Power Market Structure and Performance

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Abstract

Unbundling power generation, transmission, and distribution is not an end itself, but rather a means to achieve better performance. The key objective of the analytical framework of this paper is to explore the links between alternative market structures and performance (in terms of access, price, quality, and technical and financial performance). The results are crucial for providing policy advice, by offering alternative options to policy makers based on the lessons learned from the taxonomy of different market structures, tailored to different national contexts. The analysis is based on unique data, including a panel of 22 countries for the period beginning in 1989 and extending through 2009. The results of the analysis carried out for this study confirm the following conclusions for policy guidance on power market restructuring for developing countries.

First, unbundling delivers results in terms of several performance indicators when used as an entry point to implement broader reforms, particularly introducing a sound regulatory framework, reducing the degree of concentration of the generation and distribution segments of the market by attracting public and private players and private sector participation. Second, there seems to be a credible empirical basis for selecting a threshold power system size and per capita income level below which unbundling of the power supply chain is not expected to be worthwhile. Finally, partial forms of vertical unbundling do not appear to drive improvements, probably because the owner was able to continue exercising control over the affairs of the sector and hinder the development of competitive pressure within the power market.

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1. Introduction

The design of market structure is often the starting point for the overall reform in the power sector, having a major effect in shaping all other key decisions, including the design and structure of the contracts as well as the decisions on prices. Accordingly, market structure has a powerful influence on whether and to what extent the electricity sector can achieve improvements in performance.

About half of the 150 developing countries have embarked on reforming their power markets since the early 1990s in response to poor technical and financial performance and lack of public financing needed to expand power supply (Besant-Jones, 2006). Most of these countries have restructured their power supply arrangements by at least some or full vertical unbundling of generation, transmission and distribution. The remaining countries have retained the traditional structure of a full or partial vertically integrated monopoly, in some cases because they felt it impossible or undesirable to embark on any reform strategy that entails opening electricity production or sales to private participants. A new emerging trend in a few developing countries is to revert from an unbundled structure towards a vertically integrated one (Vagliasindi and Izaguirre, 2007).

1.1. What does theory suggest on the costs and benefits of alternative market structures?

The existing variety of power supply structures reflects differing views and a degree of theoretical ambiguity in the economic literature on the effectiveness of unbundling and competition in network industries on issues such as gains from competition versus economies of co-ordination in vertically integrated systems. In practice, the benefits of each reform and restructuring must more than compensate for the increase in transaction costs of unbundling vertically integrated systems.

The traditional economic arguments against unbundling power systems were based on the concepts of: i) electricity as a public good, as vertical integration will better ensure service reliability and uniform standards and procedure among interconnecting segments of the grid; ii) natural monopoly, as a means to avoid wasteful duplication of transmission and distribution (T&D) networks; iii) economies of scale, as horizontal integration supports the large size and capital requirement of efficient plants (hydro and coal base load plants), though such arguments were weakened when smaller combined cycle units became more cost effective; iv) economies of scope, as tight coordination (centralized investment and operation) translates into savings in metering, billing etc.; v) economies of transaction costs, due to reduced costs due to asset specificity and incompleteness of contracts; and vi) better management of investment and operational risks.

But these arguments might not hold in some country and power market conditions because they are based on specific underlying assumptions that are not valid in these conditions, including: i) a lower cost of capital for the power utility, ii) the creditworthiness of a power utility requires that it be the sole buyer of generated power, iii) third party access should be prevented to support cross-subsidies among consumers that are mandated under government policies, and iv) savings coming from competitive pressures (to reduce costs) are minor when compared to

economies of scale and scope. They ignore post-restructuring changes, including the introduction of new regulatory policies and market structures that can solve the “problem” of unbundling (but whose overall impact might go either way). For instance, whereas integration may increase retail market power, this may not be detrimental, preserving or even enhancing generation investment incentives (Dupuy, 2006). In practice, there may be trade-offs between these objectives in developing countries, notably between economic efficiency and social objectives, that could be useful to be incorporated into operational guidance.

An alternative view is based on financial risk management, rather than economic concepts, that an optimal degree of integration can exist. Such an optimal degree of integration (Chao, Oren and Wilson, 2005 and 2008) lies between total integration and total unbundling. The degree depends on the mutual interest of generators and retail services providers in mitigating “systemic” risks, through the provision of (physical and financial) reserves and contracting under unbundling. This view asserts that such risks were not sufficiently taken into account when unbundling began. Retail utilities need this integration even when the cost of energy is passed through because they continue to serve a large contingent of core customers – mostly residential and small consumers – who rely on inter-temporal smoothing of supply costs in their retail rates.

1.2 What does empirical evidence suggest on the costs and benefits of alternative market structures?

The economic literature reviewed above suggests that there were substantial vertical economies associated with networks. However, to date there is limited evidence on the (relative) success in the implementation of vertical unbundling and its links with enhanced investment (particularly in transmission) and ultimately the improvement of power utilities performance, particularly in the cases where short term privatization is out of the realm of possibilities.

The (relative) success needs to be assessed against the objectives of unbundling – which could have been to enhance transparency and governance, attract private sector investment, and/or to create a competitive market and ultimately its impact on performance. In some cases restructuring had the purpose of creating an enabling environment to attract private sector investment taking some level of market risks and/or commitments to efficiency improvements. Transferring to the private investor market risks requires greater transparency and predictability, which may be more difficult to obtain in a sector with an integrated monopoly power utility to which for example the private generator is obliged to sell.

Little analysis of empirical evidence about unbundling in power markets has been published, and this analysis is focused on economically advanced countries. Kwoka (2002) studied extensively the US system to measure economies of coordination between generation and distribution for about 150 US electric utilities with a wide range of size and degree of vertical integration that operate in regional power pools. He concluded that the least integrated distributors incur on average significantly higher total costs than the most integrated (6.27 cents/kWh versus 5.35 cents/kWh). But this difference increased markedly with utility size. The smallest utilities – which are nearer in size to utilities in developing countries – showed small diseconomies of coordination. The largest utilities showed very substantial economies of coordination (over a level of 50%). Two recent studies report much lower economies of vertical

integration. Nemoto and Goto (2004) estimate that the cost efficiency gain from vertical integration in the case of 9 Japanese utilities varies from 0.2% to about 3%. Jara-Diaz et al (2004) based on the sample of Spanish electricity utilities conclude that about 7% of costs can be saved from joint generation and distribution. Despite providing useful insights, these studies are not really relevant to developing countries, however, because of the large differences in economic conditions between advanced and developing countries.

Two recent studies expand the available empirical analysis of vertical unbundling. Arocena et al (2009) studied the economies of integration (economies of scale and of scope) for a group of 116 investor owned power utilities in the United States based on data for the year 2001. The results provided a reference for the expected cost of unbundling. They concluded that vertical integration provided a substantial and significant cost saving relative to vertical unbundling, and also that horizontal integration in the generation sector provided a further – but smaller – cost saving relative to horizontal unbundling. Taken together, global savings from integration amount to as much as 12.5% of costs for the sample average firm. This level indicates a level of anticipated gains needed to justify unbundling. Meyer (2010) applied a frontier benchmarking approach to measure the economies of scope between the vertical stages of electricity supply in the U.S. electric industry. The study concluded that the costs of separating the generation stage from networks and retail stages compared to integration is strongly related to the size of the utility. For the larger utilities in the sample, this type of separation lowers their overall costs because the gains exceed synergy losses, whereas for the smaller utilities this type of separation increases their overall costs. The threshold size that divides utilities whose costs decrease from those that increase is about 10,000 to 12,000 GWh of annual generation and distribution.

