Estimating the Impact of Restructuring on Electricity Generation Efficiency: The Case of the Indian Thermal Power Sector

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Questions addressed

- How has restructuring of the state-owned electricity sector in India affected generation efficiency?
- How has unbundling generation from transmission and distribution at state-owned thermal plants affected:
  - Operating reliability (Plant availability and plant load factor)
  - Thermal efficiency of plants (Coal usage per kWh)
- Do effects depend on length of time since restructuring?

Context for the study

- Currently 75% of electricity generated is from coal-fired power plants
- In 1990:
  - 63% of installed capacity owned by state electricity boards
  - 33% by the federal government;
  - 4% by private companies (power sector nationalized in 1956)
- State Electricity Boards were vertically integrated monopolies: controlled virtually all of the distribution and most of the transmission services
- SEB revenues fell short of costs: partly due to transmission and distribution losses (30% of generation), but also due to subsidized pricing of electricity to agriculture, households
- Generation at state-owned thermal plants inefficient by international standards and also relative to centrally owned plants:
- 1988-91: Mean thermal efficiency 25%; mean plant load factor 50% mean forced outage= 19%

Nature of power sector reforms

- Generation opened up to Independent Power Producers – 1991
- State Electricity Regulatory Commissions (SERCs) allowed (1998 Act) and required (Electricity Act of 2003)
- SERCs to corporatize the SEBs, face them with hard budget constraints
- SERCs to unbundle generation from transmission and distribution
- SERCs to reform electricity tariffs
  - Subsidies to households, agriculture to be eliminated
  - Generators to be compensated based on plant availability and operating heat rate
- Ultimate goal is privatization

Why study unbundling?

- Unbundling/corporatization could increase operating reliability and thermal efficiency by:
  - Reducing diseconomies of scope
  - Providing an incentive to cut costs and reduce operating heat rate (e.g., by importing or washing coal)
  - Providing an incentive to improve plant reliability by increasing plant maintenance
- Timing of Unbundling Was Staggered:
  - 8 states unbundled between 1998 and 2002
  - 4 states unbundled between 2004 and 2008
  - 5 states unbundled after 2008
- Using panel data on state power plants from 1994-2008, estimate difference in differences models to examine effects of unbundling on plant reliability and thermal efficiency

Our approach

- Construct a panel dataset on 59 state power plants and 23 centrally owned plants, 1994-2008
- Estimate difference in differences models that control for plant and year fixed effects, state time trends and plant characteristics that vary over time (e.g., average unit age, capacity)
- Unbundling dummy (= 1 beginning in the year after unbundling occurs). Coefficient captures average impact of unbundling over all years and states

$$Y_{ijt} = \theta_{\{i\}} + \tau_{\{t\}} + X_{ijt}\beta + \gamma\, UNB_{\{jt\}} + \sum \varphi_j TREND_{jt} + \varepsilon_{ijt}$$

- Falsification test: Estimate models with central plants included (ascribing an unbundled dummy to them once the state in which they are located unbundles)
- Estimate models with impact of unbundling distinguished by whether unbundled prior to 2003
  - Does duration of time since unbundled matter?

