Assessing the Impact of the Diffusion of Shale Oil and Gas Technology on the Global Coal Market

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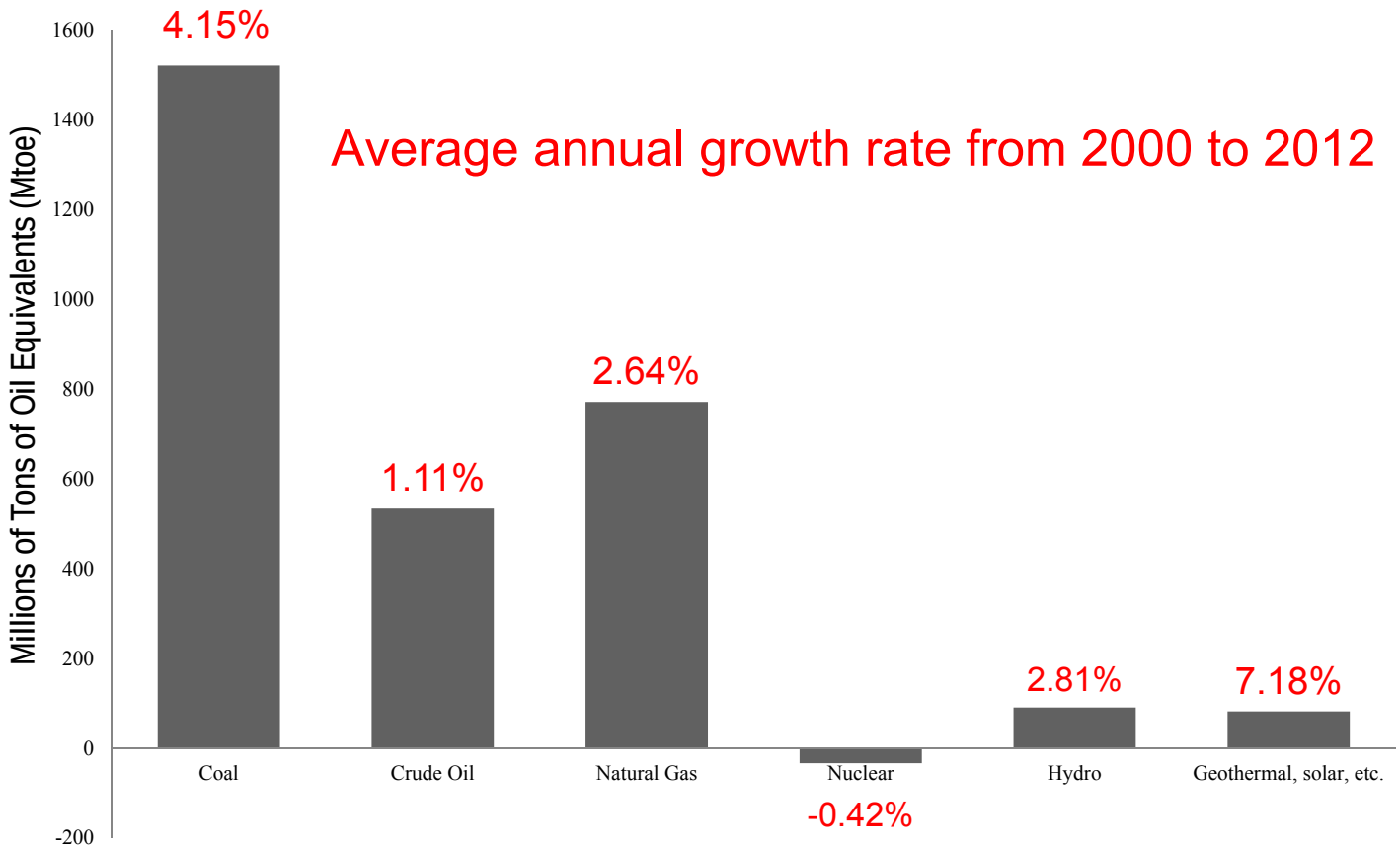
Coal versus Natural Gas Competition in Global Energy Markets

- Shale oil and gas boom has impacted global coal markets
  - Low cost domestic shale gas leads to coal to natural gas switching in electricity sector
  - Reduces domestic coal prices which also lowers world coal prices
  - Makes coal more attractive in regions without domestic shale gas resources
  - Reduces demand for LNG exports to these regions
- Build model of global coal and LNG markets that can be used to quantify these impacts