There is also some published evidence about the links between integrated power systems and country-level corruption for the EU. Both for the EU-15 member states and the NMS-10 member states, the more corrupt the countries the more likely they are to choose a weak unbundling regime, even though the results are stronger in the case of EU-15 member states (van Koten and Ortmann, 2007).

1.3 What do we know about the taxonomy of market structures?

The distinction between integration and unbundling of power supply arrangements is not clear cut in practice, as several different structures exist around the world:

- vertical unbundling without horizontal unbundling (but not the reverse);
- partial vertical unbundling (generation and transmission separated from distribution, generation separated from transmission and distribution, etc);
- full vertical and horizontal unbundling in generation (and integration of transmission & distribution);
- vertical unbundling in lesser forms than ownership unbundling, such as accounting, management, legal (holding company) unbundling;

- unbundling of retail supply from distribution, and then some re-integration of generation with supply for risk management, keeping transmission and distribution unbundled;
- unbundling of generation services in wholesale power markets.

In addition, unbundling can take lesser forms than full ownership unbundling that is discussed above. These forms include by legal/corporate means in holding companies, by internal management structure, and just by accounts. The conventional view is that the potential benefits from unbundling are greatest with full ownership unbundling, and that these benefits decline with lesser forms of unbundling. Where country and market conditions cannot support privatization of fully unbundled power suppliers in the highly sub-optimal environments found in many developing countries, other forms of unbundling and associated public-private participation have to be adopted as the best solutions in practice – even if second-best in theory.

The current distribution of power markets around intermediate structures between full integration and full unbundling suggests that there has not been a linear path to reform in practice. Instead, many developing countries may retain intermediate structures for foreseeable future. This possibility exposes a large gap in understanding about power market structures, since most theoretical work has focused on the two extreme structures and there is limited evidence on the impact of unbundling for developing countries. For instance, Nagayama (2007) finds that the introduction of IPPs contributes to lowering the industrial prices at least in some developing regions (ECA) whereas unbundling of generation from transmission increased industrial and residential prices in the same regions. Basically, it appears that unbundling in most developing countries is undertaken for reasons other than or in addition to the introduction of competition, which is the purpose generally advanced in the theoretical literature. One of the purposes of the proposed task is therefore to obtain a better understanding of these developments and the policy requirements for successful outcomes under the intermediate market structures in the economic, social and political conditions of developing countries. More detailed analysis is needed to better understand the costs and benefits of unbundling and the characteristics of well functioning unbundled power systems.

The rest of the paper is organized as follows. Section 2 will describe the methodology used in analyzing the data. Section 3 introduces the theoretical hypotheses that will guide the empirical analysis, whose results are reported in section 4. Section 5 concludes the paper and Section 6 presents new directions for future research.

2. Methodology

Jamasb et al. (2004) classified the approaches to analyzing electricity reforms into three broad categories: (i) econometric methods, (ii) efficiency and productivity analysis methods, and (iii) comparative case studies. They argue that econometric studies are best suited to the analysis of well-defined issues and the testing of hypotheses through statistical analysis of reform determinants and performance. Efficiency and productivity analyses are suitable for measuring the effectiveness with which inputs are transformed into outputs, relative to best practice.

Jamasb et al. (2004) also maintain that single or multi-country case studies are suitable when in-depth investigation or qualitative analysis is needed. Within this classification, our study well suits the first category.

Our study proposes an analytical approach to model market structure (M), together with ownership (O), regulation, (R) controlling for several variables, as determinants of performance across several indicators of performance (P), including access, operational and financial performance and environmental sustainability.

$$P_t = f(O_t, M_t, R_t, E_t)$$

where:

P = performance variables (e.g. access, operational and financial efficiency and environmental indicators)

O = ownership (e.g. public vs private ownership)

M = market structure (e.g. degree of vertical integration, degree of concentration)

R = introduction of an autonomous regulator

E = endowment (e.g size of the system)

This methodology represents a novelty with respect to most empirical studies. To date, there has been limited empirical work including market structure variables in the analysis, particularly in the case of developing countries. Only a selected number of variables of performance have been used in the literature and there is no evidence reported on the impact of reforms in terms of environmental sustainability.

As it is a priori difficult to make assumptions about the explanatory power of the selected independent variables, including various indicators of unbundling and other sector reforms on the dependent variables, so that we use both a fixed and random effects model.

We run the specifications of the model using both Fixed Effects (FE) and Random Effects (RE) regressions as specified below:

$$\text{FE } Y_{it} = \alpha_i + \beta' X_{it} + \varepsilon_{it} \quad \text{where } \varepsilon_{it} \sim \text{IID } (0, \sigma_\varepsilon)$$

$$\text{RE } Y_{it} = \alpha + \beta' X_{it} + u_i + w_{it} \quad \text{where } \varepsilon_{it} = u_i + w_{it} \text{ and } u_i \sim \text{IID } (0, \sigma_u) \text{ and } \varepsilon_{it} \sim \text{IID } (0, \sigma_\varepsilon)$$

u_i are assumed independent of w_{it} and X_{it} which are also independent of each other for all i and t

i and t represent unit of observation (in our case countries) and time period, respectively

Y_{it} is dependent variable (that is, performance indicators, represented by access, operational and financial efficiency and environmental sustainability).

α_i is the individual effect

β' is the inverted vectors of parameters to be estimated

X_{it} includes both reform variables and control variables (GDP per capita and installed system capacity).

ε_{it} is the vector of random disturbances

We then select the most appropriate specification using the Hausman and Breusch and Pagan test (described below).

In the FE model, the country-specific effects (α_i) are assumed to be the fixed parameters to be estimated. In RE model, the country-specific effects (α) are treated as stochastic. The fixed effects model is a reasonable approach when we can be confident that the differences between units (in our case, countries) can be viewed as parametric shifts of the regression function. This model may be viewed as only applicable to the cross-sectional units in the study, not to additional ones outside the sample. In another setting, as it may be in our case, when for example the sampled cross-sectional units were drawn from a large population, it may be more appropriate to view individual specific constant terms as randomly distributed across cross-sectional units.

A FE model is estimated by ordinary least squares (OLS) which is a matrix weighted average of the within and between units estimators. A random effect model is estimated by generalized least squares (GLS) when the variance structure is known and feasible generalized least squares (FGLS) when the variance is unknown. The fixed effect model produces consistent estimates, whereas the estimates obtained from the random effect model is more efficient but the estimates may be inconsistent. The inefficiency of least squares follows from an inefficient weighting of the two (within and between) least squares estimators. In particular compared to the GLS, OLS places too much weight on the between unit variation. It includes all in the variation in X , rather than apportioning some of it to random variation across groups attributable to the variation in u across units. The inconsistency of the random effect model derives from the fact that there is no justification for treating the individual effects as uncorrelated with the other regressors so that it may suffer from the inconsistency due to omitted variables.

The Hausman specification test compares the fixed versus random effects under the null hypothesis that the individual effects are uncorrelated with the other regressors in the model (Hausman 1978). If correlated (namely if the null hypothesis is rejected), a random effect model produces biased estimators, violating one of the Gauss-Markov assumptions; so a fixed effect model is preferred. Hausman's essential result is that the covariance of an efficient estimator with its difference from an inefficient estimator is zero (Greene 2003).

