Historical coal peak and destabilization mechanisms

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Why care about peaks?

- Technology lifecycle: expansion -> stagnation -> decline
- Our assumption: Coal declines towards zero in countries where we observe peaks and 10% decline over the post-peak period
- Few cases of near-zero coal; more cases of peaking coal plus 10% decline

Capacity or generation?

- Generation is more relevant for climate change
- But generation fluctuates a lot; can bounce back from a 10% decline
- Generation always peaks when capacity peaks
- Capacity peaks therefore seems to be a better indicator of the beginning of decline toward zero

Under what circumstances do we expect peaks?

- Declining electricity demand
- Large electricity system
- High import dependence
- Weak coal sector
- Old power plants
- High level of economic development
- High quality of government and democracy
- War or radical regime change
- PPCA

Excluded variables: PPCA, war/radical regime change

- PPCA and war/radical regime change never occur at the same time and place as peaking capacity
- UK-peak co-occurs with Northern Ireland conflict if we use a less conservative indicator of war/regime change
- All peaks among medium-large PPCA-countries occur before 2015 (mean: 1997), but capacity has not yet peaked in Israel, Mexico, Chile, and Ukraine
- Only two peaks among non-PPCA countries: Australia (2009), and United States (2011)

Sample

- Initial sample (i.e., available WEPP and IEA data): 72 countries
- Excluding countries with small or immature coal sectors: 21 countries (including 25 PPCA members)
- Excluding countries with insufficient data for independent variables: 3 countries
- Final sample: 47 countries that account for 99% of coal generation in the world

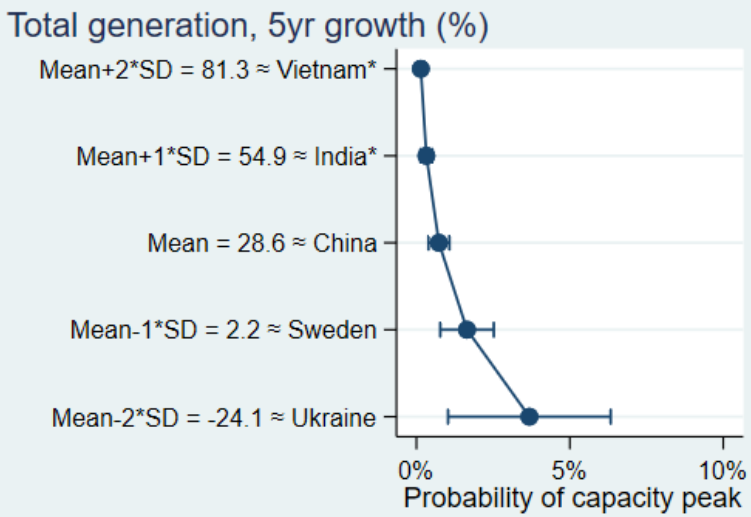
Method

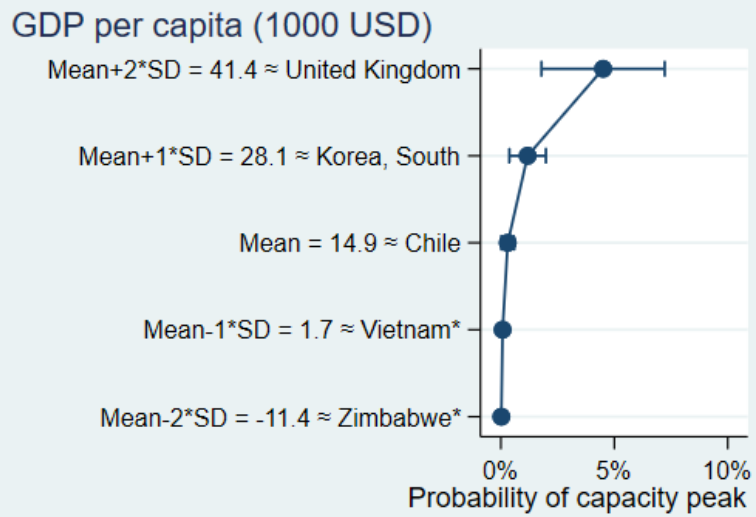
- Years nested in countries
- Regression analysis with complementary log-log link
- Linear function of time
- Country-clustered standard errors
- Robustness tests: alternative functions of time, bivariate models, time-varying coefficients, fixed country effects (excluding years with no failures), factor analysis, omitting outliers, additional controls

