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Energy markets in transition with a focus on LNG:
Growing pains, new technologies and new trading arrangements

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IAEE Distinguished Lecturer, 2016

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Outline of Talk

- Economic growth and energy demand
- Technological change and fossil fuels
- Alternative energy technologies
- Modeling the transition process
- The future role of natural gas
- LNG market developments
- The value of long-term LNG contracts
- Indexing in long-term LNG contracts

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TOPIC 1

Economic growth and energy demand

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Economic growth and overall energy demand

- Access to modern energy is essential for economic growth
  - Access to non-human/non-animal energy sources was an essential ingredient in the industrial revolution
- Fossil fuels are relatively dense energy sources:
  - Gasoline 46.9GJ/t by weight, 34.6 MJ/L by volume; Diesel 45.8 GJ/t, 37.3 MJ/L
  - Filling a car, flow rate is ~ 40L/minute = 83 GJ/hour = 23 MW power plant output
  - Power of average human worker is about 75W, so 2000 hours of work per year delivers 150 kWh = 540 MJ = energy in about 15 L of diesel

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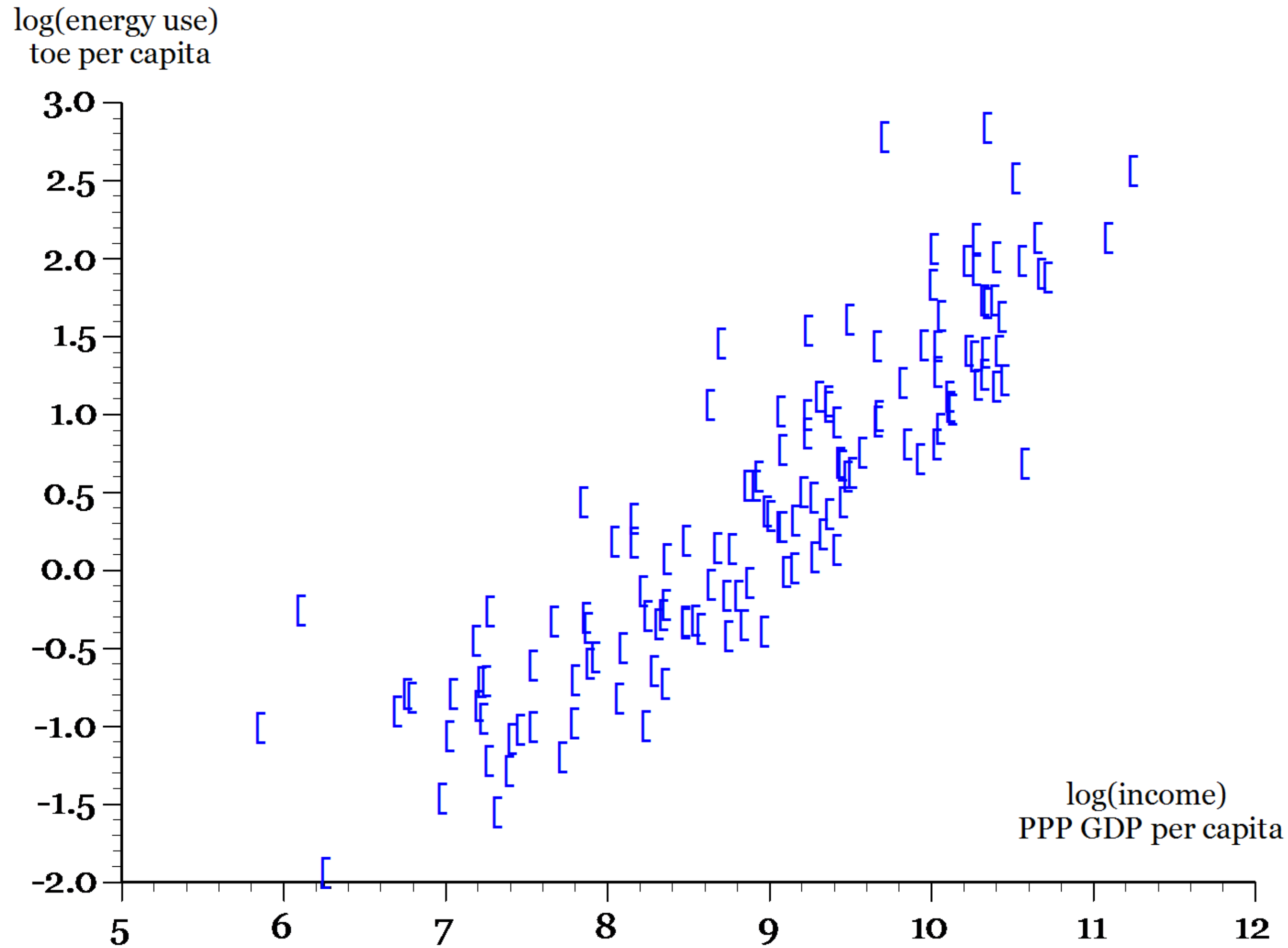
2011 TPE/capita versus GDP/capita



Source: Gapminder

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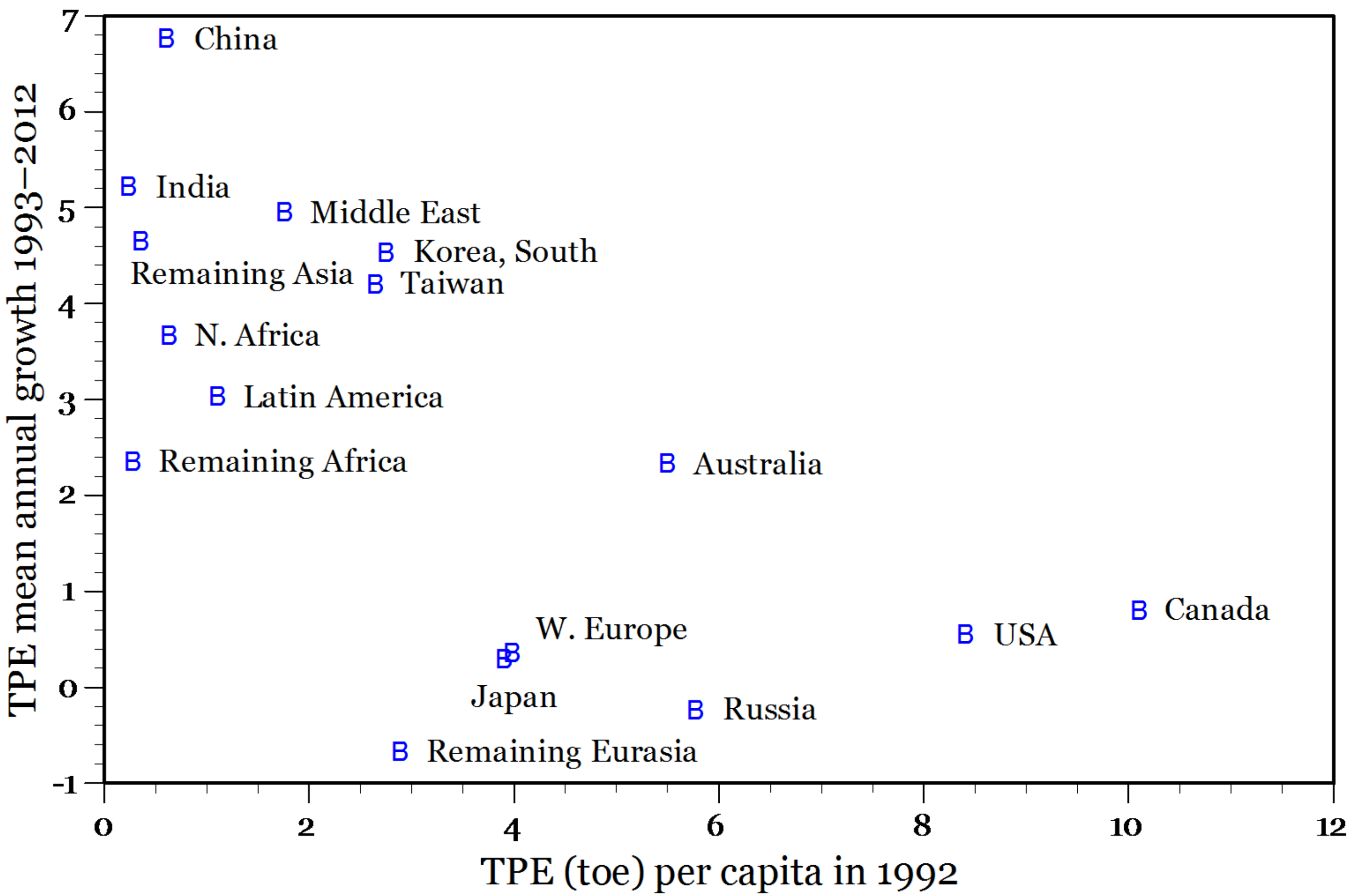
TPE demand growth