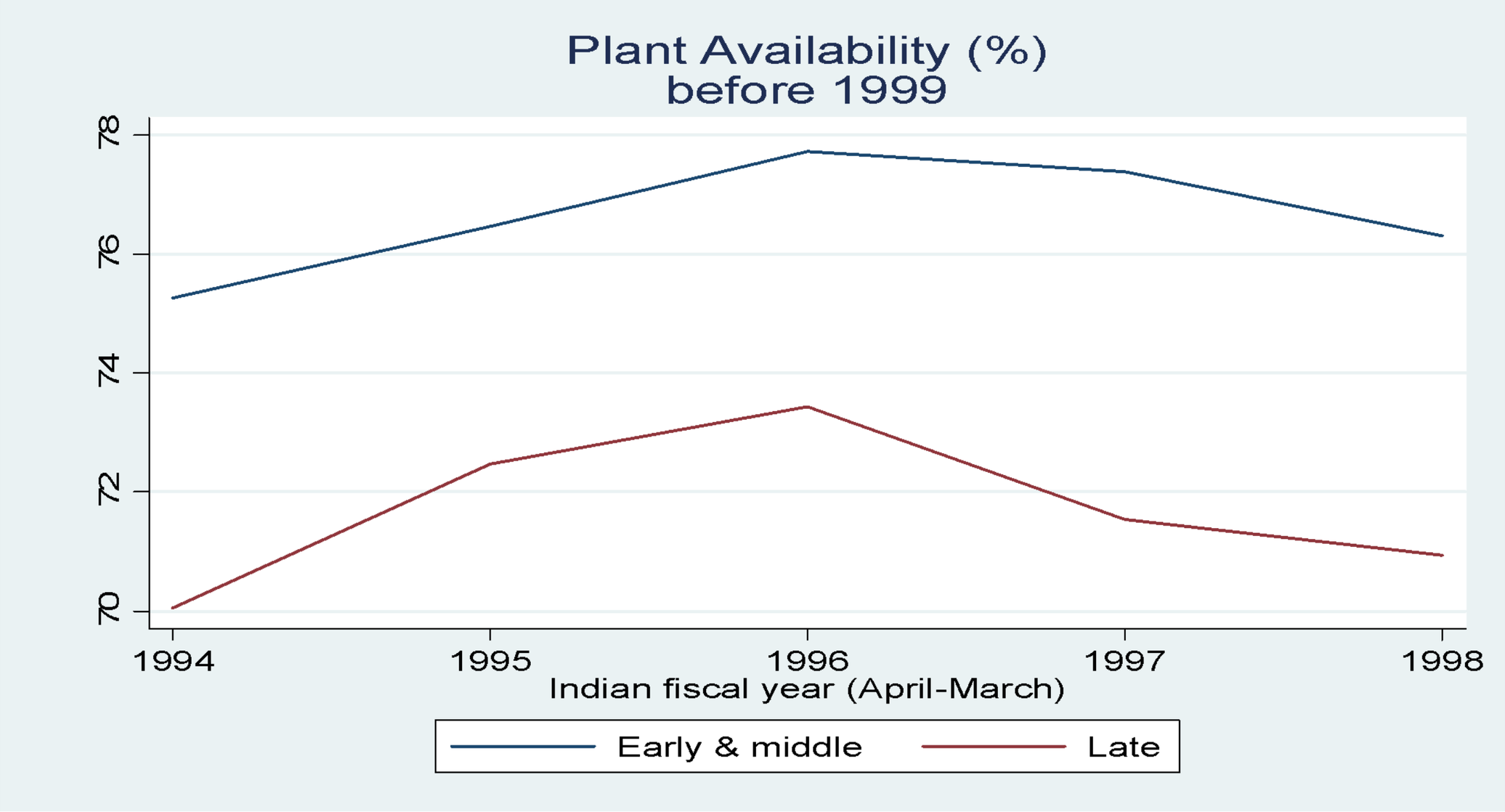
Timing of unbundling

State	Year Unbundled	Per capita income 1999 (Rs.)	Per capita generation 1997 (kWh)
Andhra Pradesh	1998	15,400	404
Haryana	1998	23,200	503
Orissa	1998	10,600	312
Karnataka	1999	17,500	349
Uttar Pradesh	1999	9,750	197
Rajasthan	2000	13,600	319
Delhi	2002	38,900	N/A
Madhya Pradesh	2002	12,400	398
Assam	2004	12,300	122
Maharashtra	2005	23,000	594
Gujarat	2006	18,900	723
West Bengal	2007	15,900	210
Tamil Nadu	2008	19,400	497
Punjab	2010	25,600	860
Bihar	Not yet	5,790	152
Chhattisgarh	Not yet	11,600	N/A
Jharkhand	Not yet	11,500	N/A