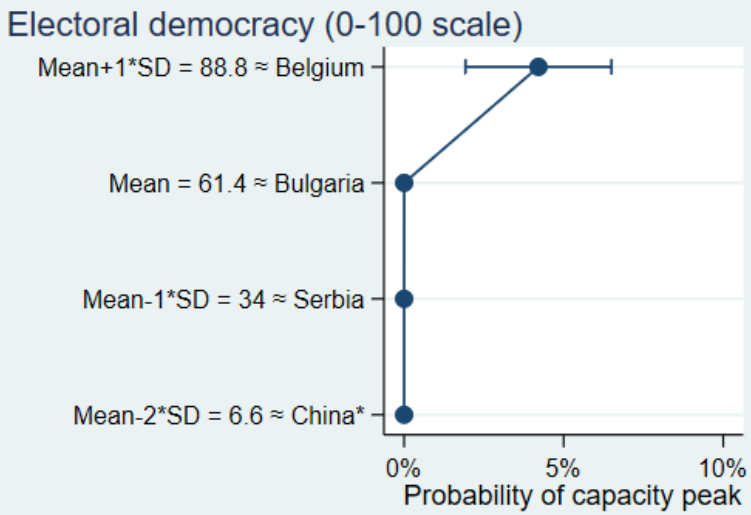
Results

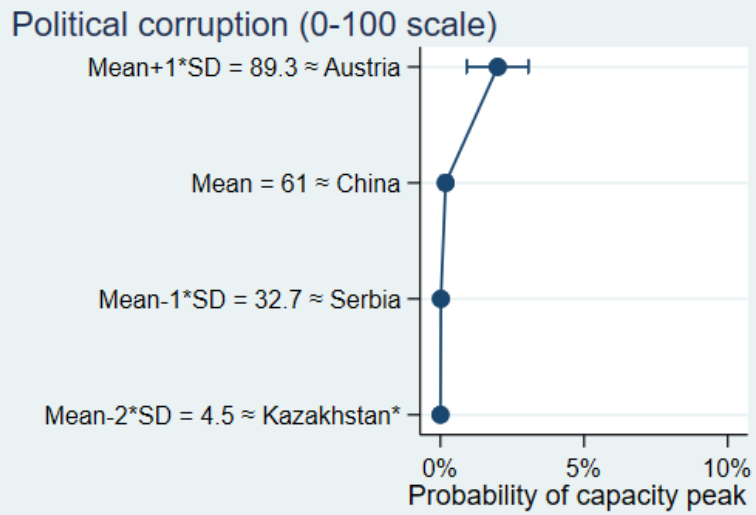
- Robust effects:
  - Demand growth (-)
  - GDP per capita (+)
  - Electoral democracy (+)
  - (absence of) Political corruption (+)