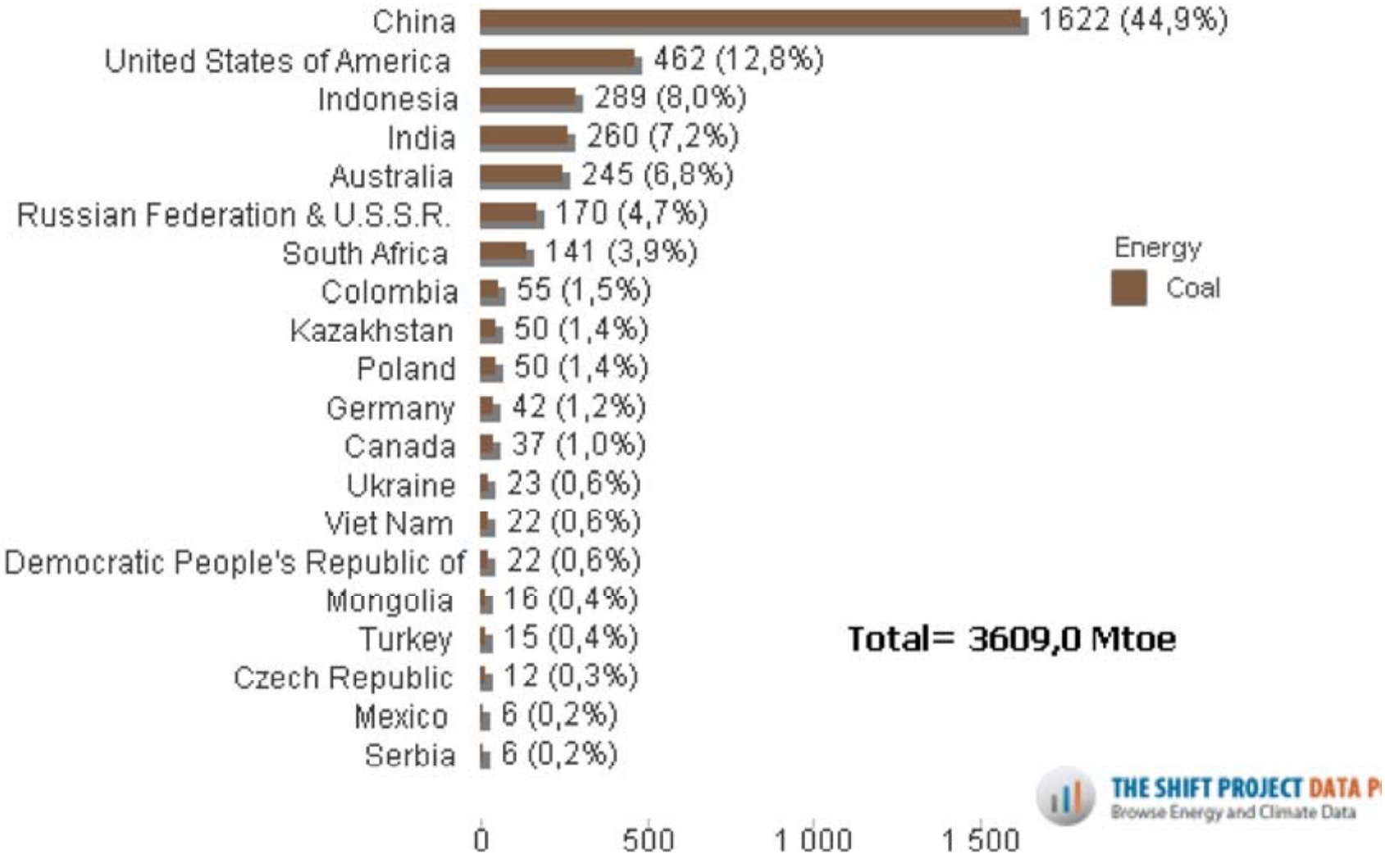
Coal: The World's Fastest Growing Fossil Fuel