Source: EIA

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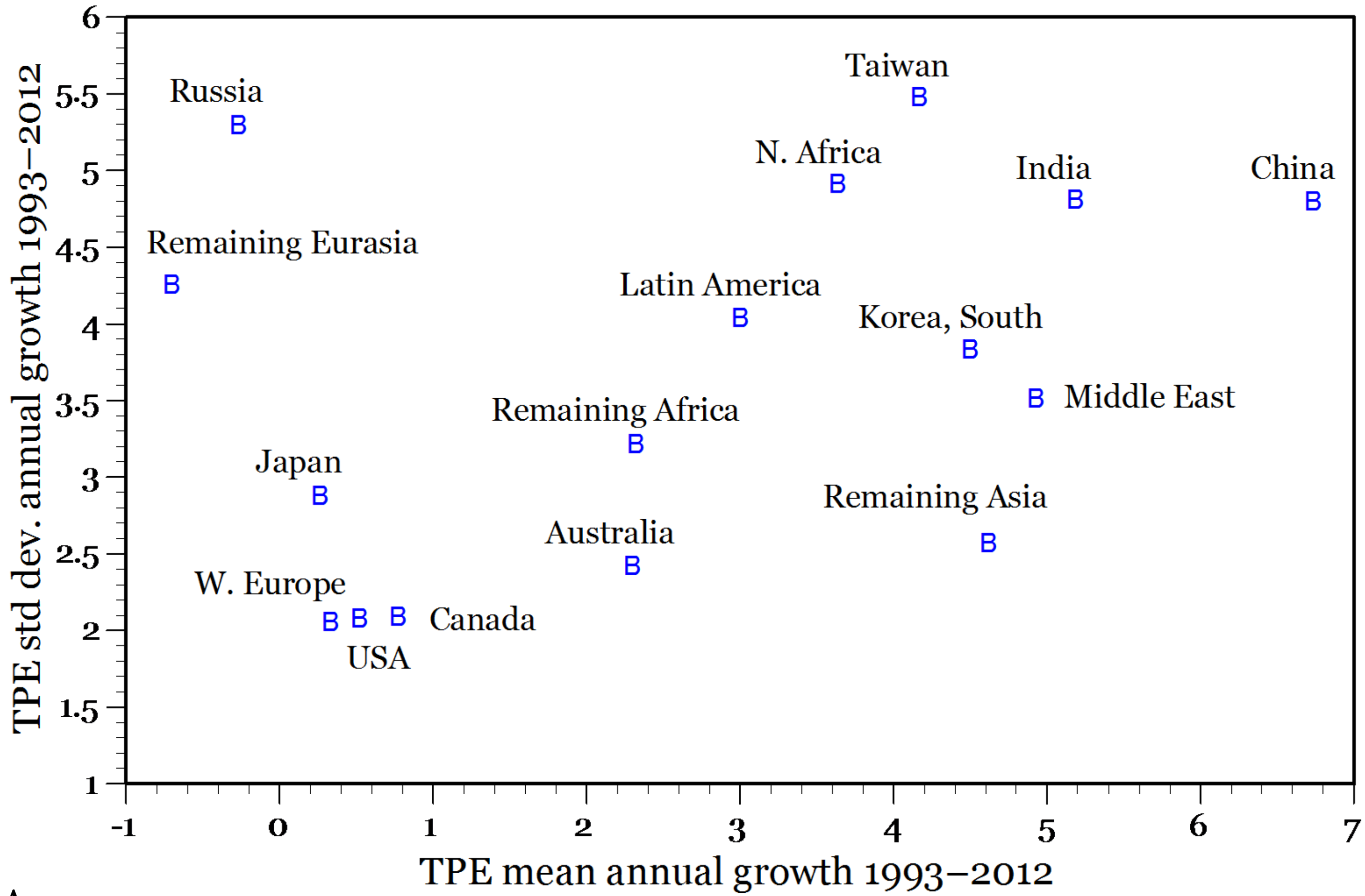
Higher growth tends to more unstable



Source: EIA

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Growth and the pattern of energy use

- Economies tend to undergo a predictable pattern of energy use as they develop:
  - First, industrial and construction sector use grow most rapidly, especially via construction of infrastructure, which is very energy and material intensive
    - But industrial use eventually declines in *per capita* terms as economy matures
  - Commercial and residential energy use increase next
  - Rapid increase in energy use for transportation occurs later, and does not attain the growth rates of industrial or commercial, but…
    - Transportation eventually becomes the largest component of final energy demand
- The share of primary energy used to generate electricity grows over time
- Environmental concerns increase as people get wealthier, favouring natural gas especially at the expense of coal

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Future sources of energy demand growth?

- Extraordinary feature of the recent episode: High growth combined with high population
  - Rapid Chinese growth stressed not only energy but also other commodity markets
- Sources of rapid economic growth:
  - Movement of labour from agriculture to industry
  - Investment in physical and human capital
  - Adoption of technologies from more developed economies
- Eventually countries converge to the long run growth path of the leading nations
  - Very high growth rates get more difficult to achieve as a straight numerical issue
  - Countries at the frontier can no longer take new technologies “off the shelf”
  - In particular, Chinese growth is unlikely to return to its previous highs
- Might India or SE Asia, which also have high populations move into the high growth phase?