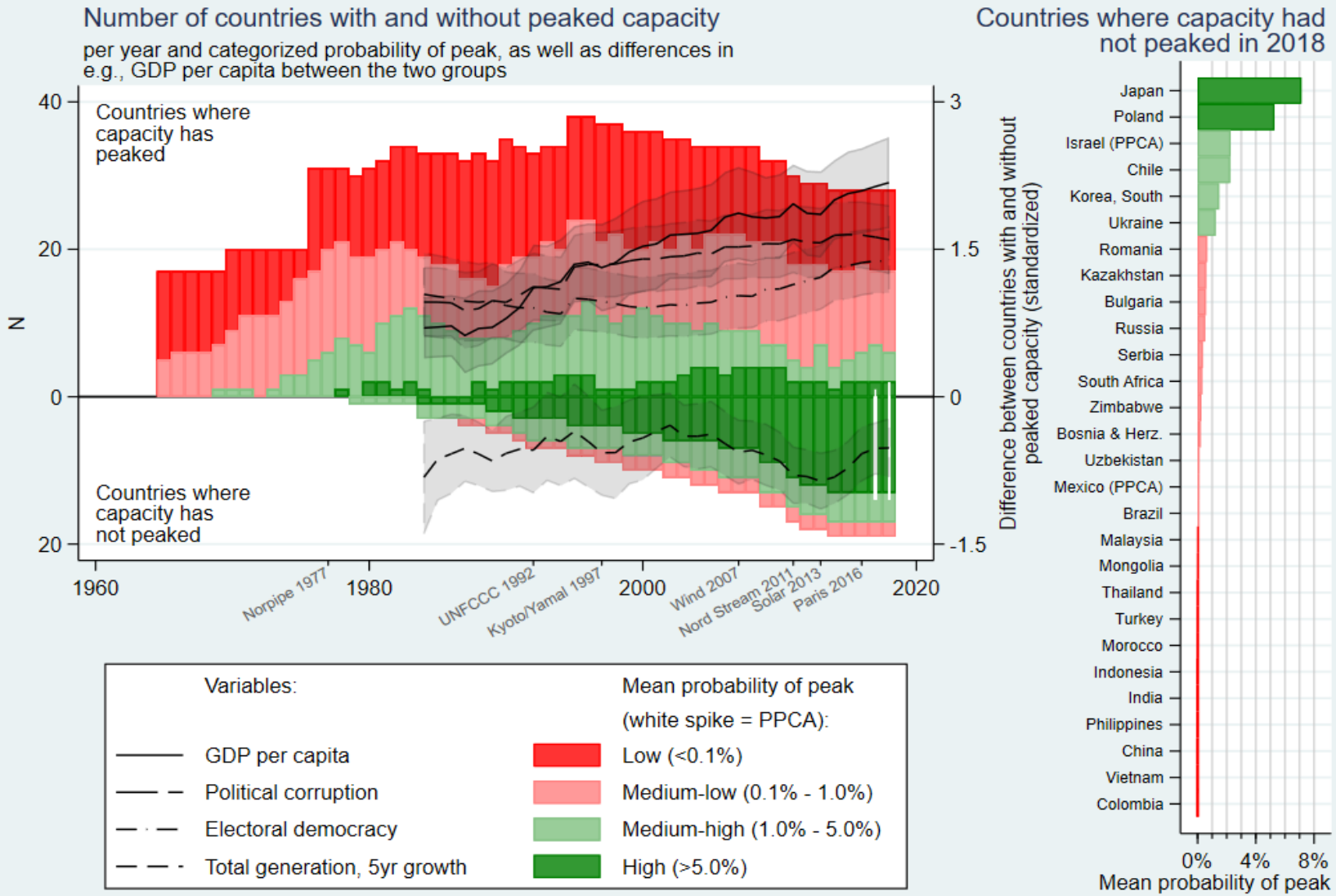
- Null or non-robust results
  - Size of electricity system
  - Import dependence
  - Age of power plants
  - Year


Total generation, 5yr growth (%)
Mean+2*SD = 81.3 ≈ Vietnam*
Mean+1*SD = 54.9 ≈ India*
Mean = 28.6 ≈ China
Mean-1*SD = 2.2 ≈ Sweden
Mean-2*SD = -24.1 ≈ Ukraine
0%
5%
10%
Probability of capacity peak


GDP per capita (1000 USD)
Mean+2*SD = 41.4 ≈ United Kingdom
Mean+1*SD = 28.1 ≈ Korea, South
Mean = 14.9 ≈ Chile
Mean-1*SD = 1.7 ≈ Vietnam*
Mean-2*SD = -11.4 ≈ Zimbabwe*
0%
5%
10%
Probability of capacity peak


Electoral democracy (0-100 scale)
Mean+1*SD = 88.8 ≈ Belgium
Mean = 61.4 ≈ Bulgaria
Mean-1*SD = 34 ≈ Serbia
Mean-2*SD = 6.6 ≈ China*
0%
5%
10%
Probability of capacity peak


Political corruption (0-100 scale)
Mean+1*SD = 89.3 ≈ Austria
Mean = 61 ≈ China
Mean-1*SD = 32.7 ≈ Serbia
Mean-2*SD = 4.5 ≈ Kazakhstan*
0%
5%
10%
Probability of capacity peak