Breusch and Pagan (1980) developed the Lagrange multiplier (LM) test (Greene 2003; Judge et al. 1988) to identify the presence of random effects and in order to decide on using either pooled OLS or random effects in our analysis. The null hypothesis is that cross-sectional variance

components are zero. The LM is distributed as chi-squared with one degree of freedom. If the null is rejected, the random effect model is more appropriate.

3. Analytical approach

3.1 Data and definition of indicators

Our data set is based on a panel of 22 countries for a period beginning in 1989 and extending through 2009.

The outcomes used for our econometric as well as our case study analysis are the four indicators of power sector performance listed in Table 1 that are used to measure the determinants of power sector performance, namely residential access to electricity, energy sold per employee of electricity suppliers as an indicator of labor productivity, average electricity tariff level as an indicator of financial efficiency, and the index of carbon dioxide emissions as an indicator of environmental sustainability.

Table 1
Selected Power Sector Performance Indicators

Variables	Definition
ACCESS	
Residential access (%population)	= number of residential connections divided by the total population
OPERATIONAL EFFICIENCY	
Energy sold per employee (MWh per employee)	= Amount of generated consumed from the interconnected system divided by the number of employees of the power supply entities for the whole power market (MWh per employee)
FINANCIAL EFFICIENCY	
Tariff level (US\$c per KWh)	= average tariff (US\$c per KWh)
ENVIRONMENTAL SUSTAINABILITY	
Carbon Emission Index (CO2 ton/Kwh)	= energy generated from each energy source weighted with the following coefficients of CO2 emission intensity by weight per unit of electricity generated divided by total amount of energy generated (coal = 1.00; petroleum fuels = 0.94; natural gas = 0.63; renewable energy and nuclear power = zero)

Tables 2 and 3 report the explanatory variables that our model will use to determine the power sector performance. Table 2 includes a comprehensive list of policy variables, such as the degree of vertical unbundling together with the degree of concentration and private sector participation of each segment of the market, as well as the introduction of an autonomous regulator.

Table 2
Explanatory Sectoral Policy Variables Influencing Power Sector Performance
(Expected Relationship)

Variables	Definition	Expected Sign	
		Performance indicators	Environmental indicators
DEGREE OF VERTICAL UNBUNDLING			
Partial Vertical Unbundling	= 1 from the year of separation of generation from transmission and distribution = 0 otherwise	+	-
Full Vertical Unbundling	= 1 from the year of separation of transmission from generation and distribution = 0 otherwise	+	-
DEGREE OF DISAGGREGATION			
Degree of disaggregation	= the reverse of the Hirschman-Herfindal index (HHI), computed separately for the generation, transmission, and distribution segments; in the case of generation is expressed in installed generating capacity (MW); in the case of transmission expressed in terms of km line length without discrimination between transmission voltage levels; in the case of distribution expressed in terms of total retail sales (MWh)	+	-
DEGREE OF PRIVATE SECTOR PARTICIPATION			
Share of private sector participation	= the percentage of private sector participation expressed in installed generating capacity (MW) in the generation segment; expressed in terms of km line length in the transmission segment; and expressed in terms of total retail sales (MWh) in the distribution segment	+	-
REGULATION			
Introduction of a regulatory agency	= 1 from the year of establishment of a regulatory agency = 0 otherwise	+	+

Table 3 introduces the key control variables related to GDP per capita and power system size, with a particular attention to Group A and Group D, the interaction between the groups with the policy variables, as well as additional indicators, including the financial crisis for Latin America, capital investment, and the share of fossil fuels in generation.

Table 3
Other Explanatory Variables Influencing Power Sector Performance
(Expected Relationship)

Variables	Definition	Expected Sign	
		Performance indicators	Environmental indicators
BASIC CONTROLS			
GDP per capita	= GDP per capita, PPP (constant 2005 international \$)	+	+
Installed capacity (MW)	= Total installed capacity in the power system (MW)	+	-
POWER SYSTEM SIZE GROUP CONTROLS			
Group A	= 1 if above the threshold GDP per capita and installed capacity (determined by the lowest 25 percent of capacity and income of the sample) = 0 otherwise	+	+
Group D	= 1 if below the threshold GDP per capita and installed capacity (determined by the lowest 25 percent of capacity and income of the sample) = 0 otherwise	-	-
Group A*sectoral reforms	= Interacted variable between Group A and each of the sectoral reforms (competition, privatization and regulation)	+	-
OTHER CONTROLS			
Financial Crisis	= 1 for the 5 years after 2001 = 0 otherwise	-	
Share of fossil fuels (% installed capacity)	= Percentage of the total installed capacity in fossil fuels (oil, coal and natural gas	?	
Investment (US\$/MWh)	= Capital expenditure per unit of energy generated (MWh)	+	
REGIONAL CONTROL			
Region <i>d_region1, 2, 3,4,5,6</i>	Dummies , 1=EAP, 2=ECA, 3=LAC, 4=MNA, 5=SAR, 6=SSA		

3.2 Theoretical hypotheses to be tested

Hypothesis 1 Sectoral Reforms and Performance and traditional and environmental power sector performance

The implementation of key sectoral reforms, including vertical and horizontal unbundling, privatization and regulation, is expected to be significantly associated with higher access and better operational and financial performance of the power sector. Such reforms may however be associated with environmentally non sustainable outcomes.

Some reforms (e.g. unbundling, wholesale competition) while expected to improve all indicators of technical and financial performance, may under some circumstances tend to discourage low carbon options. The arguments put forward are that integrated firms can coordinate the development of the network to accommodate renewable generations and a "single buyer" model allows policy makers to choose a mix of low carbon generators in a

centralized and smoother way. The great advantage of a more competitive structure (compared to a vertically integrated one), for instance, is that new entrants can spot opportunities that incumbents have not exploited and is generally more conducive to better investment decision and innovative outcomes. Ultimately, which of the two effects will prevail is an empirical question but one would presume that overall the former effects would dominate the latter.

Hypotheses 2A Differential impact of reforms depending on power system size and per capita income

Key sectoral reforms, particularly vertical and horizontal unbundling, are expected to produce the most significant results in the group of countries characterized by high power system size and income per capita. Such reforms are also likely to be associated with environmentally sustainable results for the same category of countries.

Hypotheses 2D Differential impact of reforms depending on power system size and per capita income

Key sectoral reforms, particularly vertical and horizontal unbundling, are not expected to be effective in the group of countries characterized by low power system size and income per capita. Such reforms are also likely to be associated with environmentally unsustainable results for the same category of countries

4. Empirical results

4.1 Results of testing Hypothesis 1

As the results reported in Tables 4 and 5 show, Hypothesis 1 is generally confirmed across the board of all indicators, reflecting the positive impact of unbundling and sectoral reforms on performance. There are however, nuances across the impact of unbundling and sectoral reforms on the different performance indicators that are reported below.

i Access

The level of access is positively linked to full vertical unbundling, even if not significantly so. Partial unbundling is negatively and significantly associated with lower levels of access. It is positively and significantly linked to the increase of disaggregation in generation. This result can be interpreted noting that developing countries have been able to scale up access after attracting more players and investment in generation, so as to add needed installed capacity and/or through entry of distributed generation and the appropriate combination of grid and off-grid generation supply. The source of power generation that is positively though not significantly associated with enhanced access is fossil fuels generation.