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Energy supply also affects growth

- In addition to economic growth affecting energy demand, energy availability, or especially lack thereof, can affect economic growth
- Many major post-WWII recessions have been associated with a preceding, and apparently precipitating, constraint on energy supply
- Major reasons for macroeconomic impacts of energy supply constraints:
  - Energy is an essential input
  - More expenditures on energy imply less available for consumption or investment
  - Energy/capital input ratios are relatively fixed in the short run
    - Reducing hours of operation is the main short-run response to high energy prices
    - If price changes are perceived as permanent, capital can be replaced with a more energy efficient alternative, but this is also disruptive in the macroeconomic sense
  - Other attempts to economize on energy use also come at some economic cost

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TOPIC 2

Technological change and fossil fuels

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Technological change and fossil fuels

- Despite repeated fears of exhaustion, technological change has continually uncovered new resources, reduced the cost of extracting "difficult" resources, and increased EUR from previously exploited sources
  - While total fossil fuel resources are finite, the known resource base is vast
  - Even the amount that could be recovered with current and reasonably foreseeable technologies is more than 2000 times current annual production
  - We will never "run out" of fossil fuels – rather at some point the remaining resources will cost more to extract than the cost of alternative energy sources
- The production of natural gas, and then light oil, from shale is just the latest "revolution" in fossil fuel technology

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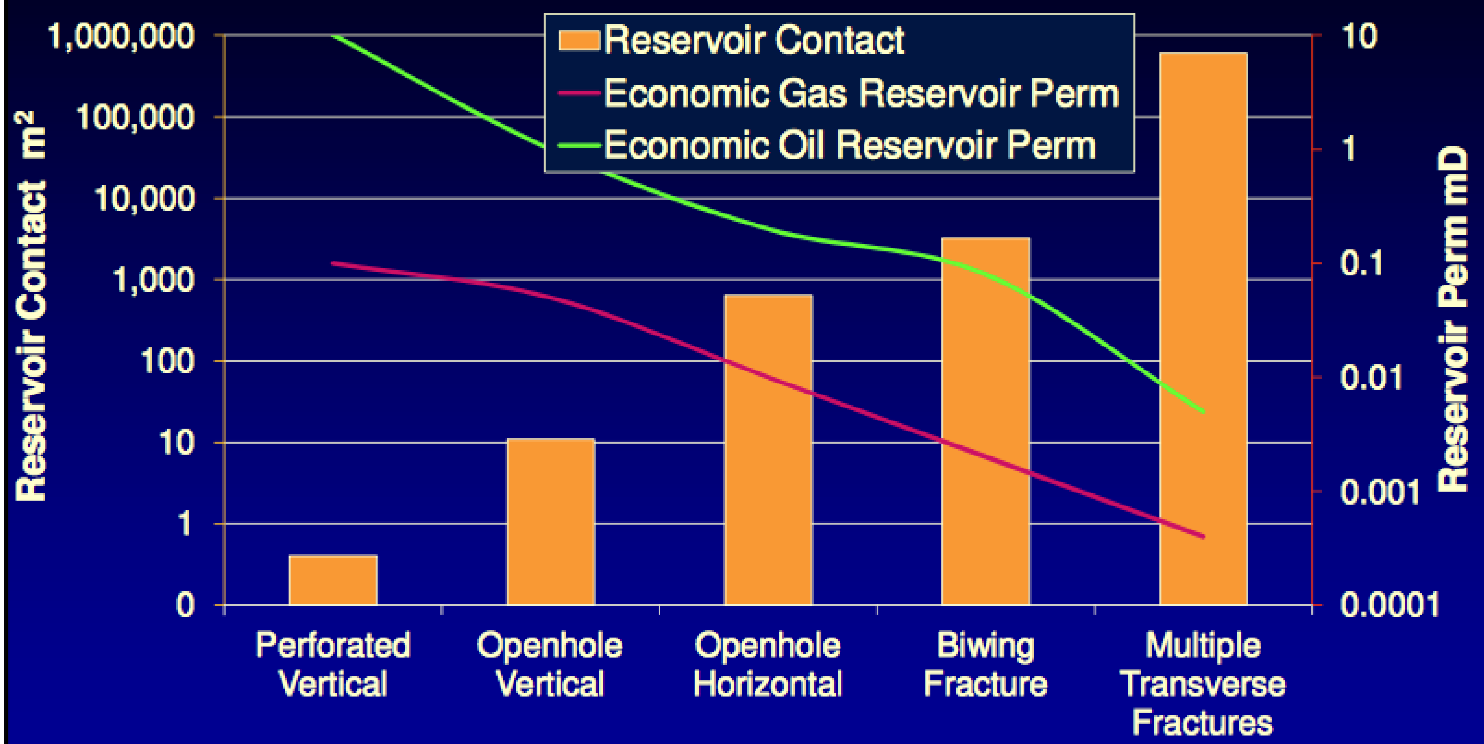
Technology Progression



Increasing our reservoir contact by 1,000,000 fold

has allowed pursuit of reservoirs with thousands of times lower perm

Source: Mike Vincent, “Five things you didn’t want to know about hydraulic fractures”

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Increased energy efficiency

- Increased end-use energy efficiency also extends fossil fuel resources
  - By allowing the same energy services to be produced with less primary energy input, fossil fuel resources are exploited more slowly
  - Costs of production then will not rise as fast
  - This is a version of the "green paradox"
  - Technologies increasing substitution between different fuels also extends resource life
- Other innovations – most especially the production and long-distance transmission of electricity – have increased the *value* of energy services
- Economic growth beyond middle income levels also tends to reduce the energy intensity of GDP
  - This is simply the result of the changing composition of GDP toward sectors – especially services – that are less energy intensive
  - This, as more countries become high income, economic growth can continue without requiring the same increases in energy input

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TOPIC 3

Alternative energy technologies

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Non-fossil fuel energy technologies

- Fossil fuels currently supply more than 90% of the world's primary energy
- Nuclear power and hydroelectricity supply more than 8%
- Other modern non-fossil energy sources are used mainly as a result of subsidies
  - Example: The DSIRE database currently lists 28 US Federal policies and 2,613 policies at the state and local level (including Washington DC) promoting renewable energy and energy efficiency technologies
- While these other sources are called "renewable" in practice they also are limited in supply
  - The energy source (basically sunlight) that is converted to energy services by sources such as wind, solar or hydroelectricity is essentially unlimited
  - However, suitable sites for constructing harvesting infrastructure are limited in supply

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Renewables – cost disadvantages

- Relative to combined cycle gas turbines, the per kW of capacity capital cost of
  - onshore wind is about 2x
  - offshore wind is about 4x
  - solar is about 5.5x
- Low average capacity utilization for renewables further raises costs per kWh
- Renewables also often need transmission upgrades
  - These also are used at a low capacity factor

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Example generating plant cost calculations (*r* = 0.075)

	Gas turbine	NGCC	Coal	Nuclear	Onshore wind	Pumped storage
Capital cost per MW ($m/MW)	0.676	1.023	2.934	5.53	2.213	5.288
Fixed O&M ($m/MW)	0.00704	0.01537	0.03118	0.09328	0.03955	0.01800
Variable O&M ($/MWh)	10.37	3.27	4.47	2.14	0	0
Fuel ($/MWh)	46.31	30.54	19.36	2.88	0	0
Heat rate (MMBTU/MWh)	9.75	6.43	8.80	10.452	0	0
Fuel price ($/MMBTU)	4.75	4.75	2.20	0.28	0	0
Load factor	0.1	0.7	0.8	0.9	0.3	0.1
Plant life	30	30	50	50	25	50
Levelised cost (¢/kWh)	13.01	5.04	6.05	7.09	9.06	48.58

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Renewables – other issues

- Wind power output fluctuates frequently and substantially
  - For wind speeds 10–30 km/h, output varies as the cube of wind speed (next slides)
  - Ancillary services are needed to maintain network stability
  - Added thermal plants then are not used when the wind blows
  - Also peaking gas turbines are less efficient and more costly than NGCC plants
  - Curtailing base load thermal plants reduces their efficiency and can raise pollution
- In many locations, wind also is strongest off-peak, weakest in peak hours
  - A large fraction of wind capacity increases the chance of inadequate capacity at peaks
- Best sites for wind and solar are often remote from major consuming locations
  - Expensive new transmission lines with low capacity factors are needed
- Wherever wind has been forced into the network via subsidies and mandates we have seen substantial rises in prices and deterioration in supply quality
- Wind and solar farms also have a large land and environmental impacts