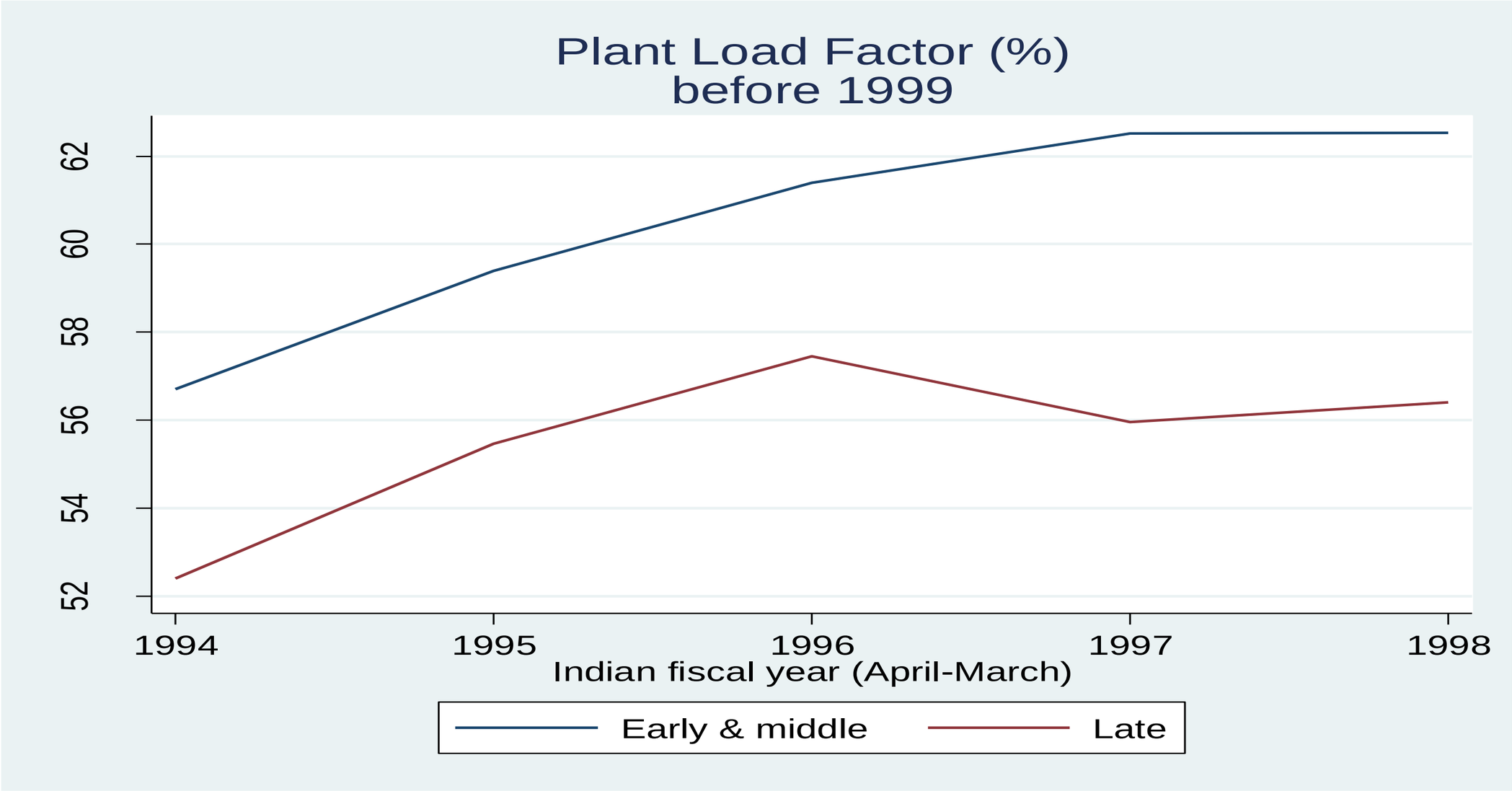
Endogeneity of unbundling

- Use of plant and year fixed effects and state time trends controls for
  - Differences in average levels of performance among plants
  - Linear trends across states
- Concern that states that would have improved faster without unbundling were the ones who unbundled first.
  - They would have deviated from their trends differently than the states that didn’t unbundle.
- Next slides show trends in plant availability, plant load factor and coal per kWh pre-reform for states that unbundled v. those that didn’t