Number of countries with and without peaked capacity
per year and categorized probability of peak, as well as differences in e.g., GDP per capita between the two groups
Countries where capacity has peaked
Countries where capacity has not peaked
N
40
20
0
20
3
1.5
0
-1.5
1960
1980
2000
2020
Norpipe 1977
UNFCCC 1992
Kyoto/Yamal 1997
Wind 2007
Nord Stream 2011
Solar 2013
Paris 2016
Variables:
GDP per capita
Political corruption
Electoral democracy
Total generation, 5yr growth
Mean probability of peak
(white spike = PPCA):
Low (<0.1%)
Medium-low (0.1% - 1.0%)
Medium-high (1.0% - 5.0%)
High (>5.0%)
Countries where capacity had not peaked in 2018
Difference between countries with and without peaked capacity (standardized)
Japan
Poland
Israel (PPCA)
Chile
Korea, South
Ukraine
Romania
Kazakhstan
Bulgaria
Russia
Serbia
South Africa
Zimbabwe
Bosnia & Herz.
Uzbekistan
Mexico (PPCA)
Brazil
Malaysia
Mongolia
Thailand
Turkey
Morocco
Indonesia
India
Philippines
China
Vietnam
Colombia
0%
4%
8%
Mean probability of peak

Conclusions

- Coal seems to declines in wealthy countries with incorrupt governments, democracy, when electricity demand declines
- The size of the coal sector, electricity system, share of imports (coal specific and total), and age of power plants seems to matter less
- Coal has already peaked in most countries with decent conditions.
- It might peak soon in Japan, Poland, Israel, Chile, South Korea, and Ukraine.
- But it is unlikely to peak in most countries – including populous and coal intensive countries like China and India.

Thanks for listening!