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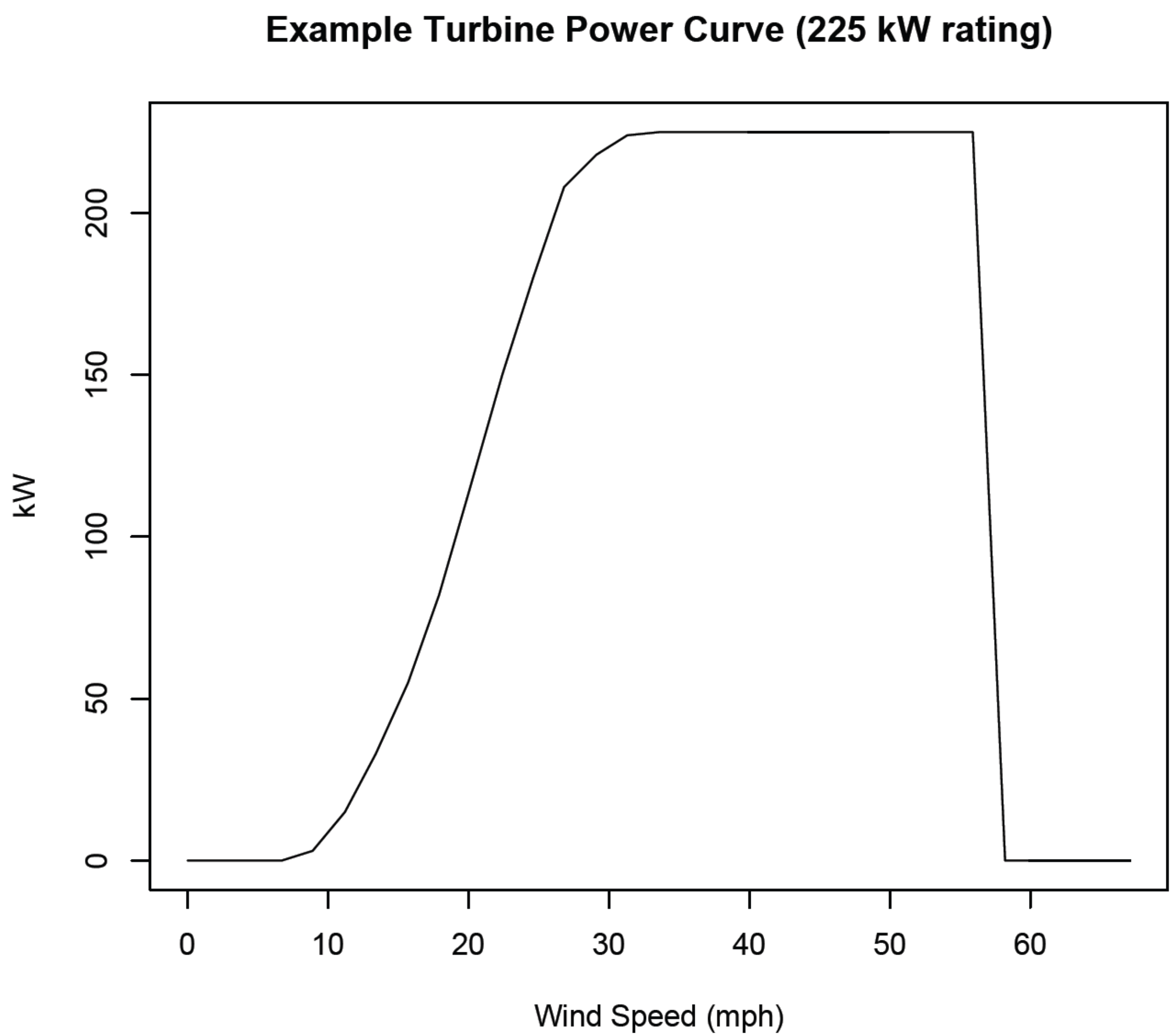

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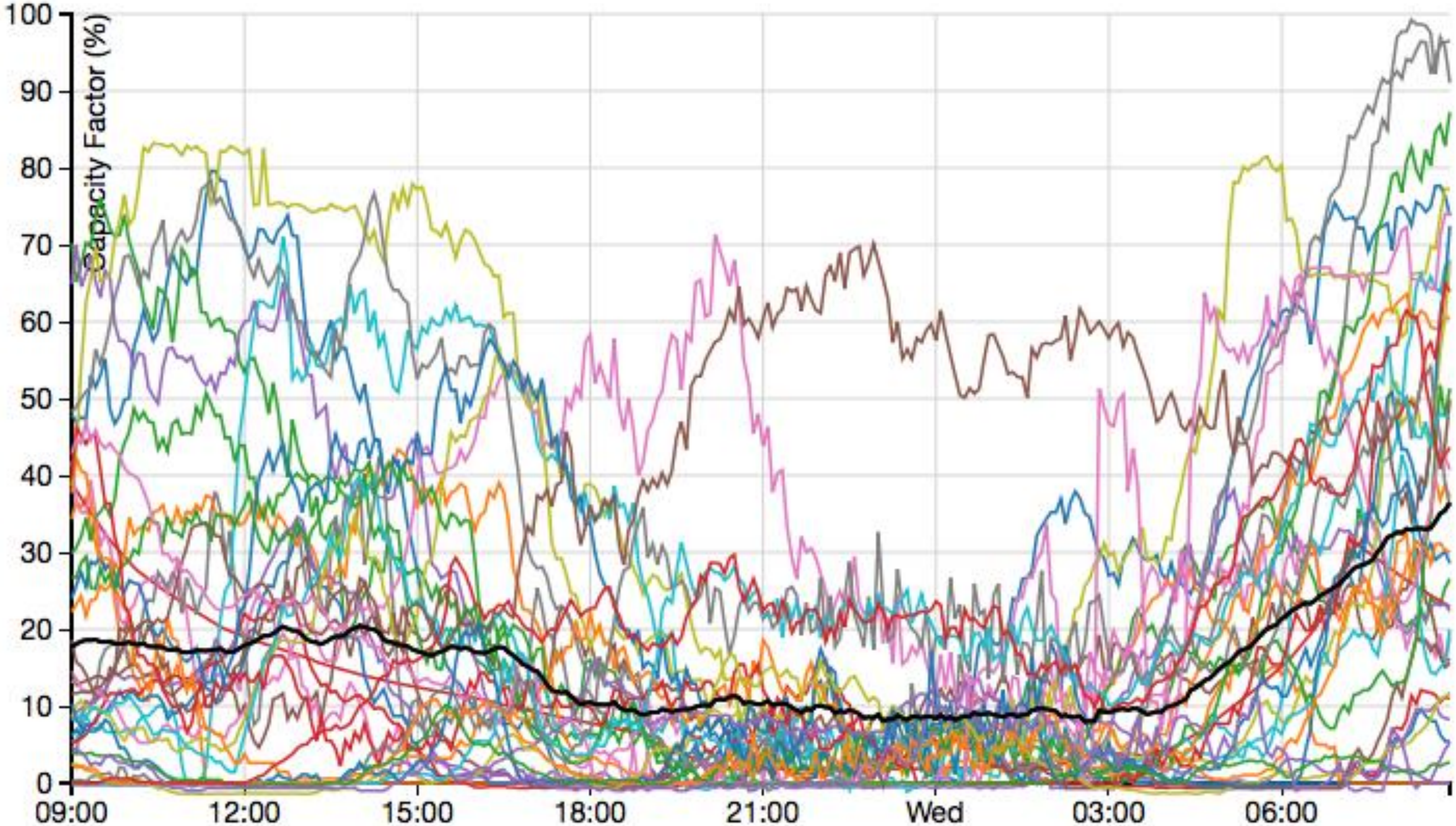
Wind production SE Australia 14/10/15