Among the forms of competition in generation the introduction of private sector participation in generation also is significantly linked to access expansions, proving that IPPs and divestiture of formerly state-owned generators can deliver positive results. Independent power producers (IPPs) are an important catalyst in the electricity sector reform as they are often the first private investors in a power market dominated by state-owned power utilities. With entry of a sufficient number of IPPs in the market, supply grew and access has been scaled up.

Table 4
Regression Results of determinants of Power Sector Performance (Fixed Effects)

<i>FIXED EFFECTS</i>	Residential Access (%)	Energy sold (MWh/employee)	Tariff (US\$/KWh)	Emission index (CO2 ton/KWh)
DEGREE OF UNBUNDLING				
Partial unbundling	-2.72* (1.43)	-542.94*** (192.53)	-0.46 (1.82)	0.02*** (0.01)
Full unbundling	0.18 (1.36)	-208.36* (118.09)	1.98*** (0.82)	0.004 (0.009)
DEGREE OF DISAGGREGATION				
HHI generation (reverse)	0.0008** (0.0003)			-0.00001*** (0.0000002)
HHI distribution (reverse)		0.63 (0.40)	-0.006*** (0.002)	
DEGREE OF PRIVATE OWNERSHIP				
Privatization in Generation (dummy)	3.46*** (1.16)			0.02*** (0.008)
Privatization in Distribution/Total (share)		9.57*** (3.47)	0.37** (0.17)	
REGULATION				
Introduction of an autonomous regulator	3.94*** (0.96)	299.34*** (88.19)	2.32*** (0.79)	-0.025*** (0.007)
CONTROLS				
GDP per capita (thousand US\$)	3.7*** (0.4)	190*** (44.)	2.*** (0.2)	0.0003 (0.002)
Installed capacity (MW thousand)	0.6*** (0.08)	169*** (16.6)	0.303*** (0.067)	- 0.003** (0.001)
GDP per capita* Installed capacity	-0.047*** (0.005)	-3.38*** (0.65)	-0.019*** (0.003)	0.0001 (0.00004)
Financial crisis			-0.87*** (0.32)	
Capex (US\$/MWh)			0.28*** (0.11)	
Share of fossil fuels (access)/hydro (emission) (% installed capacity)	0.10 (0.07)			-0.0007* (0.0004)
Constant	21.68*** (5.62)	3845.99 (3453.8)	-60.63*** (17.76)	0.79*** (0.03)
N	271	166	129	318
F	61.29***	223.77***	14.80***	8.95***
Within R²	0.64	0.90	0.53	0.23
Between R²	0.40	0.46	0.53	0.09
Overall R²	0.49	0.61	0.41	0.03

Note: *, **, *** indicate respectively level of significance of 10, 5 and 1 percent.

Table 5
Regression Results of determinants of Power Sector Performance (Random Effects)

<i>RANDOM EFFECTS</i>	Residential Access (%)	Energy sold (MWh/employee)	Tariff (US\$/KWh)	Emission index (CO2 ton/KWh)
DEGREE OF UNBUNDLING				
Partial Unbundling	-2.24 (1.42)	-492.28*** (189.52)	-0.15 (1.82)	0.02** (0.01)
Full Unbundling	0.38 (1.3)	-188.37* (112.19)	1.58* (.93)	0.007 (0.009)
DEGREE OF DISAGGREGATION				
HHI in generation (reverse)	0.0008*** (0.0003)			0.00001*** (0.0000003)
HHI in distribution (reverse)		0.24* (0.13)	- 0.001*** (0.0002)	
REGULATION				
Introduction of an autonomous regulator	4.56*** (0.91)	266.74*** (87.69)	4.02*** (0.85)	0.026*** (0.01)
DEGREE OF PRIVATIZATION				
Privatization (as per previous table)	3.52*** (1.16)	9.29*** (3.39)	0.04* (0.023)	0.02** (0.008)
MACROECONOMIC CONTROL				
GDP per capita (US\$ thousands)	3.*** (0.3)	180*** (37.)	0.3*** (0.1)	0.003 (0.002)
Financial crisis			-1.02*** (0.39)	
SECTORAL CONTROL				
Installed capacity (MW thousands)	0.6*** (0.07)	180*** (16.0)	0.1*** (0.04)	-0.001* (0.0006)
GDP per capita* Installed capacity	-0.004*** (0.005)	-2.93*** (0.612)	-0.007*** (0.003)	-0.0001*** (0.00003)
Capex (US\$/MWh)			0.25*** (0.13)	
Share of fossil fuels/hydro (% installed capacity)	0.072 (0.05)			-0.0005* (0.0003)
REGIONAL CONTROLS				
Regional dummies	Yes	Yes	Yes	Yes
Constant	45.15*** (5.27)	-170.18 (1110.83)	-7.81*** (2.34)	0.81* (0.36)
N	271	166	129	318
Wald χ^2	650.78***	1416.05***	108.37***	
Within R ²	0.64	0.90	0.33	0.22
Between R ²	0.92	0.76	0.69	0.29
Overall R ²	0.92	0.81	0.63	0.35

Note: *, **, *** indicate respectively level of significance of 10, 5 and 1 percent.

The introduction of an autonomous regulator is also significantly positively associated with higher access, confirming that regulators can also play an important role in ensuring that contracts were effectively designed. IPPs sold their generated electricity to state-owned utilities, which entered into long term power purchasing agreements (PPAs) with state-backed guarantees for the off-taking utility's performance. By signing long term PPAs, IPPs accepted construction and operating risks and shared fuel availability risk with fuel suppliers. In most cases, they were protected from demand risk under the terms of their PPAs for their debt servicing needs and equity returns.

TABLE 6
FIXED AND RANDOM EFFECT TESTS

	Access	Operational Efficiency	Financial Efficiency	Emissions Index
HAUSMAN TEST FOR FIXED EFFECT				
Hausman χ^2 (8)	7.55	17.49***	98.75***	7.39
PREFERRED SPECIFICATION				
Fixed effect	✓	✗	✗	✓
Random effect	✗	✓	✓	✗
BREUSCH AND PAGAN LAGRANGIAN MULTIPLIER TEST				
BPLM χ^2 (1)		323.91***	31.91***	
PREFERRED SPECIFICATION				
Random effect		✓	✓	
Pooled		✗	✗	

Finally as expected higher income countries are characterized by significantly higher levels of access, as is the case for countries with larger system size. The interacted term between GDP per capita and power system size is negative, revealing decreasing returns to scale by the highest income countries - such as OECD countries - which have already achieved close to universal access and face an exponentially increasing cost in connecting each new consumer as they approach full coverage. The explanatory power of these variables is very high, reaching 90% in the preferred specification of random effects.

ii. Labor productivity

The level of labor productivity (expressed in terms of energy sold per employee) is significantly reduced by both partial and full vertical unbundling. It is instead enhanced by the increase of disaggregation in distribution. More players in distribution are expected to drive efficiency gains through means such as benchmark competition (also known as yardstick competition).

The introduction of private sector participation also helped to significantly enhance operational efficiency and labor productivity in distribution.

The presence of autonomous regulator has also significantly contributed to higher labor productivity, most likely by creating a more even playing field to attract private participation in distribution.

Finally as expected higher income countries are characterized by significantly higher levels of labor productivity, as are also countries with larger system sizes. The interacted term between GDP per capita and power system size is also in this case negative, revealing decreasing returns to scale for the highest income countries with larger power systems and which have already achieved high levels of labor productivity.

