variables are independent of x and are independently equally distributed. The downside is that (2) could be criticised for ignoring variables that mirror learning effects, managerial ability, energy intensities, access to capital, among firms or industries, these unobserved factors also could vary overtime. Industry or time specific effects could be explicitly modelled, however, this data is unavailable.

CHP Model Based on Panel Structure

Two panel CHP logarithmic regressions are run. The first concerns the analysis of cumulative CHP capacity, equation 3, inclusive of purchased power as explanatory variable, while the second deals with the added feature of total power consumption for the ith industry as an independent variable, equation 4. The models presented below aim to analyse the cumulative additions of CHP capacity and to extract the influences in the decision making of industry in the period 1985-1998.

CHP capacity in industry is expressed cumulatively, as higher heat output would reflect larger CHP capacity. The *CHP* variable is obtained by stacking capacity of each industrial site within each of the sub-sectors for each year. It was chosen to focus on the analysis of process heat generation and power demand since these are the most important factors inducing firms to adopt CHP. The double logarithmic specification should yield the long run elasticities of CHP in respect to the explanatory variables such as purchased power.

Thus the econometric specification of CHP is:

$$ln\ (CHP_{IT}) = \hat{a}_i + \hat{a}_1\ ln\,(elec_{it}) + \hat{a}_2\ ln\,(tonh_{\ it}) + \hat{a}_3\ ln\,(egas_t) \qquad (3)$$

$$(+) \qquad (-) \qquad (+)$$

$$+\ ln(mava_{\ it}) + \ddot{e}\ t + \mathring{a}$$

$$(+) \qquad (+)$$

The signs in brackets below each of explanatory variables, in equation 3, show the expected direction of each coefficient. All variables vary overtime and across industries. Where: *CHP* is cumulative CHP capacity in industry *i*; in kW; *TONH*: process heat capacity in industry *i* ; measured in t/h, as in Dismukes and Kleit (1999); *ELEC*: purchased electricity in industry *i* measured in kWh; *MAVA* is an index of manufacturing value added in industry *i*; and *EGAS* is an electricity to gas price ratio and changes overtime but not across industries, these prices are indices of electricity and gas; *T* is time a proxy for technological improvement. Thus higher power consumption ought to favour CHP; while higher manufacturing activity requires greater power and heat, and hence, the higher the demand for CHP.

The relative price ratio should capture the impact of energy input prices on technology adoption as in Boyd and Karlson (1993) who investigated the impact of energy prices on technological change for the iron and steel sector. They found evidence of a change in adoption following electricity price changes however, the impact is lower should the decision require a major change in the production process. More recently, Newell, Jaffe and Stavins (1998) have analysed price impacts on technological improvement of air conditioning equipment. In addition the price ratio of electricity to fossil fuel prices places upward pressures on production costs and indicates the profitability of CHP installations (Strachan and Dowlatabadi 1999).

Interpretation of Results

Results for equation 3 are shown in Table 3.The FE coefficients computed are positive and statistically significant from zero, confirming the expectation namely that electricity to gas price ratio, electricity from the grid as well as value added should impact positively on capacity additions. The coefficient for purchased power turns out positive and it is the second most important factor in the determination of CHP based on its t-value. This could imply that CHP may export some of its electricity to the grid.

The parameter of value added is larger than 1 in both the pooled, ignores the panel structures, and in the FE models, reflecting increasing returns to scale. The relative energy prices parameter is lower in the fixed effects model than the pooled coefficient. Meanwhile the process heat capacity coefficient is negative for the fixed pooled effects indicating a strong substitution of CHP for conventional boiler capacity. A question that comes to mind is whether to select the random or the fixed effects model. Based on the highly significant Hausman test value, the fixed effect model is selected.

Table 3. Estimation Results of Cogeneration Supply Equations (dependent variable: log CHP[1]) based on Equation 3 for the Pooled and Fixed Effects

No. of equation	1	2
Modelling of constant	á $_i$ = á pooled	á $_i$ Fixed effects
Power Consumption	.177 (1.86470)	1.31 (2.41703)
Process heat Capacity	-.675 (-4.01)	-7.25 (4.83226)
Manufacturing Value added	-1.81 (-1.86908)	.503 (-.391845)
Electricity to gas price ratio	1.14 (2.06257)	.32 (.629592)
TIME	.30 (3.37642)	.169 (3.82219)
Adj. R^2	.55	.66
Observations	98	98
Hausman test p-value		(.000)[2]
F- test Ho:equal slopes and intercepts		6.1676 (.000)[2]