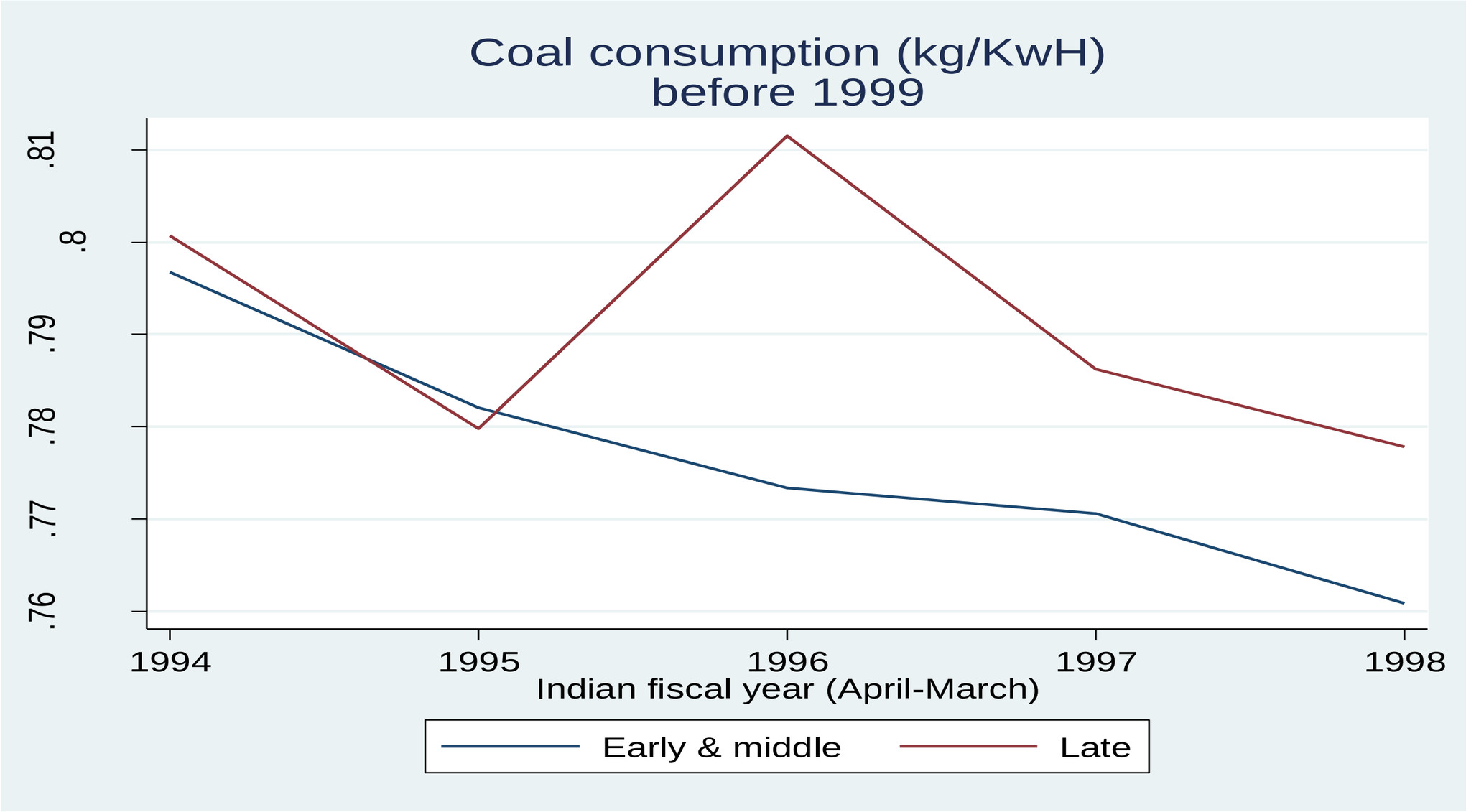
Plant availability trends pre-reform



Plant load factor trends pre-reform



Trends in coal consumption pre-reform



Thermal Efficiency Models

Dependent Variables

- Operating heat rate (kcal/kWh)
- Deviation of operating from design heat rate
- Coal burned per kWh