Growth in Global Energy Supply 2000-2012 in MTOE



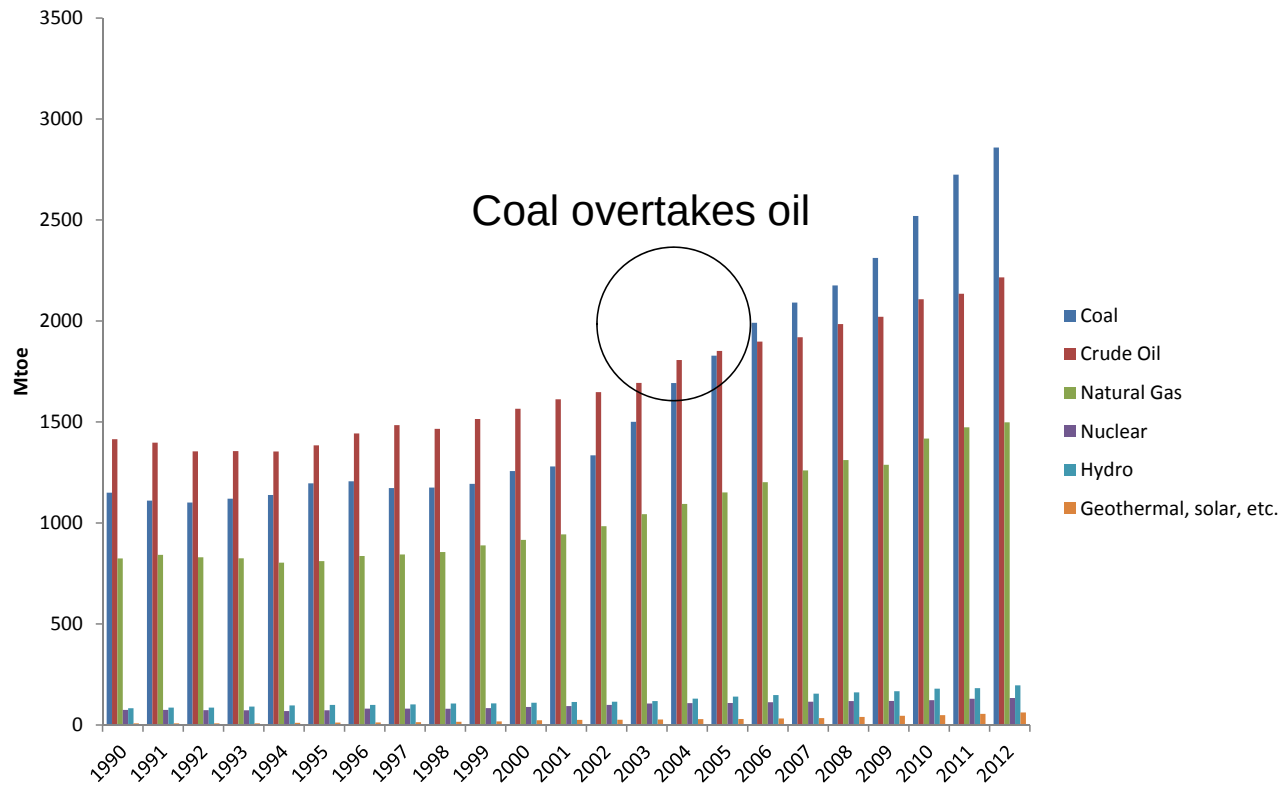
Sources of Global Coal Supply in 2014 in MTOE

China is Coal Importer (approximately 5 percent of consumption)