[1] t-values are in parenthesis
2 Probability value

CHP Model and Total Power Consumption

In the second stage of the analysis it was decided to incorporate the impact of total power consumption on CHP; the assumption is that electricity intensity of the various industries should correlate positively with CHP. The econometric specification stems from equation 3 but assumes that CHP is determined by total power consumption of industry, which includes both self-generated and purchased power.

$$ln\ (CHP_{IT}) = \text{á}_i + \text{â}_1\, ln\,(ipc_{it}) + \text{â}_2\, ln\,(tonh_{it}) + \text{â}_3\, ln\,(egas_t) \quad (+) \quad (-) \quad (+)$$

$$+ ln(mava_{it}) + \text{ë}\, t + \text{å} \quad (+) \quad (+) \qquad (4)$$

where IPC is the total power consumed in year t and various industries, including self-generated power. Table 4 shows regression results.

Table 4. Estimation Results of Cogeneration Supply Equations based on Equation 4 (dependent variable: log CHP[1]) for the Pooled and Fixed Effects

No. equation	1	2
Modelling of constant	$á_i = á$ pooled	$á_i$ Fixed effects
Total power consumption	-.078 (-.359767)	2.30 (3.04364)
Process heat capacity	0.640 (3.35145)	-6.22 (-4.11861)
Manufacturing Value Added	1.16 (-1.14552)	1.76 (1.68868)
Electricity to gas price ratio	1.16 (2.06670)	0.85 (1.61452)
TIME	.31 (9.45656)	.20 (6.02356)
$\bar{A}$dj. R^2	.53	.67
Observations	98	98
Hausman test p-value		(.000)[2]
F- test Ho:equal slopes and intercepts		7.70 (000)[2]

[1] t-values are in parenthesis
[2] probability value

Under the FE coefficients only three parameters were statistically significant: total power consumed, process heat capacity and time. Adding all 4 coefficients yields a negative impact on CHP. In contrast, under the absence of unequal intercepts and slopes, the pooled model, 3 variables are significant at 5 % and two below 10 % probability values. The FE model, in contrast to the pooled model, captures higher variation of CHP, with an Adj. R^2 of .66 against .55 respectively. Only two coefficients, *EGAS* and *IPC*, bear positive influences on CHP capacity additions, the others have a negative impact; equally the Hausman test indicates that the fixed effect model should be chosen.

Hypothesis Tests

Table 3 and 4 depict CHP F-tests results. All of the computed F-tests are statistically significant under the null hypothesis that intercepts do not vary by industrial CHP sub-sectors, thereby rejecting homogeneity across industrial cogenerators in both CHP equations 3 and 4.

Conclusions

The link between CHP and firm size indicates the typical site that adopted CHP. Small and medium size industrial sites, 100 to 999 workers, have been more active in the adoption of CHP. Only 13 % of industrial sites have adopted modern CHP systems, however, uncertainty over nuclear power targets may boost the prospects for CHP in the following years.

Panel data are useful in dealing with heterogeneity among industrial cogenerators. A panel CHP model is proposed to capture the effects of costs and technical variables using a double logarithmic specification. Sectoral data on process heat and power demand as well as economic activity was utilised to gauge their impact on the probability of adding CHP during the 1985-1998 period. The results confirm that relative price changes increase the probabilities of CHP installations; similarly process heat (boilers) capacity retirements is a key driver of CHP as the former are replaced with the latter. Purchased power supports the growth of CHP since interconnection plays an important role in the ability of plants to export power. Additionally power consumption in the 7 manufacturing industries examined conditions CHP instalments. Although Japanese industry has achieved considerable energy efficiency gains there is still scope for a larger share of CHP systems.

Any future forecast of CHP growth should investigate the sub-sectoral level of industry. Several tests established a link between the double logarithmic model of CHP capacity additions and the fixed effect model. Further evidence is required to establish whether there was strong substitution of new CHP systems for boiler capacity and whether purchased power acted as a lever for CHP.

The contention can be made that industries that showed a decline in conventional boiler capacity mirror CHP capacity additions; therefore the larger the boiler capacity retirements in a given industry, other things equal, the larger the additions of CHP systems during the period considered. Further investigation should focus on the analysis of CHP capacity on the basis of heat capacity, heat to power ratio and specific plant prices. Energy policy efforts ought to focus on the gradual phasing out of boilers and on the intensive introduction of CHP.

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