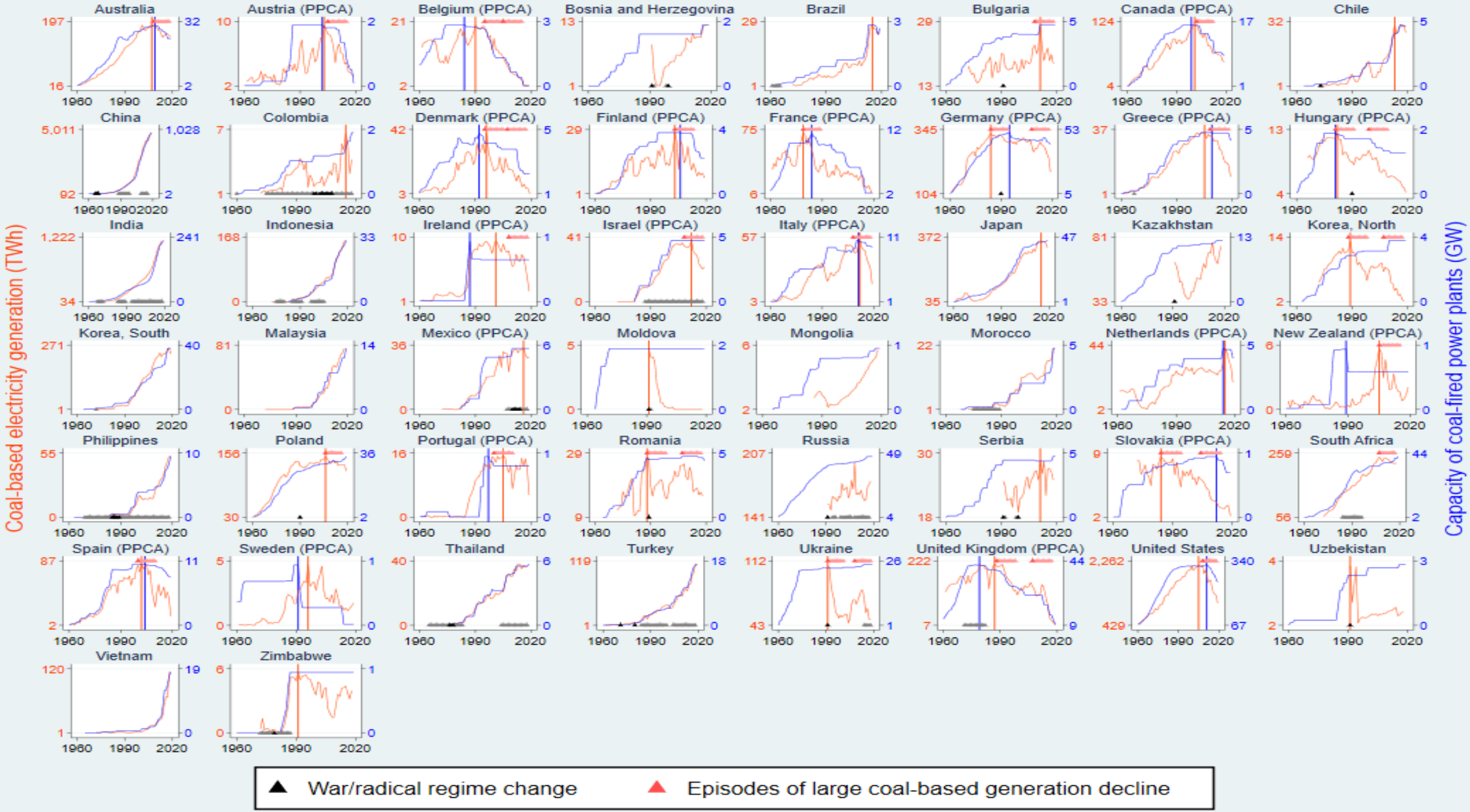

Coal-based electricity generation (TWh)
Capacity of coal-fired power plants (GW)
Australia
Austria (PPCA)
Belgium (PPCA)
Bosnia and Herzegovina
Brazil
Bulgaria
Canada (PPCA)
Chile
China
Colombia
Denmark (PPCA)
Finland (PPCA)
France (PPCA)
Germany (PPCA)
Greece (PPCA)
Hungary (PPCA)
India
Indonesia
Ireland (PPCA)
Israel (PPCA)
Italy (PPCA)
Japan
Kazakhstan
Korea, North
Korea, South
Malaysia
Mexico (PPCA)
Moldova
Mongolia
Morocco
Netherlands (PPCA)
New Zealand (PPCA)
Philippines
Poland
Portugal (PPCA)
Romania
Russia
Serbia
Slovakia (PPCA)
South Africa
Spain (PPCA)
Sweden (PPCA)
Thailand
Turkey
Ukraine
United Kingdom (PPCA)
United States
Uzbekistan
Vietnam
Zimbabwe
War/radical regime change
Episodes of large coal-based generation decline

Table 2. Countries in the initial sample, countries excluded for various reasons and the final sample

Initial sample (data available for capacity and generation) (72 countries)
Argentina, Australia, Austria, Bangladesh, Belgium, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Cambodia, Canada, Chile, China, Colombia, Croatia, Denmark, Dominican Republic, Finland, France, Germany, Greece, Guatemala, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Kazakhstan, Korea (Dem. People's Rep. of), Korea (Rep. of), South, Kyrgyzstan, Laos, Malaysia, Mexico, Moldova*, Mongolia, Montenegro, Morocco, Myanmar, Namibia, Netherlands, New Zealand, Niger, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Romania, Russia, Senegal, Serbia, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Tajikistan, Tanzania, Thailand, Turkey, Ukraine, United Kingdom, United States, Uzbekistan, Vietnam, Zambia, Zimbabwe
Small or immature coal sector (peak generation<1 TWh OR (peak generation 1-3 TWh AND share of coal in total generation<33%) OR pre-2010 peak capacity < 500 MW) (21 countries)
Argentina, Bangladesh, Botswana, Cambodia, Croatia, Dominican Republic, Guatemala, Kyrgyzstan, Laos, Montenegro, Myanmar, Namibia, Niger, Panama, Peru, Senegal, Slovenia, Sri Lanka, Tajikistan, Tanzania, Zambia
Countries with insufficient time series for independent variables (3 countries)
Hungary, Korea (Dem. People's Rep. of), Pakistan
Final sample (47 countries)
Australia, Austria, Belgium, Bosnia and Herzegovina, Brazil, Bulgaria, Canada, Chile, China, Colombia, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Israel, Italy, Japan, Kazakhstan, Korea (Rep. of), Malaysia, Mexico, Mongolia, Morocco, Netherlands, New Zealand, Philippines, Poland, Portugal, Romania, Russia, Serbia, Slovakia, South Africa, Spain, Sweden, Thailand, Turkey, Ukraine, United Kingdom, United States, Uzbekistan, Vietnam, Zimbabwe

* We exclude Moldova because of difficulties of obtaining reliable socio-economic variables due to a frozen conflict essentially splitting the country in two disconnected economies.