This specification has a very strong explanatory power with a level for R^2 of more than 80% for the preferred random effect specification.

iii. Tariffs

Full unbundling in line with the finding of earlier literature, including Steiner (2001), significantly enhanced the level of tariffs, whereas partial unbundling has no significant impact on tariffs. On the other hand, more disaggregation in distribution drives electricity tariffs down, most likely as a result of yardstick competition and less collusion between players in the market. An earlier study by Steiner (2001) of 19 OECD countries for the period 1986-1996 found instead that unbundling was not associated with lower prices, but is associated with a lower industrial to residential price ratio.

In this case however, a higher share of private sector participation significantly raises the level of tariffs, most likely reflecting the need to raise tariffs to attract private participation in distribution.

The presence of an autonomous regulator is also significantly and positively associated with higher tariffs, reflecting the need to insulate crucial decisions related to pricing from political interferences.

As expected, higher income countries are characterized by significantly higher levels of prices, as are also countries with larger system sizes. The interacted term between GDP per capita and power system size is once again negative, revealing decreasing returns to scale in the highest income countries which have already achieved high levels of tariffs.

Some cautionary remarks are needed. A more accurate indicator of financial efficiency would be provided by the degree of cost recovery. However, the much smaller number of observations available for such an indicator made a rigorous approach (through panel analysis not possible). Accordingly, additional regressions were performed, controlling for the level of costs and energy endowment. As shown in Table 4, higher investment in the power sector is also significantly associated with higher tariffs, reflecting the fact that capital expenditure is partially financed by the tariff and passed through to consumers. Short run shocks including financial crises are significantly and negatively associated with tariffs, reflecting the challenges of keeping prices at cost reflective levels in periods when consumer protection takes priority.¹

¹ Other variables (including the sources of energy from which electricity is generated) do not indicate the presence of a relation with the tariff level. In order to keep the model parsimonious the coefficient is not included into the specification presented in Table 5. All other coefficients including the policy variables are not affected from the inclusion of this parameter into the specification.

iv. Carbon emission index

Partial and vertical unbundling is associated with higher carbon emissions, but only partial unbundling significantly so. Higher competition in generation is also significantly associated with higher sustainable environmental outcomes, reducing the carbon emissions from fossil fuels. A possible interpretation is that integrated firms can coordinate the development of the network to accommodate renewable generation sources and a "single buyer" model allows policy makers to ensure that a mix of low carbon generators is incorporated into the centralized dispatch of generation capacity to meet demand on the power system without compromising supply reliability.

Private ownership in generation is also significantly and positively associated with less environmental sustainable outcomes, raising the carbon emissions from burning fossil fuels.

The presence of an autonomous regulator is also significantly associated with higher carbon emissions, proving that environmental considerations have a relatively lower priority compared to the traditional functions of energy policy and regulation, such as to protect consumers from high prices and ensure that power firms will be able to recoup their investment. These goals can be sometimes conflicting with each other. Improved access to reliable, secure, affordable, energy represent a much higher priority particularly in countries characterized by low levels of income.

As expected, higher income countries are characterized by significantly higher levels of carbon emissions. However, countries with larger system sizes are significantly associated with lower levels of carbon emissions, most likely due to the presence of economies of scale and the fact that smaller and isolated systems are in many cases mostly dependent on oil imports and find it more difficult to diversify sources of energy. The interacted term between GDP per capita and power system size is not significant.

4.2 Results of testing Hypothesis 2A

As the results reported in Table 7 show, Hypothesis 2A postulating the greatest effectiveness and impact of unbundling and reforms for countries in Group A, characterized by large power system and higher GDP per capita, is generally confirmed across the board of all performance indicators, reflecting the positive impact of unbundling and sectoral reforms on performance. There are however, nuances across the impact of unbundling and sectoral reforms on the different performance indicators that are reported below.

To undertake this task for each of the regressions reported in Table 8, we introduce interaction variables which allow us to explore the synergistic effects of the combined predictors. The interaction variables are created by multiplying each of the selected reform variables with Group A. For instance, in the case of unbundling the interacted variable is given by the product between (either partial or full) unbundling and Group A of countries, capturing the differential impact of unbundling in the group of countries characterized by large system size and high income per capita.

Differential impact of vertical unbundling in Group A

- Vertical unbundling (in both specifications, namely either partial or full or full only) when interacted with Group A countries is significantly associated with enhanced access and more sustainable levels of CO₂ emission generated by fossil fuels, reflecting both economic and environmental benefits to power users, due to increased efficiency of use of fossil fuels.
- There is, however, no significant link with operational or financial efficiency. This implies that for this group of countries the high prevailing level of labor productivity offers decreasing returns to scale. It should also be noted that unbundling per se did not have any significant impact on labor productivity in the overall sample (see Table 4). In the case of financial efficiency, instead, the overall link between vertical unbundling and tariff was positive and significant, reflecting the fact that the costs of unbundling were passed through to consumers.

Differential impact of disaggregation in Group A

- Similarly to vertical unbundling, higher disaggregation of the generation segment of the market when interacted with group A is significantly associated with enhanced access and more sustainable levels of CO₂ emission generated by fossil fuels, reflecting the benefits to the users as well as to environment, due to increased efficiency of use of fossil fuels when more players are introduced.
- Reduction in the concentration of the distribution segment of the market for the countries belonging to Group A is positively and significant linked with enhanced operational efficiency, but there are no links with enhanced financial efficiency. This implies that for group of countries the already achieved in the level of tariff is already so high that there are decreasing returns to scale. It should also be noted that disaggregation of the distribution segment per se did not have a significant impact on labor productivity in the overall sample (see Table 4). Its effectiveness is found only for countries characterized by large system size and high GDP per capita. In the case of financial efficiency, instead, the overall link between distribution disaggregation and tariff was negative and significant, reflecting the fact that the beneficial impact of competition (or at least benchmarking) of additional distribution players on reducing costs and tariffs.

Differential impact of private sector participation in Group A

- The introduction of private sector participation in the generation segment of the market when interacted with Group A is not significantly associated with access or carbon emissions generated from fossil fuels. It should also be noted that higher degree of private sector participation per se did have a significant and positive impact by enhancing access but at the cost of adding carbon emissions (see Table 4). This implies that for countries belonging to Group A, the achieved level of access is already so high that privatization of generation is not sought to enhance connectivity. There is also no significant evidence of environmental unsustainability results brought by the private sector in generation, differently from the overall sample where higher private sector participation was associated with higher emission levels.

Table 7
Determinants of Power Sector Performance (Fixed Effects and interactions with Group A)