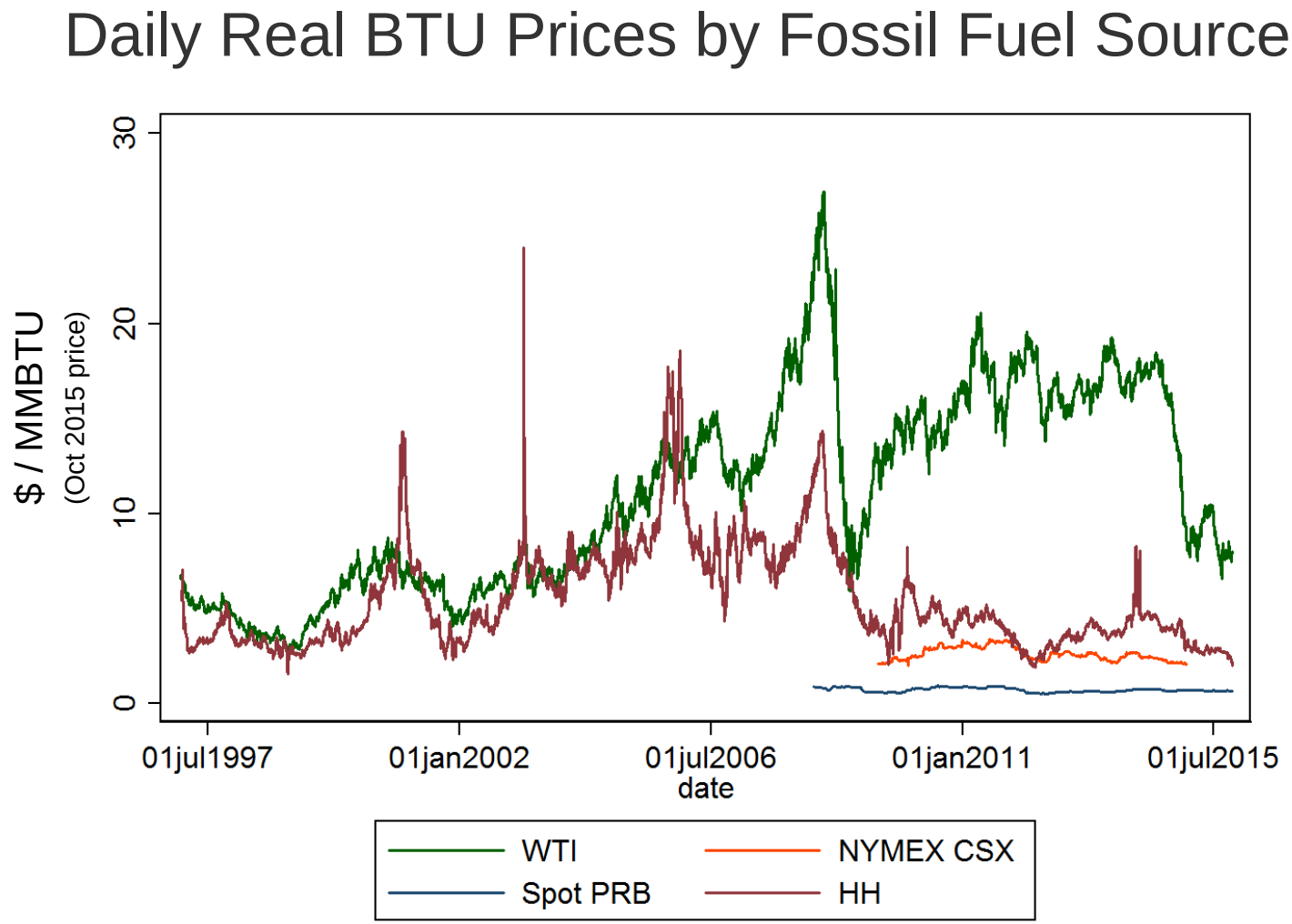


Non-OECD Country Energy Consumption 1990-2012 in MTOE

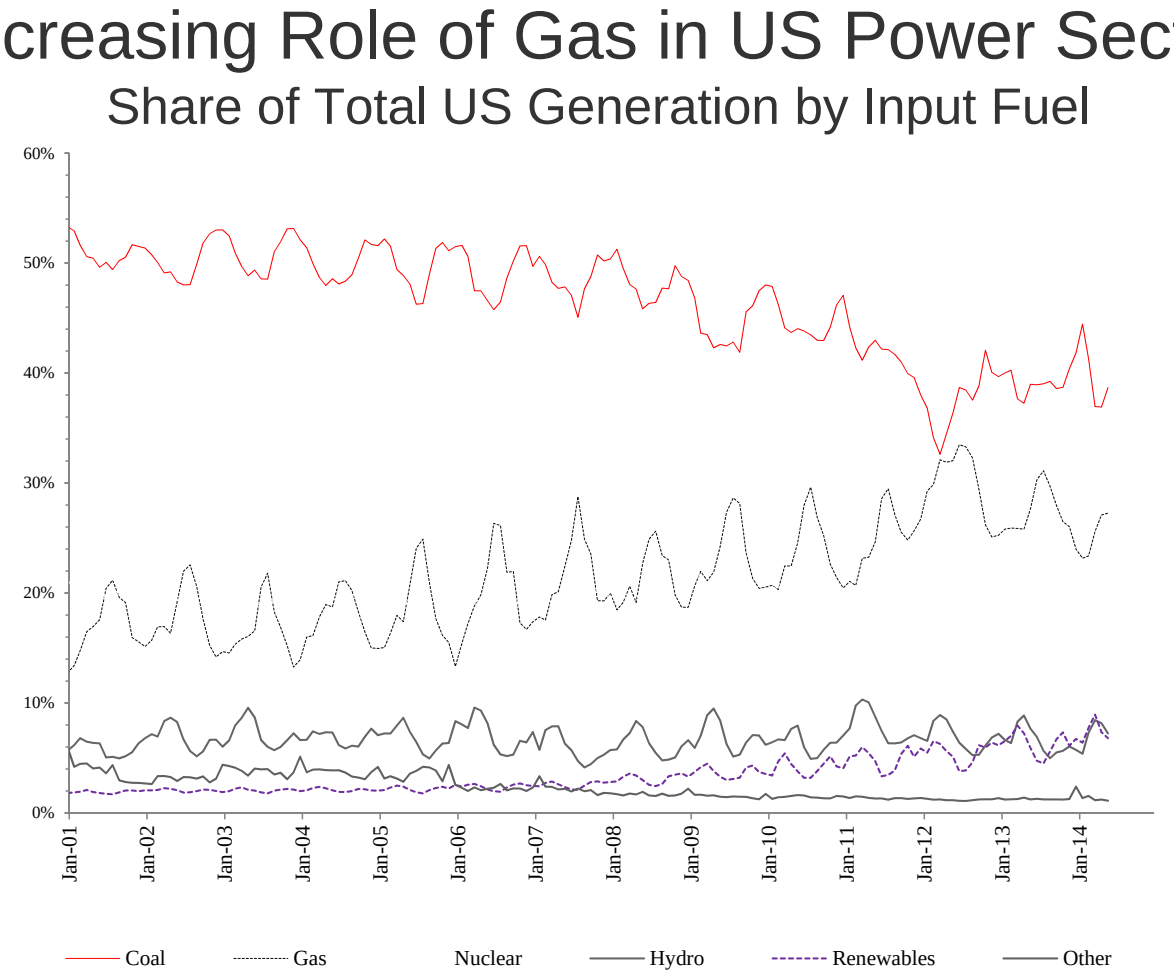
Low Cost Energy (Coal) Drives Economic Development in Non-OECD Countries