Table 3. Peak coal capacity timing in countries with and without PPCA membership

	Peak	No peak	Peak year			Country
	N	N	Earliest	Mean	Latest	(peak year)
PPCA members	18	2	1979	1997	2014	Austria (2002), Belgium (1984), Canada (1999), Denmark (1992), Finland (2006), France (1984), Germany (1995), Greece (2009), Hungary* (1981), Ireland (1987), Italy (2011), Netherlands (2014), New Zealand (1989), Portugal (1997), Slovakia (2012), Spain (2004), Sweden (1991), United Kingdom (1979) Israel (none), Mexico (none), Chile (none), Ukraine (none)
Non-members	2	28	2009	2010	2011	Australia (2009), United States (2011) Bosnia and Herzegovina (none), Brazil (none), Bulgaria (none), China (none), Colombia (none), India (none), Indonesia (none), Japan (none), Kazakhstan (none), Korea, North* (none), Korea, South (none), Malaysia (none), Moldova** (none), Mongolia (none), Morocco (none), Philippines (none), Poland (none), Romania (none), Russia (none), Serbia (none), South Africa (none), Thailand (none), Turkey (none), Uzbekistan (none), Vietnam (none), Zimbabwe (none)
25 PPCA members with no or only small coal power plants (not included in the sample)	n/a	n/a	n/a	n/a	n/a	Albania (n/a), Angola (n/a), Azerbaijan, Costa Rica (n/a), Croatia (n/a), El Salvador (n/a), Estonia, Ethiopia (n/a), Fiji (n/a), Latvia (n/a), Liechtenstein (n/a), Lithuania (n/a), Luxembourg (n/a), Marshall Islands (n/a), Mauritus, Montenegro (n/a), North Macedonia (n/a), Peru (n/a), Senegal (n/a), Singapore, Slovenia, Switzerland (n/a), Tuvalu (n/a), Uruguay (n/a), Vanuatu (n/a)