Interactions with Group A Fixed effects	Residential Access (%)	Energy sold (MWh/employee)	Tariff (US\$/KWh)	Emission index (CO2 ton/KWh)
DEGREE OF UNBUNDLING (EITHER PARTIAL OR FULL)				
Group A	9.13*** (1.99)	-61.05 (251.98)		0.01 (0.01)
Vertical Unbundling	-6.67*** (1.78)	47.97 (146.29)	2.51*** (0.92)	0.03** (0.01)
Group A*Vertical Unbundling	7.92*** (2.12)	-365.51 (230.38)	-1.36 (1.23)	-0.03** (0.02)
FULL VERTICAL UNBUNDLING				
Group A	9.71*** (1.96)	-186.01 (237.65)		0.03** (0.01)
Vertical Unbundling (full)	-6.75*** (1.83)	77.04 (136.79)	2.49*** (0.92)	0.03** (0.01)
Group A*Vertical Unbundling (full)	7.81*** (2.27)	-63.59 (222.99)		-0.08*** (0.02)
DEGREE OF DISAGGREGATION				
Group A	-29.18*** (5.96)	-2247.13** (48097.47)		0.15*** (0.41)
HHI (reverse)	-0.002*** (0.0006)	18*** (13.38)	-0.021 (.016)	0.00002*** (0.000004)
Group A* HHI (reverse)	0.002*** (0.0006)	0.66** (13.38)	0.019 (0.016)	-0.00002*** (0.000004)
DEGREE OF PRIVATIZATION				
Group A	12.27*** (2.40)	-702.76* (370.87)		0.09 (0.01)
Privatization	2.51* (1.59)	4.40 (3.51)	0.17 (0.27)	0.023*** (0.01)
Group A*Privatization	1.66 (2.18)	21.61** (9.14)	0.47 (0.38)	-0.009 (0.01)
REGULATION				
Group A	10.48*** (2.39)	-341.33 (283.82)		-0.0008 (0.01)
Introduction of a regulatory agency	3.06*** (1.12)	73.41 (120.71)	4.96*** (0.95)	0.04*** (0.01)
Group A*Regulatory Agency	5.9*** (1.65)	564.08*** (176.14)	-9.6*** (1.66)	-0.04*** (0.01)

Note: *, **, *** indicate respectively level of significance of 10, 5 and 1 percent.

- The introduction of private sector participation in the distribution segment of the market for the countries belonging to Group A is positively and significantly linked with enhanced operational efficiency, but there are no links with enhanced financial efficiency. It should also be noted that higher private sector participation in the distribution segment per se did also have a significant impact on labor productivity in the overall sample (see Table 4). In the case of financial efficiency, instead, the overall link between private sector participation in distribution and tariff was positive and significant, reflecting the fact that in order to attract the private sector more cost reflective tariffs were needed. This seems to imply that for Group A of countries the already achieved level of tariff is already found enough to attract private sector participation in distribution.

Differential impact of regulation in Group A

- The introduction of an autonomous regulator when interacted with Group A is significantly associated with enhanced access, higher operational efficiency, lower tariffs and more sustainable level of CO2 emission generated by fossil fuels, reflecting the benefits to the users, producers as well as to environment, due to increase efficiency of use of fossil fuels.

4.3 Results of testing Hypothesis 2D

As the results reported in Table 8 shows, Hypothesis 2D postulating the lower effectiveness and impact of unbundling and reforms for countries in Group D, characterized by small power system and lower GDP per capita is generally confirmed across the board of all indicators, reflecting the negative impact of unbundling and sectoral reforms on performance. There are however, nuances across the impact of unbundling and sectoral reforms on the different performance indicators that are reported below.

Also in this case for each of the regressions reported in Table 5, we introduce interaction variables created by multiplying each of the selected reform variables with Group D. For instance, in the case of unbundling the interacted variable is given by the product between (either partial or full) unbundling and Group D of countries, capturing the differential impact of unbundling in the group of countries characterized by small system size and low income per capita.

Differential impact of vertical unbundling in Group D

- Vertical unbundling (in both specifications, namely either partial or full or full only) when interacted with Group D is significantly associated with reduced access and less sustainable levels of CO2 emission generated from fossil fuels. Full vertical unbundling is also positively and significantly associated with higher level of tariffs, as found for the overall sample of countries.
- Vertical unbundling is, however, significantly linked with higher operational efficiency. This implies that for this group of countries the benefits of unbundling are only reflected through restructuring and laying off of redundant employees. It should also be noted that unbundling per se did not have any significant impact on labor productivity in the overall sample (see Table 4).

Differential impact of disaggregation in Group D

- Similarly to vertical unbundling, higher disaggregation of the generation segment of the market when interacted with Group D is significantly associated with reduced access, but in this case it is associated with more sustainable level of CO2 emission generated by fossil fuels.
- Reduction in the concentration of the distribution segment of the market for the countries belonging to Group D is negatively linked with operational and financial efficiency, but not significantly so.

Differential impact of private sector participation in Group D

- The introduction of private sector participation in the generation segment of the market when interacted with Group D is significantly associated with reduced level of access but is not significantly linked to the carbon emission generated by fossil fuels. It should also be noted that for the overall sample of countries higher degree of private sector participation per se did have a significant and positive impact by enhancing access but at the cost of adding carbon emissions (see Table 4).
- The introduction of private sector participation in the distribution segment of the market for the countries belonging to Group D is negatively and significantly linked with operational efficiency, but there are no links with enhanced financial efficiency. This result contrasts with the overall finding that higher private sector participation in the distribution segment per se did have a significant impact on labor productivity (see Table 4). In the case of financial efficiency, instead, the overall link between private sector participation in distribution and tariff was positive and significant, reflecting the fact that in order to attract the private sector more cost reflective tariffs were needed.

Differential impact of regulation in Group D

- The introduction of an autonomous regulator when interacted with Group D is significantly associated with reduced access, lower operational efficiency, higher tariffs, reflecting a lack of benefits to users and producers. It is however associated with more sustainable level of CO2 emission generated from fossil fuels. This result underscores the challenges in implementing regulatory reforms in this group of countries.

Problems of collinearity and endogeneity have been addressed as detailed in Appendix 1.

Table 8
Determinants of Power Sector Performance (Fixed Effects and interactions with Group D)

Interactions with Group D Fixed effects	Residential Access (%)	Energy sold (MWh/employee)	Tariff (US\$/KWh)	Emission index (CO2 ton/KWh)
UNBUNDLING (EITHER PARTIAL OR FULL)				
Group D	8.76* (4.72)	-17.83 (468.29)	-0.22 (2.20)	-0.05* (0.04)
Vertical Unbundling	1.65 (1.13)	-336.29** (174.92)	1.14 (0.83)	0.003 (.009)
Group D*Vertical Unbundling	-8.74*** (2.04)	403.85* (222.61)	1.48 (1.25)	0.03** (0.01)
FULL VERTICAL UNBUNDLING				
Group D	9.76* (5.23)	207.63 (438.64)	-1.33 (2.05)	-0.08** (0.04)
Vertical unbundling (full)	3.04* (1.67)	-44.22 (174.55)		-0.03*** (0.01)
Group D*Vertical unbundling (full)	-9.47*** (2.37)	138.85* (214.28)	2.61*** (0.94)	0.06*** (0.02)
DEGREE OF DISAGGREGATION				
Group D	-29.18*** (5.96)	-2247.13** (48097.47)		0.15*** (0.41)
HHI (reverse)	0.0002 (0.0004)	0.88** (0.44)	-0.002 (0.002)	-0.000004* (0.000003)
Group D* HHI (reverse)	-0.002*** (0.0007)	-0.02 (0.04)	-0.0001 (0.0002)	-0.00002*** (0.000005)
DEGREE OF PRIVATIZATION				
Group D	8.03 (5.74)	515.03 (391.43)	1.32 (2.12)	-0.03 (0.04)
Privatization	4.08*** (1.36)	25.95*** (8.67)	0.39** (0.19)	0.019** (0.008)
Group D*Privatization	-5.67* (3.49)	-21.36** (9.14)		0.0004 (0.023)
REGULATION				
Group D	6.03 (4.97)	402.67 (380.55)	-1.60 (2.11)	-0.005 (0.03)
Regulation	3.06*** (1.12)	73.41 (120.71)	4.96*** (0.95)	-0.006 (0.007)
Group D*Regulation	-6.92*** (1.96)	-397.54** (185.61)	8.51*** (2.09)	-0.07*** (0.01)

Note: *, **, *** indicate respectively level of significance of 10, 5 and 1 percent.