Real Fossil Fuel Prices in $/MMBTU 1997-2015



Coal to Gas Switching in Electricity Sector 2001 to 2014



In April 2012, Coal provided 34% and Natural Gas 32% of Total US Generation

At same $/MMBTU price, natural gas-fired electricity is typically cheaper

- Average heat rate of coal-fired unit significantly larger than that for combined-cycle gas turbine (CCGT) unit
  - Heat Rate = MMBTU of input fuel required to produce 1 Megawatt-hour (MWh) of electricity
- Average Heat Rate of coal unit could be twice that of CCGT generation unit
- Even if $/MMBTU price of coal is less than price of natural gas, economics could favor natural gas
  - 12 MMBTU/MWh x $2/MMBTU coal = $24/MWh from coal
  - 7 MMBTU/MWh x $3/MMBTU gas = $21/MWh from gas
  - Variable O&M cost for coal > Variable O&M cost for gas
- $/MW of capacity cost for coal-fired power unit greater than $/MW of capacity cost for natural gas-fired unit

US Shale Oil and Gas Revolution and Global Coal Market

- Low natural gas prices in US led to coal-to-natural gas switching in US electricity sector and reduced US GHG emissions
- Reduced US coal use, lowered US coal prices, which increased coal exports to Europe
  - From 2009 to 2013 coal use in Europe increased and only recently it has begun to fall
  - Coal consumption in Europe fell in part because of a significant decline in European natural gas prices due to reduction in global oil prices
- Coal consumption, particularly in developing world, remains strong

US Shale Oil and Gas Revolution and Global Coal Market

- Liquified natural gas (LNG) is marginal source of natural gas in continental Europe
  - LNG price must recover cost of liquefaction at origin and cost of re-gasificatin at destination (typically adds about $3/MMBTU to delivered price
  - Persistent natural gas price differences between regions with domestic shale or conventional gas and those that rely on LNG imports creates opportunities for increased sales of displaced coal in markets without domestic natural gas
- Research Questions: What is impact of diffusion of US shale oil and gas technology on global coal market?
- How much does diffusion of shale oil and gas technology reduce global GHG emissions?

Research Strategy I

- Specify spatial equilibrium model of global coal market that accounts for
  - Major producing regions (26 regions)
  - Major consuming regions with particular focus on US and China (23 regions)
  - Land and Ocean Transportation between regions
  - Models demand for coal in terms of energy (Gigajoules (GJ)) and price of coal in ($/GJ)
  - Models production cost and transportation costs in terms of weight (Tonnes)
  - Allows for export constraints and transportation link constraints in coal movements
  - Allows for capacity constraints on annual production from producing region

Research Strategy II

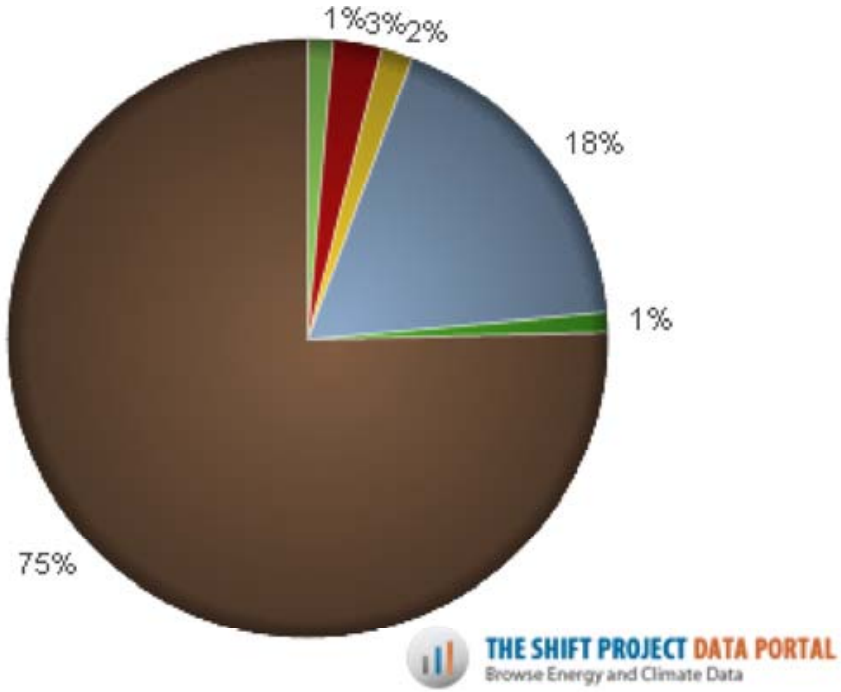
- Allow for price-elastic and demand for coal in regions with potential for coal-to-natural gas switching
  - Requires significant installed coal-fired and natural-gas fired generation capacity in consuming region
  - This is only the case in a few industrialized regions–US and European Union (EU)
  - Econometrically estimate own-price elasticity of demand for coal and cross-price elasticity with respect to price of natural gas
- Eight future natural gas price scenarios in the US and EU–Baseline, continued boom, and end of boom
- Coal export constraint from Western US limits Powder River Basin coal's ability to compete in vast Asian market
  - Use model to measure impact of relaxing this constraint

