Economies of scale in power generation, transmission and distribution: integration or unbundling?

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Common Belief in Power Sector Reform

- Since the mid-1980s, many countries has adopted the unbundling and generation privatization policy.

- ADB (2000) *Developing Best Practices for Promoting Private Sector Investment in Infrastructure – Power*
  - "The power sector should be completely unbundled into separate generation, transmission, distribution…retailing sectors."
  - "Privatization should include the sale of power distribution utilities, as well as generation."
  - "Open access to transmission…wires…and the ability to trade power are critical."

Motivation of the Study

- Various experiences in developed countries with power-sector liberalized.
  - California electricity crisis in 2000
  - Setback of power markets in England and Wales

- Fundamental question:

  Whether unbundling is really suitable and feasible, particularly in the context of developing countries?

- Focus on a traditional issue about diseconomies of scale in each stage of power generation and distribution.
- Provide an empirical result with data from Vietnamese electricity industry and an implication from the viewpoint of double marginalization (Spengler, 1950).

Earlier Studies related to Vertical Integration in Electricity Industry

- Vertical integration economies
  - Economies of scope -- 42% efficiency gain of integration in US (Kwoka, 2002).
  - Allen-Uzawa Elasticity of Substitution -- separability hypothesis rejected in US (Lee, 1995).
  - Subadditivity test -- no evidence of subadditivity in US (Gilsdorf, 1995).
- Effects of power transaction mechanisms
  - Power market auction and transmission constraints (Leautier, 2001)
- Effects of power market structure
  - Market concentration in generation (Borenstein *et al.*, 2002)

Vertical Integration Economies

Sources of integration economies (Landon, 1983; Kwoka, 2002)

1. Internalization of externalities in planning and investment (location, timing and matching)
2. Reduction of the transaction costs (asset specific investment, contract costs) generated from information asymmetry
3. Reduction of the OM costs
4. Reduction of overhead costs by sharing labor
5. Saving of double monopoly markup

Earlier Empirical Studies on Economies of Scale in Electricity Industry

- Diminishing returns to scale (RTS) for US generation plants: 0.94-2.52 (Nerlove, 1963).
- RTS for Australian coal-fired power plants: 1.080 (Coelli, 1996).
- Degree of homogeneity for US steam generation plants: 1.267 (Hisnanick, Kymn, 1999).
- RTS for US steam generation plants: 1.06-1.56 (Kleit, Terrell, 2001).
- RTS for Swiss municipal distribution utilities: 1.02-1.10 (Fillippini, 1998).
- RTS for Swedish retail power distributors: 1.04-1.24 (Kumbhakar, Hjalmarsson, 1998).
- Decreasing marginal cost curve for US vertically integrated utilities (Berry, Mixon, 1999).

Vietnamese Electricity Industry

- Rapid increase in power demand: generated power 9,152 GWh in 1991; 30,608 GWh in 2001.
- A state-owned vertically integrated monopolist, Electricity of Viet Nam under the Ministry of Industry.
- 13 major generation plants; 4 transmission companies; 7 power distribution companies.
- Current restructuring policy:
  - Established the independent accounting system for each unit of generation plants and T&D companies

    ⇨ Corporatization and unbundling(?)
  - Integrating transmission companies.
  - Single buyer model ⇨ Retail liberalization

Econometrics and Data

- Production function estimation for power generation and distribution separately by SUR method (Hisnanick, Kymn, 1999).
- Flexible translog production function
- Assume that each unit maximizes its own output with respect to of inputs.
- Parameter restrictions: homogeneity and symmetry

$$\beta_{ij} = \beta_{ji}, \sum_{ij} \beta_{ij} = \sum_{ji} \beta_{ji} = 0, \sum_i \beta_{Ti} = 0, \sum_i \beta_{LF,i}$$

- Estimated returns to scale: $\Theta = \sum_i \beta_i$
- Originally collected in cooperation with EVN
- Period: 1995 to 2001

Production Function – Generation

$$\ln Y = \beta_0 + \sum_i \beta_i \ln X_i + \beta_T \ln T + \beta_{LF} LF + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln X_i \ln X_j + \beta_{TT} (\ln T)^2$$
$$+ \sum_i \beta_{Ti} \ln T \ln X_i + \beta_{LF,LF} (LF)^2 + \sum_i \beta_{LF,i} LF \ln X_i + TypeDummy + \varepsilon$$

$$S_i = \alpha_i + \sum_j \alpha_{ij} \ln X_j + \alpha_{Ti} \ln T + \alpha_{LF,i} LF$$

- 16 power plants
- Inputs: Labor(employee); Capital(installed capacity); Fuel(TJ equivalents)
  - *employee=plant-level personnel expenditure/Avg annual income* (1)

  (1) CEIC Data Company
- Output: Generated power (GWh)
- Type: Coal-thermal; Gas-turbine; Hydropower; Oil-thermal
- Load factor (Operational heterogeneity)

Production Function – Transmission and Distribution

$$\ln Y = \beta_0 + \sum_i \beta_i \ln X_i + \beta_T \ln T + \beta_{CU} \ln CU + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln X_i \ln X_j + \beta_{TT} (\ln T)^2$$
$$+ \sum_i \beta_{Ti} \ln T \ln X_i + \beta_{CUCU} (\ln CU)^2 + \sum_i \beta_{CUi} \ln CU \ln X_i + \beta_{TR} Transmission + \varepsilon$$

$$S_i = \alpha_i + \sum_j \alpha_{ij} \ln X_j + \alpha_{Ti} \ln T + \alpha_{CU,i} \ln CU$$