5. Conclusions

The results of the analysis carried out for this study confirm the following conclusions for policy guidance on power market restructuring for developing countries:

- *Vertical unbundling delivers results in terms of* several performance indicators when used as an entry point to implement broader reforms, particularly introducing a sound regulatory framework, reducing the degree of concentration of the generation and distribution segments of the market by attracting additional numbers of both public and private players and attracting private sector participation.
- *There seems to be a credible empirical basis for selecting a threshold power system size and per capita income level* below which unbundling of the power supply chain is not expected to be worthwhile.
- *Partial forms of unbundling do not appear to drive improvements*, probably because the owner was able to continue exercising control over the affairs of the sector and hinder the development of competitive pressure within the power market.

Table 9 summarizes the analytical evidence for these results. The analysis with the regression model used for the study produces the following main findings for each of the reform indicators.

A. Vertical unbundling:

- ❖ The level of access is positively linked to full vertical unbundling, even if not significantly so. Partial unbundling is negatively and significantly associated with lower levels of access.
- ❖ The level of labor productivity (expressed in terms of energy sold per employee) is significantly reduced by both partial and full vertical unbundling.
- ❖ Full unbundling significantly enhanced the level of tariffs, whereas partial unbundling has no significant impact on tariffs.
- ❖ Partial and vertical unbundling is associated with higher carbon emissions, but only partial unbundling significantly so.

Differential impact of vertical unbundling between Groups A and D

- ❖ Vertical unbundling (in both specifications, namely either partial or full or full only) when interacted with Group A is significantly associated with enhanced access and more sustainable levels of CO₂ emission generated by fossil fuels, reflecting both economic and environmental benefits to power users, due to increased efficiency of use of fossil fuels. The opposite result holds for Group D.
- ❖ There is no significant link between vertical unbundling and enhanced operational or financial efficiency for Group A, whereas there is a positive and significant link for Group D. This implies that for Group A the high prevailing level of labor productivity offers decreasing returns to scale, or there is an increasing use of outsourcing. For group D the benefits of unbundling may be reflected mainly through restructuring and laying off of redundant employees.

B. Degree of disaggregation:

- ❖ The level of access is positively and significantly linked to the increase of disaggregation in generation. This result can be interpreted noting that developing countries have been able to scale up access after attracting more players and investment in generation.
- ❖ Labor productivity is enhanced by the increase of disaggregation in distribution. More players in distribution are expected to drive efficiency gains through means such as benchmark competition.
- ❖ More disaggregation in distribution drives electricity tariffs down, most likely as a result of benchmark competition and less collusion between players in the market.
- ❖ Higher competition in generation is significantly associated with higher sustainable environmental outcomes, reducing the carbon emissions from fossil fuels.

Differential impact of disaggregation between Groups A and D

- ❖ Higher disaggregation of the generation segment of the market when interacted with group A is significantly associated with enhanced access and more sustainable levels of CO2 emission generated by fossil fuels, reflecting the benefits to the users as well as to environment, due to increase efficiency of use of fossil fuels when more players are introduced. For Group D a tradeoff emerges between reduced access, but a more sustainable level of CO2 emission generated by fossil fuels.
- ❖ Reduction in the concentration of the distribution segment of the market for the countries belonging to Group A is positively and significant linked with enhanced operational efficiency, but there are no links with enhanced financial efficiency. This implies that for group of countries the already achieved in the level of tariff is already so high that there are decreasing returns to scale. Reduction in the concentration of the distribution segment of the market for the countries belonging to Group D is negatively linked with operational and financial efficiency, but not significantly so.

C. Regulation:

- ❖ The introduction of an autonomous regulator is significantly positively associated with higher access, confirming that regulators can also play an important role in ensuring that contracts were effectively designed.
- ❖ The presence of autonomous regulator has also significantly contributed to higher labor productivity, most likely by creating a more even playing field to attract private participation in distribution.
- ❖ The presence of an autonomous regulator is also significantly and positively associated with higher tariffs, reflecting the need to insulate crucial decisions related to pricing from political interferences.
- ❖ The presence of an autonomous regulator is also significantly associated with lower carbon emissions, proving that environmental considerations started to be given a relatively higher priority compared to the traditional functions of energy policy and regulation, such as to protect consumers from high prices and ensure that power firms will be able to recoup their investment.

Differential impact of regulation between Groups A and D

- ❖ The introduction of an autonomous regulator when interacted with Group A is significantly associated with enhanced access, higher operational efficiency, lower tariffs and more sustainable level of CO₂ emission generated by fossil fuels, reflecting the benefits to the users, producers as well as to environment, due to increase efficiency of use of fossil fuels. In contrast, the introduction of an autonomous regulator when interacted with Group D is significantly associated with reduced access, lower operational efficiency, higher tariffs, reflecting a lack of benefits to users and producers. It is however associated with more sustainable level of CO₂ emission generated from fossil fuels, as well as to environment. This result underscores the challenges in implementing regulatory reforms in this group of countries.

D. Private Sector Participation:

- ❖ The introduction of private sector participation in generation also is significantly linked to access expansions, proving that IPPs and divestiture of formerly state-owned generators can deliver positive results. The introduction of private sector participation also helped to significantly enhance operational efficiency and labor productivity in distribution.
- ❖ A higher share of private sector participation significantly raises the level of tariffs, most likely reflecting the need to raise tariffs to attract private participation in distribution.
- ❖ Private ownership in generation is also significantly and positively associated with less environmental sustainable outcomes, raising the carbon emissions from burning fossil fuels.

Differential impact of private sector participation between Groups A and D

- ❖ The introduction of private sector participation in the generation segment of the market when interacted with Group A is not significantly associated with access or carbon emissions generated from fossil fuels. This implies that for countries belonging to Group A, the achieved level of access is already so high that privatization of generation is not sought to enhance connectivity. There is also no significant evidence of environmental unsustainability results brought by the private sector in generation. The introduction of private sector participation in the generation segment of the market when interacted with Group D is significantly associated with reduced level of access but is not significantly linked to the carbon emission generated by fossil fuels.
- ❖ The introduction of private sector participation in the distribution segment of the market for the countries belonging to Group A is positively and significant linked with enhanced operational efficiency, but there are no links with enhanced financial efficiency. In the case of financial efficiency, instead, the overall link between private sector participation in distribution and tariff was positive and significant, reflecting the fact that in order to attract the private sector more cost reflective tariffs were needed. This seems to imply that for Group A of countries the already achieved level of tariff is already found enough to attract private sector participation in distribution. The introduction of private sector participation in the distribution segment of the market for

the countries belonging to Group D is negatively and significantly linked with operational efficiency, but there are no links with enhanced financial efficiency.

E. Control variables:

- ❖ As expected, countries characterized either by higher income or larger system size have significantly higher levels of access, labor productivity and tariffs. The links with environmentally sustainable outcomes are instead different. *Ceteris paribus*, as one would expect, higher income countries are positively associated to higher carbon emissions, whereas countries characterized by larger system size are negatively and significantly associated to lower carbon emissions. The latter result is most likely due to the presence of economies of scale and the fact that smaller and isolated systems are in many cases mostly dependent on oil imports and find it more difficult to diversify sources of energy.
- ❖ The interacted term between GDP per capita and power system size is negative, revealing decreasing returns to scale by the highest income countries - such as OECD countries - which have already achieved close to universal access and face an exponentially increasing cost in connecting each new consumer as they approach full coverage. The explanatory power of these variables is very high, reaching 90% in the preferred specification of random effects.