No Potential for Coal-to-Natural Gas Switching in China

Electricity Production
from All Energy Sources from 1980 to 2014 (China, TWh)

Electricity Source	TWh
Others	801
Oil	1 544
Nuclear	1 009
Hydroelectric	10 631
Gas	609
Coal	44 680

Total = 59274 TWh

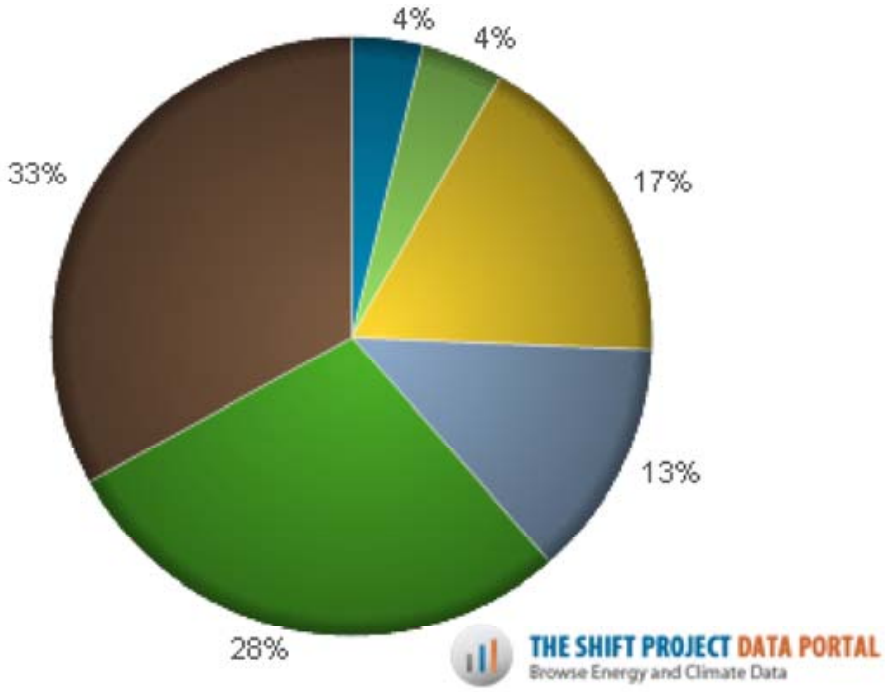


Potential for Coal-to-Natural Gas Switching in US

Electricity Production
from All Energy Sources in 2014 (North America, TWh)

Electricity Source	TWh
Wind	198
Others	231
Nuclear	907
Hydroelectric	673
Gas	1 477
Coal	1 724