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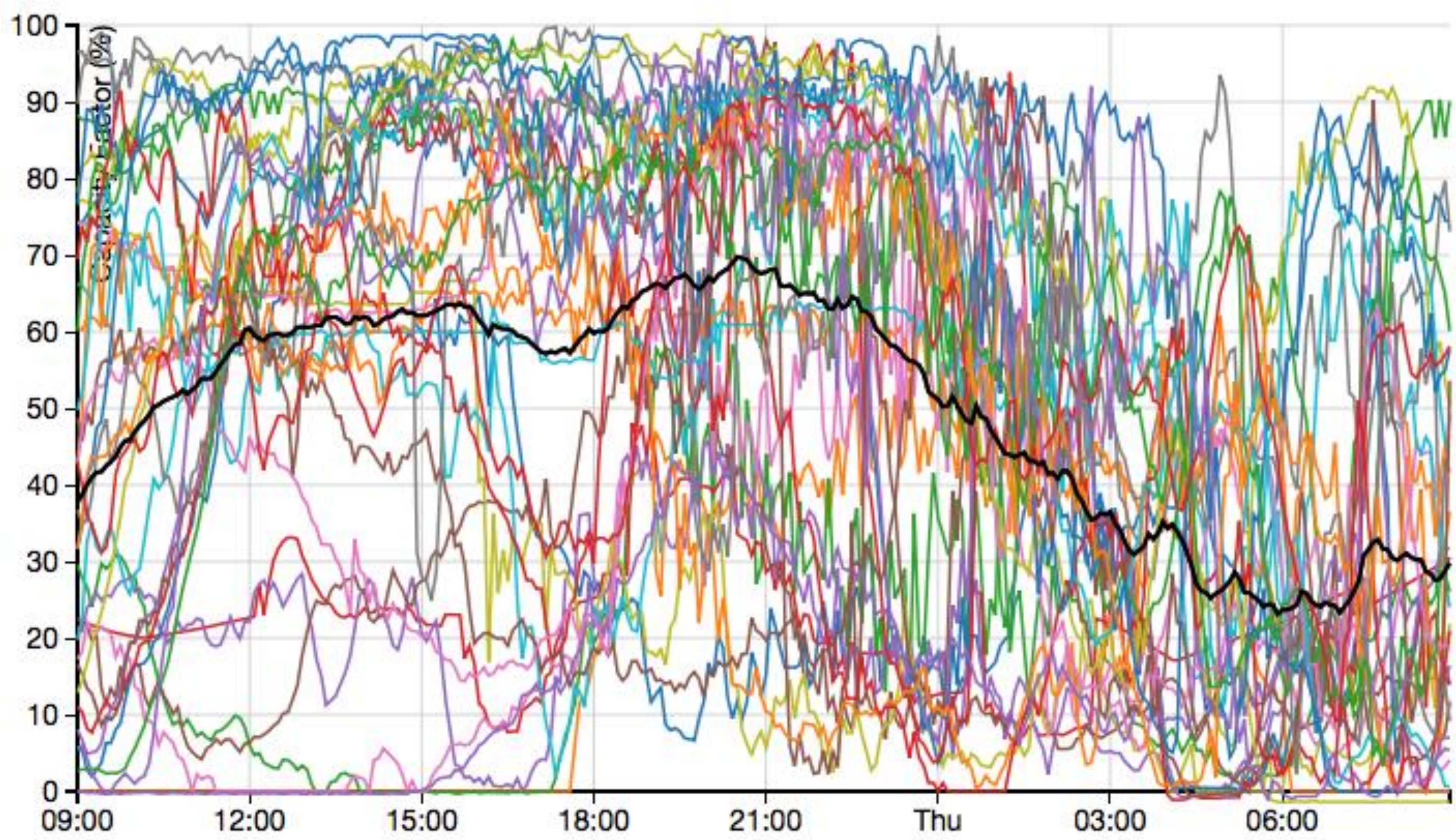
Wind production SE Australia 15/10/15



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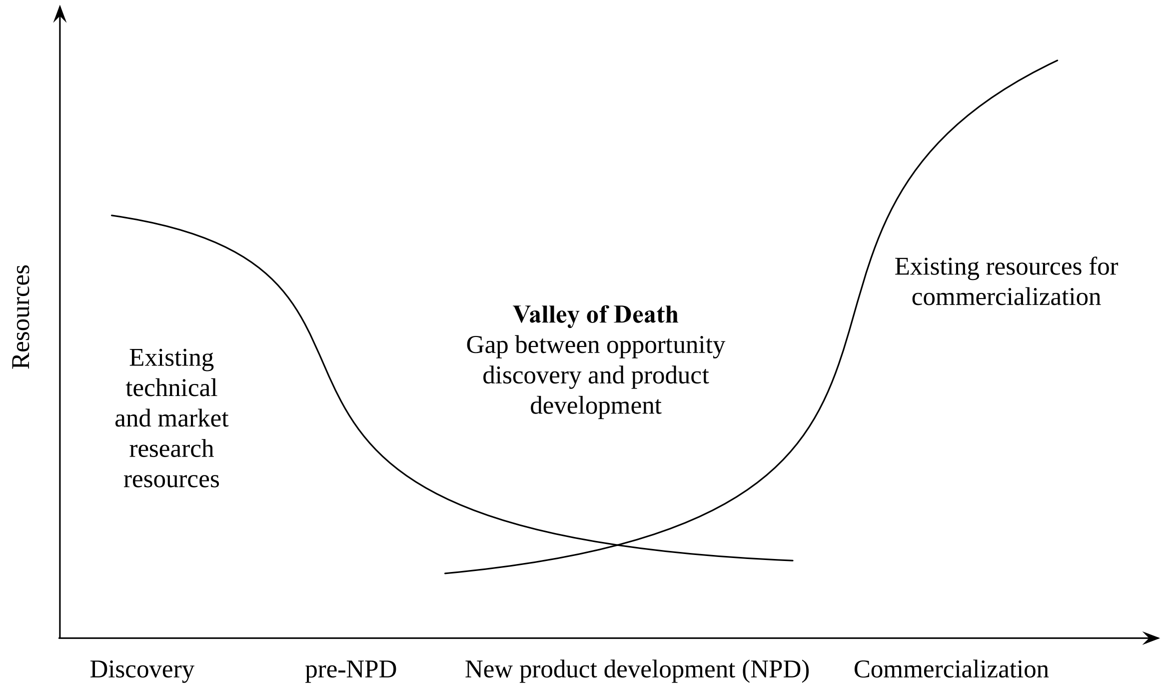
The "valley of death" for new energy technologies



- Claimed paucity of funding for commercializing new technologies relative to funds for basic R&D
- Discussions typically focus on remedial policies
- Why are apparently profitable opportunities ignored?

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Previous explanations for the valley

- Informal justifications include:
  - Information spillovers that make it hard to capture benefits of R&D
  - Information asymmetries, uncertainty about viability, and financial and product market volatility that make it hard to "sell" the project to investors
  - Higher costs of early plants make initial prototypes unprofitable even if the technology would be viable in the long run (an "infant industry" argument)
  - Inability to use many assets (especially intellectual property, patents) as collateral
- But one would think that most of these problems would be more severe at the "discovery" phase than at the "new product development" stage
- A 2009 paper argues that a "non-economic" motivation (public subsidies) for R&D at stage 1 alone can lead to more stage 1 than later stage projects
  - Actually, more subsidies for stage 1 research could be efficient if more basic research has more extensive spillovers that are hard to monetize
- Another issue: why energy but not pharmaceuticals or IT, for example?