Table 9
Summary of Analytical Evidence

	Access		Labor Productivity		Tariff		Emissions Index	
Group	A	D	A	D	A	D	A	D
VERTICAL UNBUNDLING (EITHER PARTIAL OR FULL)								
Unbundling	-		-		+ ^{**}		+ [*]	
Unbundling* Group	+ ^{***}	- ^{***}	-	+ [*]	-	+	- ^{**}	+ ^{**}
FULL VERTICAL UNBUNDLING								
Full Unbundling	+		- [*]		+ ^{***}		+	
Full Unbundling* Group	+ ^{***}	- ^{***}	-	+ [*]	- ^{***}	+ ^{***}	- ^{***}	+ ^{***}
DEGREE OF DISAGGREGATION								
Disaggregation	+ ^{***}		+		- ^{***}		- ^{***}	
Disaggregation* Group	+ ^{***}	- ^{***}	+ ^{**}	-	+	-	- ^{***}	- ^{***}
REGULATION								
Regulation	+ ^{***}		+ ^{***}		+ ^{***}		- ^{***}	
Regulation* Group	+ ^{***}	- ^{***}	+ ^{***}	- ^{**}	- ^{***}	+ ^{***}	+ ^{***}	- ^{***}
PRIVATIZATION								
Privatization	+ ^{***}		+ ^{***}		+ ^{**}		+ ^{***}	
Privatization* Group	+	- [*]	+ ^{**}	- ^{**}	+	-	-	+
CONTROL VARIABLES								
GDP per capita	+ ^{***}		+ ^{***}		+ ^{***}		+	
Installed capacity	+ ^{***}		+ ^{***}		+ ^{***}		- ^{***}	
GDP per capita*Capacity	- ^{***}		- ^{***}		- ^{***}		+ ^{***}	
EXPLANATORY POWER								
Within R ² (fixed effect)	64		90		54		22	
Between R ² (random effect)	92		77		52		30	

6. Directions for New Research

- For the purposes of this research the countries in the sample were divided into different categories based on the specific threshold levels of system size and income. The selected thresholds are in line with the previous research (Besant-Jones, 2006). The alternative way of categorizing countries would be to apply a cluster analysis. This technique allows assigning a set of observations into subsets, such that observations in the same subset are similar in some parameters (for example, GDP per capita and power system size), but that the subsets differ between each other. The application of the cluster analysis allows obtaining the optimal number of subsets as well as the threshold levels based on the underlying data.
- Different definitions of the aggregate index of reforms can be used to examine the robustness of the results to the different specifications. More sophisticated dynamic error correction models and the instrumental variable approach to allow for potential possible endogeneity biases can be used in future research.
- Finally, additional performance indicators, including indicators of quality (such as SAIDI and SAIFI), operational efficiency (including capacity utilization, load factor), financial efficiency (such as cost recovery index), and long run environmentally sustainability indicators (such as the share renewables) and energy endowment (such as reserve capacity, and self-sufficiency) can be studied in more detail with the help of the econometric models.

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Appendix 1

Cautionary note and sensitivity analysis

Multicollinearity

- Multicollinearity can represent a serious problem when estimating generalized linear models (as in the case of a Probit model). Multicollinearity is a statistical phenomenon in which two or more variables in a multiple regression model can be obtained as the linear combination of the other variables, which makes them highly correlated. In a nutshell, multicollinearity emerges when the explanatory variables are strongly linearly dependent. In such a case, the coefficient estimates may change erratically in response to small changes in the model or in the data. Even if multicollinearity does not reduce the predictive power or reliability of the model as a whole, it seriously influences calculations concerning individual predictors.²
- If multicollinearity is present, one should check for the so-called dummy trap; increase the dimension of the data set; remove one or more variables from the analysis (doing this may imply in some cases losing some explanatory power and biasing the coefficients of the remaining regressors, if those variables are relevant for the analysis); impose special structures.
- There are different possible tests to check for multicollinearity. Some of them are based on specific measures, such as the variance inflation factor and the condition index, but their interpretation is often heuristic. Here we prefer to use the standard F-test on regression coefficients, since it is the simplest to read and interpret. The test is based on the consideration that collinear variables tend to have insignificant coefficients, since every variable is able to explain a certain but not sufficient amount of the total sample variability. Hence, in case of multicollinearity, we can observe insignificant regression coefficients for the affected variables, but we reject the joint null hypothesis that those coefficients are all zero, indicating that in some way they have some explanatory power. This analysis is based on a simple F-test (i.e. a multivariate extension of the t-test).
- Our F-test tests show that multicollinearity is not present in our model (the null hypothesis of all insignificant coefficient being zero is not rejected), thus the not significant regressors can be simply removed from the analysis, increasing the overall power of the model and decreasing its complexity.

Endogeneity

- A possible criticism to our model is the likely presence of endogeneity, a quite common problem in econometric models. A variable is defined endogenous when there is a strong correlation between that variable and the error term. Intuitively, a loop of causality between the independent and dependent variables of a model leads to endogeneity. In more details,

² A high degree of multicollinearity may also occasion computer software packages to be unable to perform the matrix inversion, which is essential for computing the regression coefficients, making the results of that inversion inaccurate. It is indeed known that if two or more columns (rows) of a matrix are collinear, then the determinant of that matrix is 0 and inversion is not possible. Stata did not report any case of problems of the inversion of the matrix.

endogeneity can arise as a result of measurement errors, autocorrelated errors, simultaneity, omitted variables, and wrong sample selection.

- The main effect of endogeneity is that, in an OLS regression, the coefficients are biased. If there is no simultaneity, the estimates can still be consistent. In the worst case, this is the situation of our analysis.
- There are many methods to overcome endogeneity. Two of the most used ones are instrumental variables and the Heckman selection correction. Panel analysis can also be a good way to deal with endogeneity issues. In fact if the correlation structure that causes endogeneity is constant over time, a simple fixed effect model is able to deal with, possibly removing it from the analysis. This is due to the fact that, if the fixed effect model is the appropriate one, differencing (one of the possible tools used in fixed effect models) is able to remove constant structures from the data. However, if the correlation structure is not constant over time, other techniques, such as instrumental variables, are more suitable to treat endogeneity. If some endogeneity is present in our data/model, it is very likely due to a constant correlation structure, hence the panel analysis we have used should be sufficient to deal with it.
- Anyway, it is worth stressing that, in economics, everything tends to be endogenous. Therefore the use of some degree of moderation and wisdom is necessary when raising the point of endogeneity in a model.
- To partly control for endogeneity and multicollinearity among the different reform indicators we use a simple average index. The index takes the values 1 and 0 for countries that have implemented unbundling together with other reforms (reduction in market concentration, introduction of an autonomous regulator, and introduction of private ownership) and others that have not done so. However, this procedure imposes the restriction that each of the variables included in the index has the same proportionate impact on the dependent variable. This is a strong assumption, but at least our index is derived from direct observation rather than from impressionistic indicators that may not have an economic meaning (such as those derived by principal component analysis). That the core results are maintained even with combined aggregated reforms index suggests an underlying causal relationship and allow to control to some extent for endogeneity and multicollinearity. Even if they are not statistical artifacts arising from failures to address dynamics or endogeneity adequately, they may still be merely descriptions of a past set of events that cannot be applied to unbundling and future reform changes in sample countries—let alone to the implementation of unbundling and/or other sectoral reforms and/in other developing economies.