Total = 5211 TWh

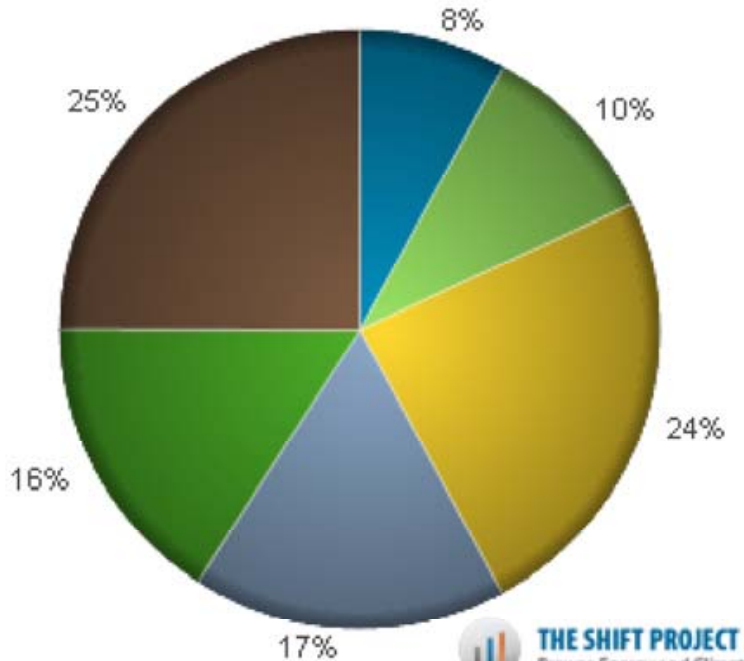


Potential for Coal-to-Natural Gas Switching in EU

Electricity Production
from All Energy Sources in 2014 (Europe, TWh)

Electricity Source	TWh
Wind	283
Others	362
Nuclear	858
Hydroelectric	604
Gas	571
Coal	889

Total = 3568 TWh



Estimating Coal Demand in US and EU

- Estimate conditional (on total fossil fuel generation in region) demand for coal given price of coal and price of natural gas
- Functional form for demand curve
$ln(QCoal_{rt}) = \beta_{r1} ln(coalp_{rt}) + \beta_{r2} ln(gasp_{rt}) + \beta_3 ln(fossilgen_{rt}) + \alpha_r + \epsilon_{rt}$
  - $QCoal_{rt}$ is the quantity of coal in GJ consumed in region r in quarter t,
  - $coalp_{rt}$ is the price of coal in dollars per GJ in region r in quarter t,
  - $gasp_{rt}$ is the price of natural gas in dollars per GJ in region r in quarter t,
  - $fossilgen_{rt}$ is the total amount of fossil-fuel generation in terawatt-hours (TWh) in region r in quarter t
  - α_r is a region-specific fixed-effect
  - ϵ_{rt} is a mean zero disturbance term.

US Coal Demand Estimates

VARIABLES	(1) log_coal_consumption	Standard Errors
Central Region log coal price	-0.0892	(0.0110)
East Region log coal price	-0.524	(0.0280)
Gulf Region log coal price	-0.282	(0.0202)
Rocky Mtn Region log coal price	-0.308	(0.0250)
South Region log coal price	-0.149	(0.0159)
Central Region log gas price	0.0587	(0.0105)
East Region log gas price	0.274	(0.0293)
Gulf Region log gas price	0.185	(0.0181)
Rocky Mtn Region log gas price	0.00616	(0.0179)
South Region log gas price	0.124	(0.0140)
Log total fossil gen	0.698	(0.0178)
Constant	8.150	(0.319)
Observations	740	
R-squared	0.975	

Arellano (1987) robust standard errors in parentheses
Model Estimates Using Quarterly Region-Level Data from EIA