- 4 PTC and 7 PC
- Inputs: Labor; Capital(total length of transmission lines); Energy(received power in GWh)
- For cost share equation, assume that power is traded at a unique price, say 495 Dong/kWh [(2)].
  - [(2)] Wholesale price to domestic private power distributors
- Dummy for power transmission companies
- Number of retail customers (*economies of customer density*)

Estimation Results – Generation

Table 2: Production Frontier for Power Generation

Model	OLS	SUR	OLS	SUR
β_K	1.007	1.008	0.698	0.697
	(0.027)	(0.026)	(0.094)	(0.084)
β_L	0.040	0.039	0.345	0.346
	(0.044)	(0.042)	(0.115)	(0.103)
β_F	0.009	0.009	0.069	0.069
	(0.006)	(0.005)	(0.019)	(0.017)
β_{LF}	0.026	0.025	-0.057	-0.055
	(0.026)	(0.025)	(0.045)	(0.040)
β_T	2.086	2.086	5.651	5.640
	(0.106)	(0.101)	(0.226)	(0.202)
β_{GT}	-0.038	-0.043	0.356	0.348
	(0.145)	(0.139)	(0.109)	(0.098)
β_{HY}	0.316	0.322	3.523	3.537
	(0.148)	(0.141)	(0.819)	(0.734)
β_{OT}	0.070	0.069	0.072	0.069
	(0.076)	(0.073)	(0.060)	(0.053)
β_{KK}			0.093	0.092
			(0.037)	(0.033)
β_{LL}			0.013	0.011
			(0.025)	(0.023)
β_{FF}			-0.006	-0.006
			(0.001)	(0.001)

Model	OLS	SUR	OLS	SUR
β_{KL}			-0.052	-0.050
			(0.025)	(0.022)
β_{KF}			0.004	0.004
			(0.001)	(0.001)
β_{TT}			0.013	0.013
			(0.020)	(0.018)
β_{TK}			-0.012	-0.012
			(0.015)	(0.014)
β_{TL}			0.013	0.013
			(0.016)	(0.014)
$\beta_{LF,LF}$			-2.947	-2.943
			(0.208)	(0.186)
$\beta_{LF,K}$			0.230	0.229
			(0.061)	(0.054)
$\beta_{LF,L}$			-0.235	-0.234
			(0.061)	(0.055)
β_0	-0.053	-0.053	-1.389	-1.380
	(0.200)	(0.191)	(0.245)	(0.220)
Obs	103	103	103	103
R-Squared	0.9812	0.9812	0.9962	0.9962

Note that the dependent variable is the logarithm of generated power. The standard errors are shown in parentheses.

Estimation Results – Transmission and Distribution

Table 3: Production Frontier for Power Distribution

Model	OLS	SUR	OLS	SUR
β_K	0.029	0.029	-0.081	-0.044
	(0.011)	(0.010)	(0.207)	(0.173)
β_L	-0.025	-0.025	0.270	0.273
	(0.018)	(0.017)	(0.229)	(0.190)
β_E	0.987	0.984	0.826	0.791
	(0.007)	(0.006)	(0.166)	(0.138)
β_{TR}	-0.200	-0.155	-2.618	-1.877
	(0.179)	(0.169)	(3.409)	(2.834)
β_T	0.027	0.028	0.051	0.041
	(0.007)	(0.007)	(0.030)	(0.025)
β_{CU}	-0.024	-0.021	-0.360	-0.253
	(0.015)	(0.014)	(0.534)	(0.444)
β_{KK}			0.068	0.058
			(0.066)	(0.055)
β_{LL}			0.055	0.100
			(0.120)	(0.099)
β_{EE}			0.156	0.159
			(0.040)	(0.034)
β_{KL}			0.005	-0.016
			(0.073)	(0.060)
β_{KE}			-0.052	-0.031
			(0.032)	(0.027)
β_{TT}			-0.008	-0.001
			(0.013)	(0.011)
β_{TK}			-0.029	-0.039
			(0.017)	(0.014)
β_{TL}			0.064	0.075
			(0.023)	(0.019)
$\beta_{CU,CU}$			0.012	0.008
			(0.021)	(0.017)
$\beta_{CU,K}$			-0.006	-0.001
			(0.006)	(0.005)
$\beta_{CU,L}$			-0.014	-0.019
			(0.005)	(0.004)
β_0	0.203	0.182	2.414	1.654
	(0.135)	(0.127)	(3.328)	(2.767)
Obs	69	69	69	69
R-Squared	0.9983	0.9982	0.9988	0.9988

Note that the dependent variable is the logarithm of transmitted power. The standard errors are shown in parentheses.

Estimated Economies of Scale

- Generation: Significantly positive scale economies
- Distribution: Positive but statistically insignificant economies of scale

Table 4: Estimated Economies of Scale

	Returns to Scale
Generation	1.112 (0.033)
Transmission and Distribution	1.019 (0.036)

- Both stages are operating under increasing returns to scale.

→ A monopoly firm can generate (distribute) power more efficiently than one more firm does.

→ Those two monopolists should not be disintegrated (to avoid double monopoly markup).

Conclusion

- Given current technological conditions, both power generation and distribution operate under increasing returns to scale (initial stage of development).
- Both stages should be integrated under one entity.
- Limits of the model:
  - No claim about ownership: private or SOE.
  - Not estimating vertical integration economy itself, but following double marginalization model.
  - Questionable empirical model assumption: each unit maximizes his own profit with respect to labor, capital, fuel and energy.