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TOPIC 4

Modeling the transition process

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A model of the transition process

- In a recent paper, we use a dynamic intertemporal model to calculate an efficient transition between energy sources
- The model distinguishes several types of investment:
  - R&D into *both* fossil fuel and non-fossil energy technologies
  - Capital is used to produce final output, with energy services as another *essential* input
  - Energy services are produced using two types of non-substitutable capital
- We assume learning by doing and explicit R&D are both needed to reduce the cost of new non-fossil energy production
  - Such a "two factor" learning model has been estimated for progress in solar and wind and other energy technologies
- Technological progress in fossil fuel technology makes it harder for non-fossil alternatives to compete

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The valley of death in this model

- The early stage of development largely involves cost reductions through R&D expenditure and learning
- The "commercialization" phase involves building physical capital to supply energy services using the new technology
- Capital used to produce energy services from fossil fuels is a sunk cost, so it will be used so long as the energy price covers *short-run operating* costs
- Until fossil fuels are abandoned the energy price is less than even the operating costs of the alternative energy technology
- Investment into R&D and development of new technologies starts long before the technologies are deployed commercially
- Furthermore, the new technologies will be used to supply energy services before the energy price is sufficient to cover their long run costs
  - The full long-run costs are not covered until some time after fossil fuels are abandoned
- Big difference between energy and IT or pharmaceuticals: only energy requires large investments in infrastructure to deliver final product after the R&D phase

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An "optimal energy crisis"

- The transition path between technologies that we calculate is efficient
- That path involves an "energy crisis" – slower economic growth and especially reduced consumption and a lower standard of living – around the time *T* of transition between fossil and non-fossil energy sources
  - As the cost of fossil fuel production begins to rise, it becomes optimal to invest more in fossil fuel R&D (including new field development) to keep costs under control
  - Also as *T* approaches, substantial investment in infrastructure to supply energy services from non-fossil sources is required
  - It also becomes more worthwhile to accelerate R&D investment into alternative energy technologies as *T* approaches
  - Investment into fossil fuel energy supply infrastructure ceases before fossil fuels are abandoned at *T*, but this limits the supply of energy services and hence final output
  - The cost of energy services has to rise dramatically to cover the full long-run cost of alternative energy supply infrastructure and incentivize the investment required
  - Spending on energy and investments, and constrained output, reduce consumption

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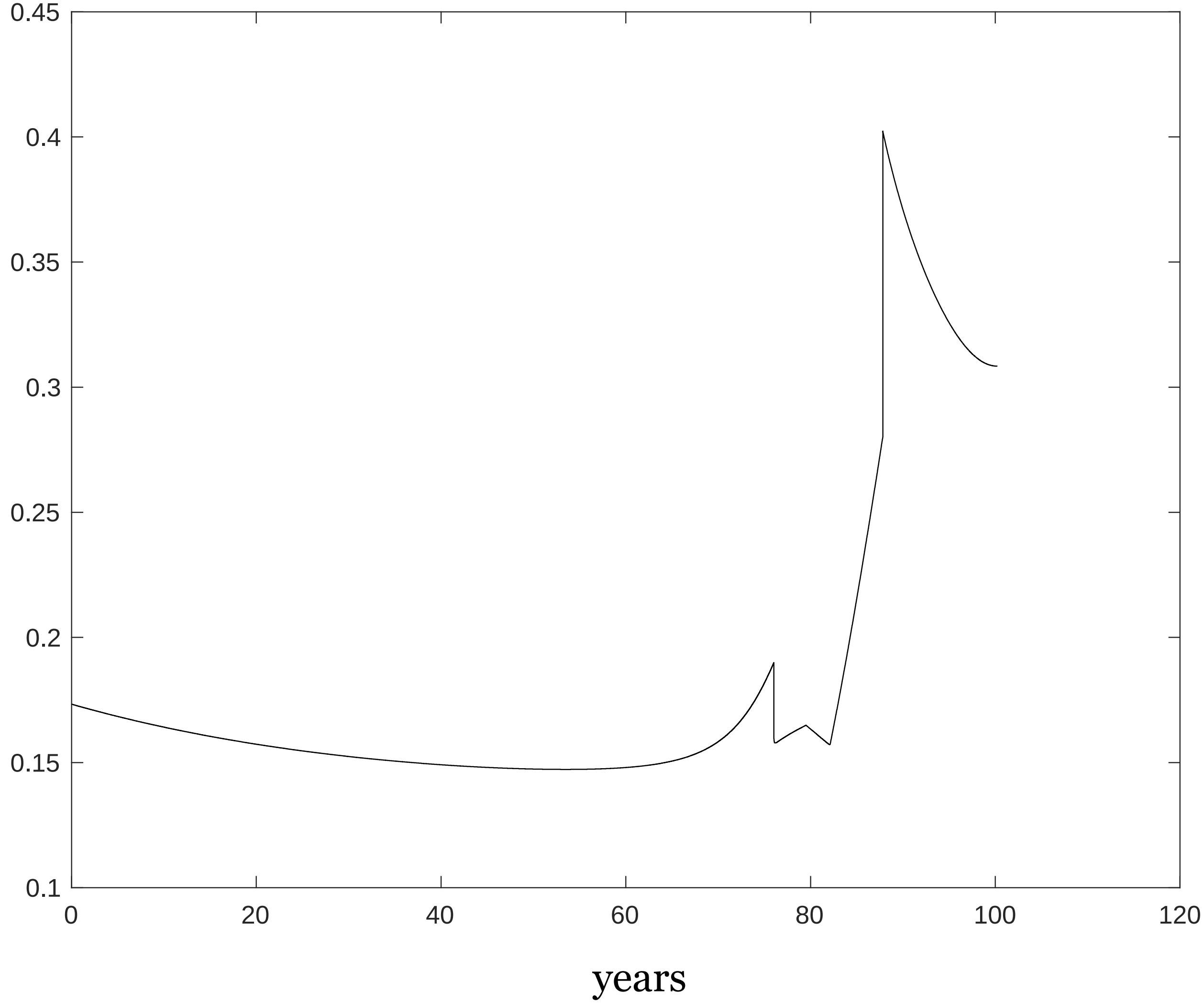
Real price of energy