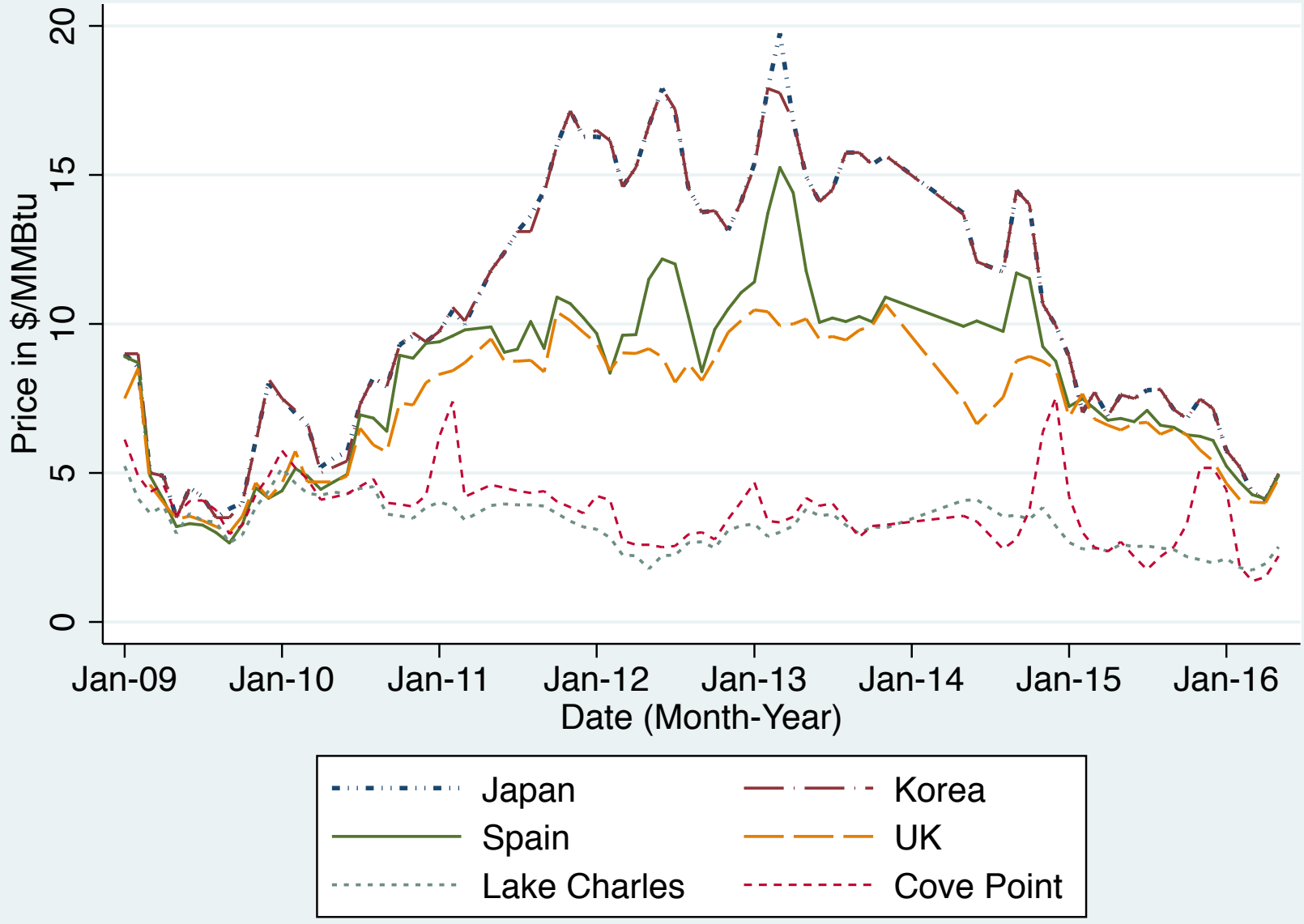
EU Coal Demand Estimates

VARIABLES	(1) ln_coal_consumption	Standard Errors
log coal price	-0.304	(0.116)
log gas price	0.182	(0.0991)
log total fossil gen	1.520	(0.390)
Constant	2.530	(4.285)
Observations	112	
R-squared	0.988	

Arellano (1987) robust standard errors in parentheses
Model Estimated Using Annual Country-Level Data from IEA

Choosing Natural Gas Price Scenarios

Global Landed LNG Prices in $/MMBTU from 2009 to 2016



Conclusions from Modeling Results I

- All shale oil and gas boom scenarios, (P_US_Cnt/P_US_Bse) < 1 and/or (P_EU_Cnt/P_US_Bse) < 1, predict larger coal consumption reductions in all EU and all US consuming regions except Rocky Mtn
  - Cheap Powder River Basin coal in Rocky Mtn region implies no coal-to-natural gas switching is economic, even at current natural gas prices
- Unilateral natural gas price reductions in US or EU yield larger in absolute value coal consumption reductions than same magnitude joint natural gas price reductions
  - Eastern US coal competes in European market, so lower US coal prices imply more US coal sold in EU

Conclusions from Modeling Results II

- Small change in both producer prices in US and delivered price across natural gas price scenarios, consistent with flat marginal cost curves for coal production
- Shale gas boom ending scenarios, (P_US_Cnt / P_US_Bse) $>$ 1 and/or (P_EU_Cnt/P_EU_Bse) $= 1$, predict increases in US and EU coal consumption
- Coal demand in other consuming regions of the does not change because these regions have little, if any, ability to switch from coal to natural gas in short to medium-term

Conclusions from Modeling Results III

- Coal to natural gas switching in US and EU in response to low natural gas prices reduces global GHG emissions
  - Every MWh of electricity produced by natural gas instead of coal implies a 1/2 to 2/3 reduction in GHG emissions
- Differential impacts of natural gas price changes across consuming regions of US due to differences in composition of generation fleet in region beginitemize
- For example, generation fleet in Rocky Mtn region composed primarily of coal units, whereas Eastern Region has mix of coal and natural gas units
- West coast coal export constraint is binding under base case and all counterfactuals, suggesting a market for Powder River Basin coal in Asia
  - Run Cmp-Cmp-Open scenario to assess impact of relaxing west coast coal port export constraint

Directions for Future Research

- Global coal and natural gas markets are integrated to the extend to which there are possibilitiies for coal-to-natural gas switching in the electricity sector
- The two markets are likely to become even more integrated as more regions install natural gas-fired generation units and more regions develop domestic shale gas resources
- Coal-to-gas switching more likely to occur and likely to be larger in regions with domestic shale gas resources
  - This reduces domestic demand for coal, which makes this coal more attractive on international market as a competitor to LNG
- Use model to understand how coal and gas production and international flows change as new domestic shale resources are developed

Questions or Comments?

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