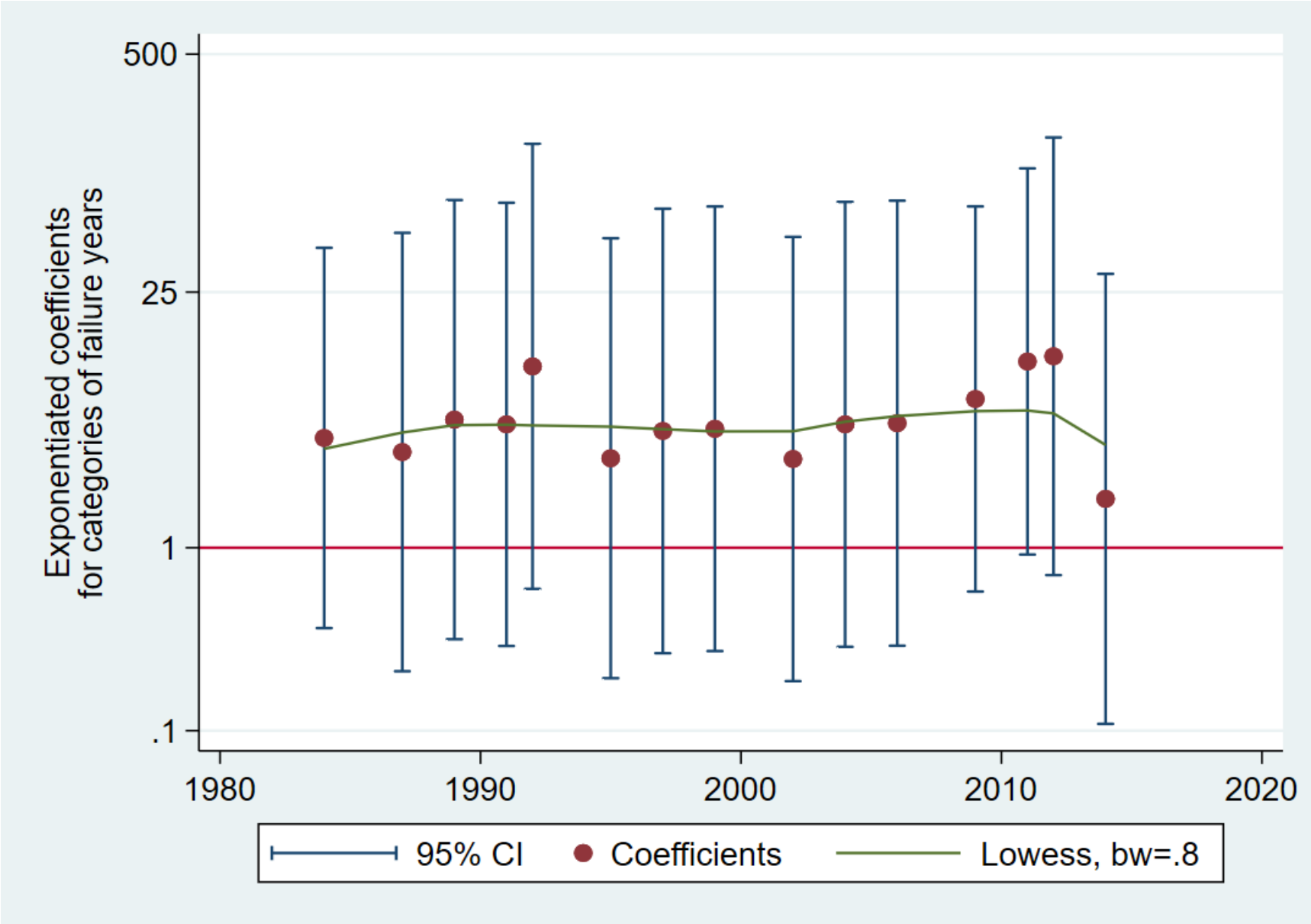

Exponentiated coefficients
for categories of failure years
500
25
1
.1
1980
1990
2000
2010
2020
95% CI
Coefficients
Lowess, bw=.8

Table 4. Results of the regression analysis

	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se
Total electricity generation, 5yr growth (%)	0.96*** (0.01)	0.92*** (0.02)	0.93*** (0.02)	0.94*** (0.01)	0.94*** (0.01)
Total electricity generation, peak (1000 TWh)	0.94*** (0.02)	0.96*** (0.01)	0.94*** (0.01)	0.96** (0.02)	0.96** (0.02)
Total electricity generation, share of coal (%)	0.99 (0.01)	0.97* (0.01)	1.05 (0.04)	0.98 (0.01)	0.97*** (0.01)
Coal-based generation, share of imports (%)	0.99 (0.01)	0.99 (0.01)	0.99 (0.01)	0.99 (0.01)	0.98** (0.01)
Total generation, share of imports (%)	1.00 (0.01)	1.00 (0.01)	0.99 (0.01)	1.01 (0.02)	1.01 (0.02)
Capacity-weighted mean plant age (years)	1.09* (0.05)	1.02 (0.03)	1.05 (0.04)	1.08* (0.04)	1.10** (0.05)
Year	0.96 (0.03)	1.03 (0.03)	1.01 (0.03)	1.02 (0.02)	1.02 (0.02)
GDP per capita (1000 USD)	1.11*** (0.02)				
Electoral democracy (0-100 scale)		1.34*** (0.10)	1.33*** (0.09)		
Political corruption (0-100 scale)				1.09*** (0.01)	1.10*** (0.01)
Total generation, share of coal (%) # Total generation, share of coal (%)			1.00** (0.00)		
Total generation, share of coal (%) # Coal-based generation, share of imports (%)					1.00*** (0.00)
Constant	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)
AIC	174	162	159	170	169
BIC	222	211	213	219	223
HL-test	0.36	0.22	0.14	0.16	0.13
Link-test	0.99	1.01**	0.99	0.95	0.95
N	1642	1642	1642	1642	1642