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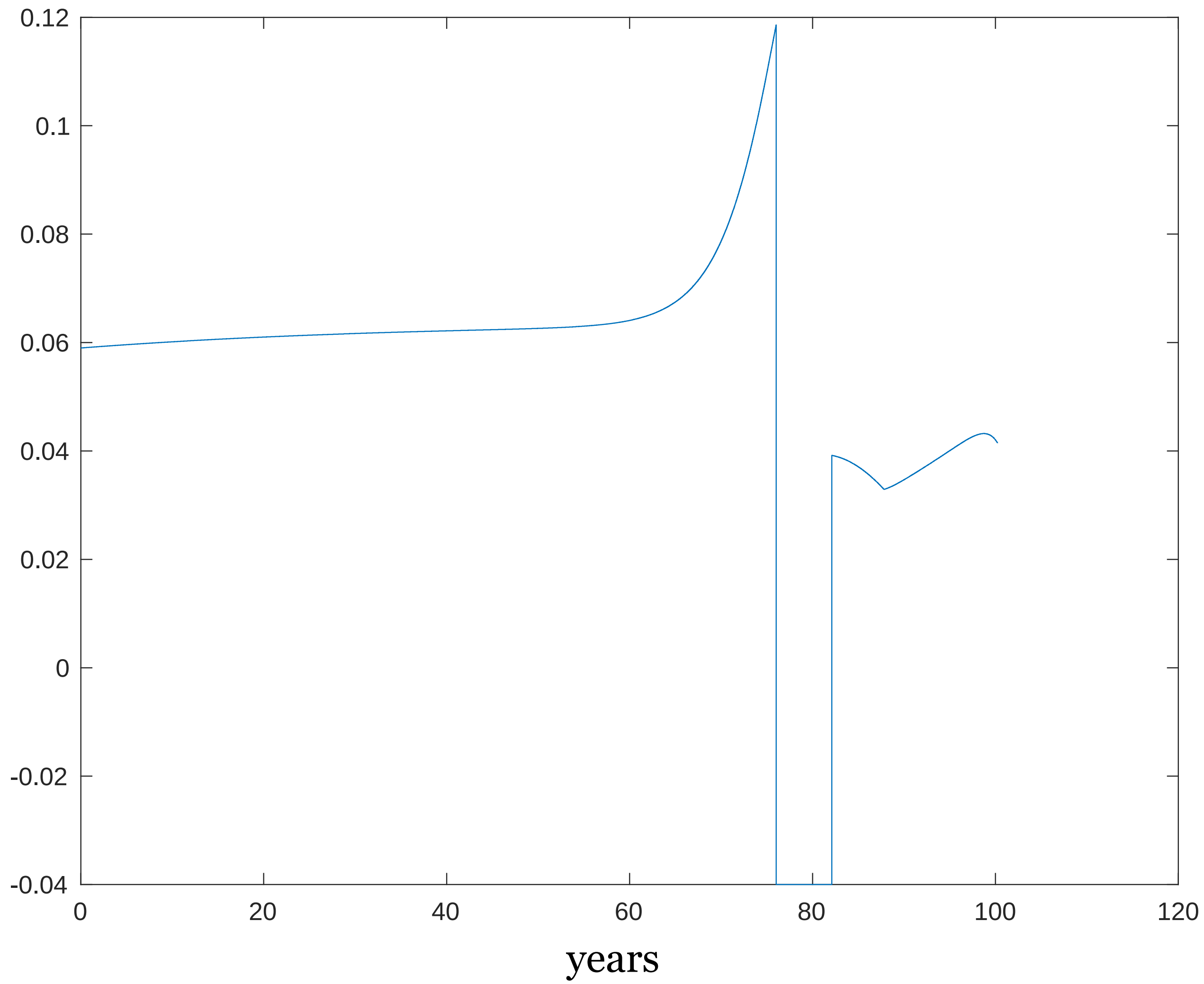
Output growth rate



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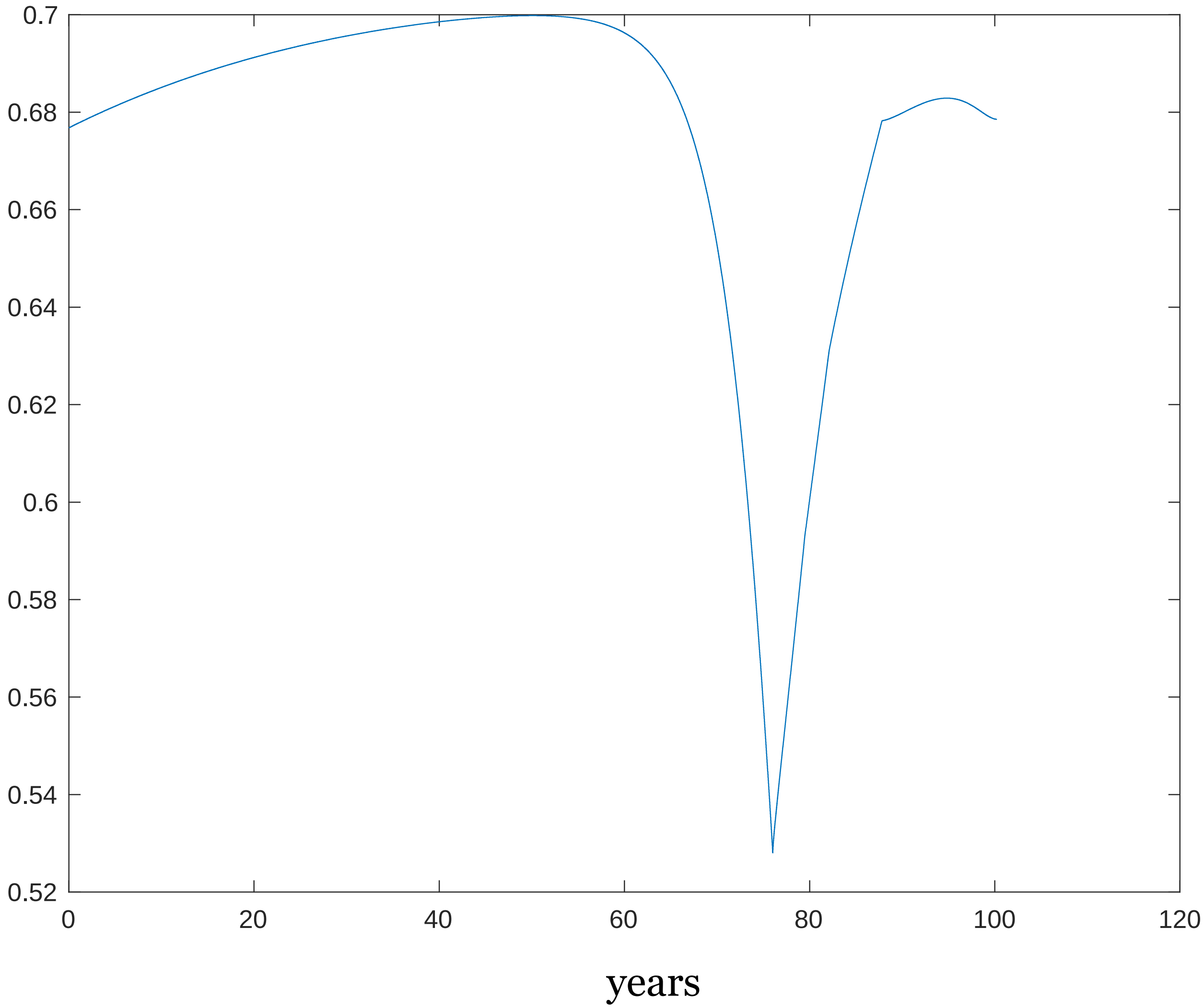
Consumption/output ratio



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TOPIC 5

The future role of natural gas

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A "golden age of gas"?

- Barring a breakthrough in alternative energy technology, fossil fuels are likely to dominate energy production for many more decades
- However, many expect natural gas to grow faster than coal or oil
- Natural gas has much lower emissions than other fossil fuels – especially coal
  - Controlling "conventional" pollutants from coal is already raising costs
  - CCS and gasification as strategies to keep coal competitive?
- The resource base for natural gas is huge – especially if one includes hydrates
- Even if renewables subsidies continue, wind and solar generation tend to require more natural gas as backup
  - Time of day pricing to smooth the load curve is a possible alternative approach

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Natural gas in transportation?