Controls

- Design heat rate
- Heating value of coal
- Average unit age
- Average unit age squared
- Average unit capacity
- Forced outage
- Plant load factor

Plant Reliability Models

Dependent Variables

- Plant availability (%)
- Plant load factor (%)
- Forced outage (%)
- Planned maintenance (%)

Controls

- Average unit age
- Average unit age squared
- Average unit capacity

Thermal efficiency results

	(1) Operating Heat Rate (Deviation)	(2) Log (Operating Heat Rate)	(3) Log (Specific Coal Consumption)	(4) Operating Heat Rate (Deviation)	(5) Log (Operating Heat Rate)	(6) Log (Specific Coal Consumption)
Unbundled	0.00934	0.0133	0.0184			
	(0.566)	(0.283)	(0.127)			
Unbundled before 2003				-0.0179	-0.00563	-0.00124
				(0.543)	(0.790)	(0.952)
Unbundled after 2003				0.0455*	0.0385*	0.0446**
				(0.0688)	(0.0535)	(0.0286)
Observations	376	376	376	376	376	376
R-squared	0.942	0.965	0.945	0.943	0.966	0.946

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Plant Reliability – State Plants Only

	(1) Plant Availability	(2) Plant Load Factor	(3) Forced Outage	(4) Planned Maintenance	(5) Plant Availability	(6) Plant Load Factor	(7) Forced Outage	(8) Planned Maintenance
Unbundled	2.765*	0.905	-1.483	-1.281				
	(0.0803)	(0.643)	(0.269)	(0.218)				
Unbundled before 2003					4.666**	3.287	-2.765	-1.902
					(0.0160)	(0.153)	(0.114)	(0.362)
Unbundled after 2003					0.200	-2.311	0.246	-0.443
					(0.953)	(0.502)	(0.934)	(0.866)
Observations	786	786	786	786	786	786	786	786
R-squared	0.801	0.877	0.656	0.518	0.802	0.878	0.657	0.519

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Plant Reliability with Central Plants

	(1) Plant Availability	(2) Plant Load Factor	(3) Forced Outage	(4) Planned Maintenance	(5) Plant Availability	(6) Plant Load Factor	(7) Forced Outage	(8) Planned Maintenance
Unbundled (State plants)	2.957**	-0.373	-1.234	-1.723*				
	(0.0493)	(0.846)	(0.317)	(0.0612)				
Unbundled before 2003					3.691*	0.243	-1.991	-1.700
					(0.0556)	(0.920)	(0.219)	(0.256)
Unbundled after 2003					1.793	-1.350	-0.0314	-1.760
					(0.551)	(0.680)	(0.991)	(0.361)
Unbundled (Center plants)	0.828	3.134	-3.763	2.936	1.234	3.476	-4.183*	2.949
	(0.768)	(0.365)	(0.137)	(0.162)	(0.646)	(0.295)	(0.0952)	(0.187)
Observations	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085
R-squared	0.792	0.870	0.677	0.491	0.792	0.870	0.677	0.491

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Summary of results

- Unbundling of generation from transmission and distribution may have increased plant availability
  - Appears to have increased plant availability by about 3 percentage points
  - Main impact felt by plants in states that unbundled early (4.7 percentage points)
- No improvements in thermal efficiency due to unbundling
  - Results agree with Fabrizio, Wolfram and Rose (2007) for US
  - Khanna and Zilberman (1999) prediction that plants would import coal once tariff lowered have not been born out; little coal washing
  - No improvements in thermal efficiency between 1994 and 2008 for early, late unbundlers, thermal efficiency worsened for middle unbundlers