- For transportation, gasoline and diesel have higher energy density than CNG and are easier to handle than LNG
- Nevertheless, LNG may be used more widely in truck fleets, rail, and especially shipping, in part because of the relative environmental benefits
- Natural gas is already indirectly used in transportation via oil sands and ethanol production, and in the form of electricity
- Electric cars also have some advantages over internal combustion engines
  - Advantages in braking and idling
  - Generating plants are more energy efficient that internal combustion engines
  - But batteries currently have low energy density
  - Vehicle choice versus driving choices in multi-vehicle households

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TOPIC 6

LNG market developments

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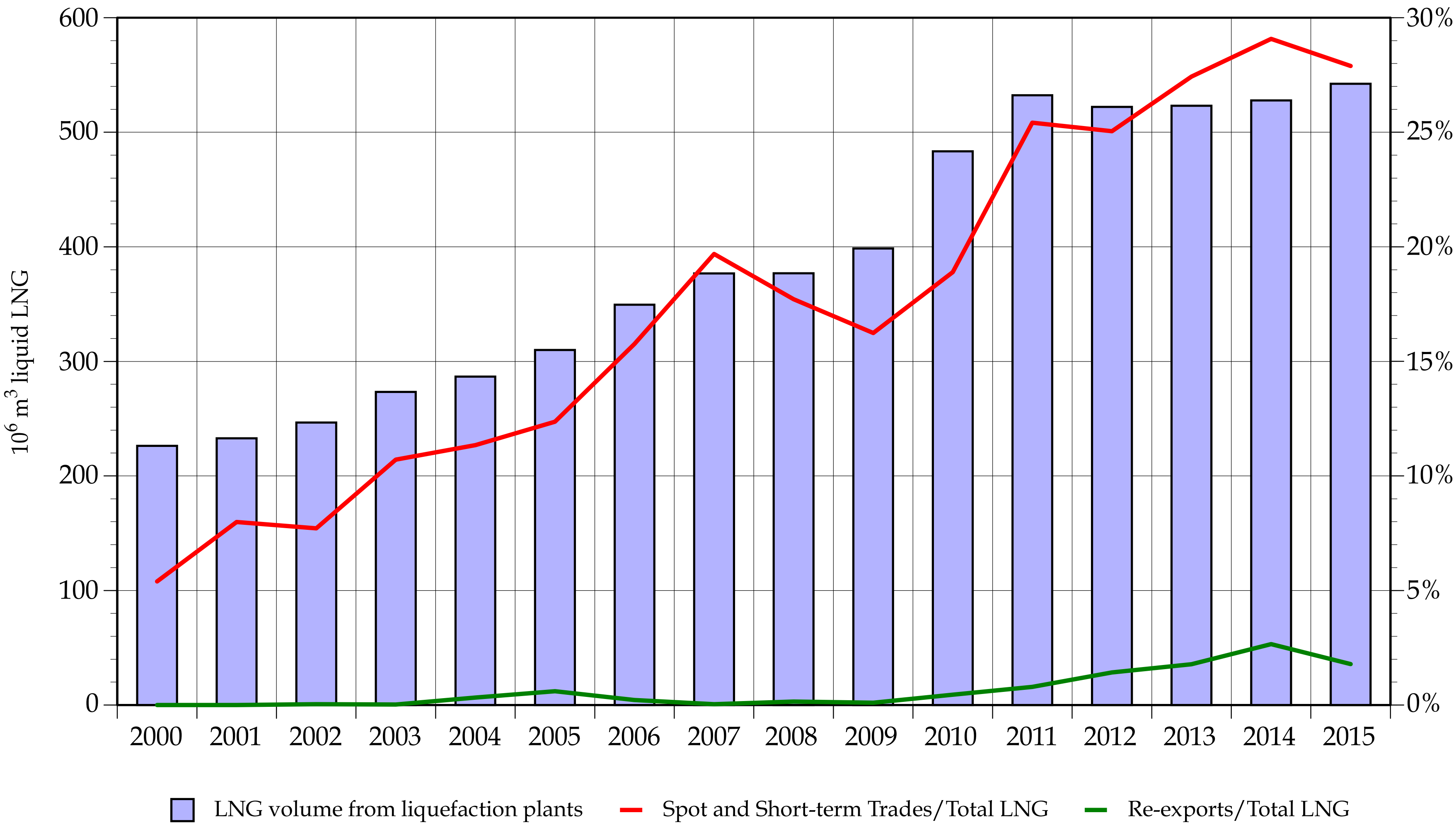
Increasing spot and short-term LNG trades



Source: GIIGNL

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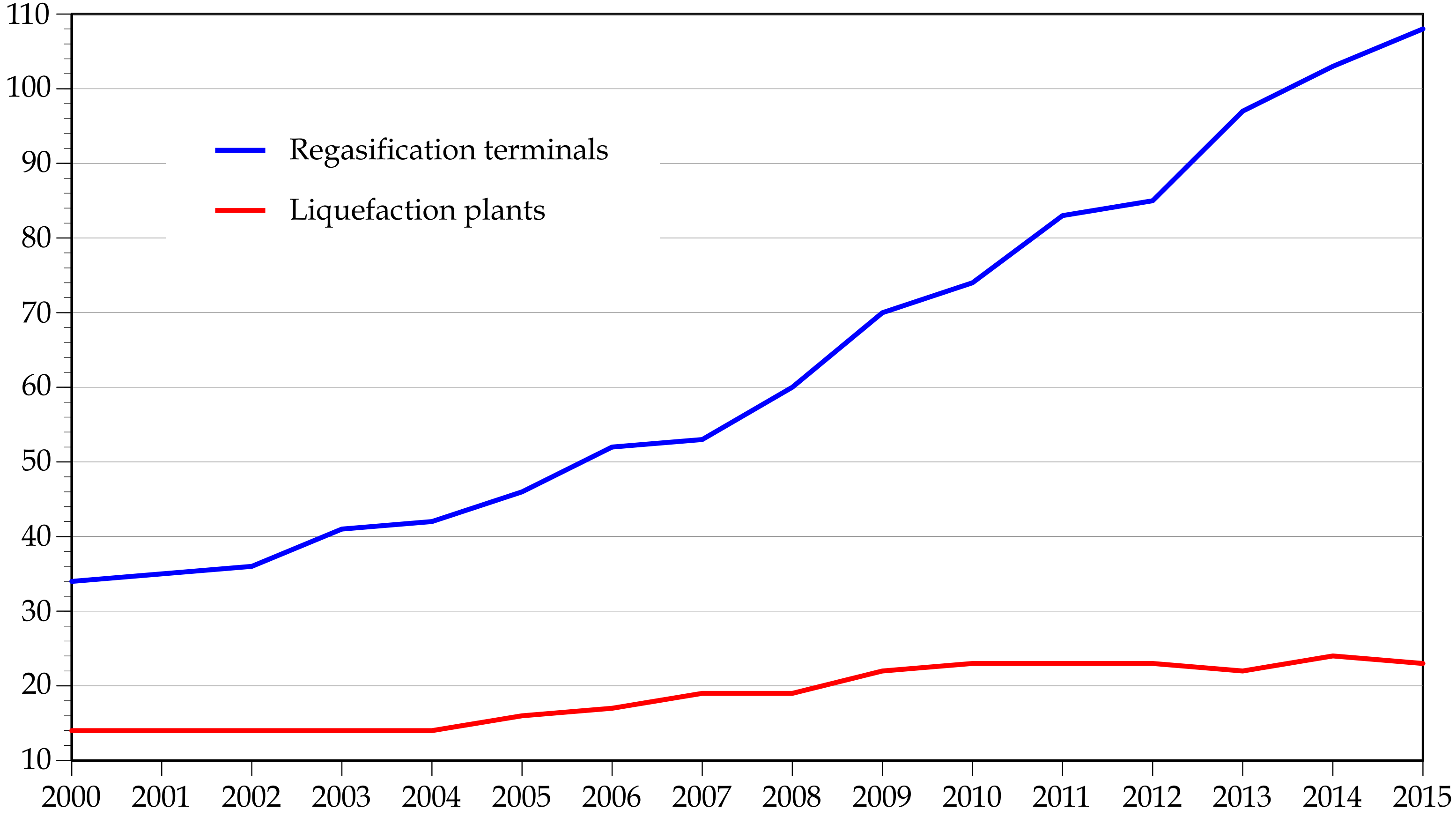
Increasing numbers of LNG traders



Source: GIIGNL

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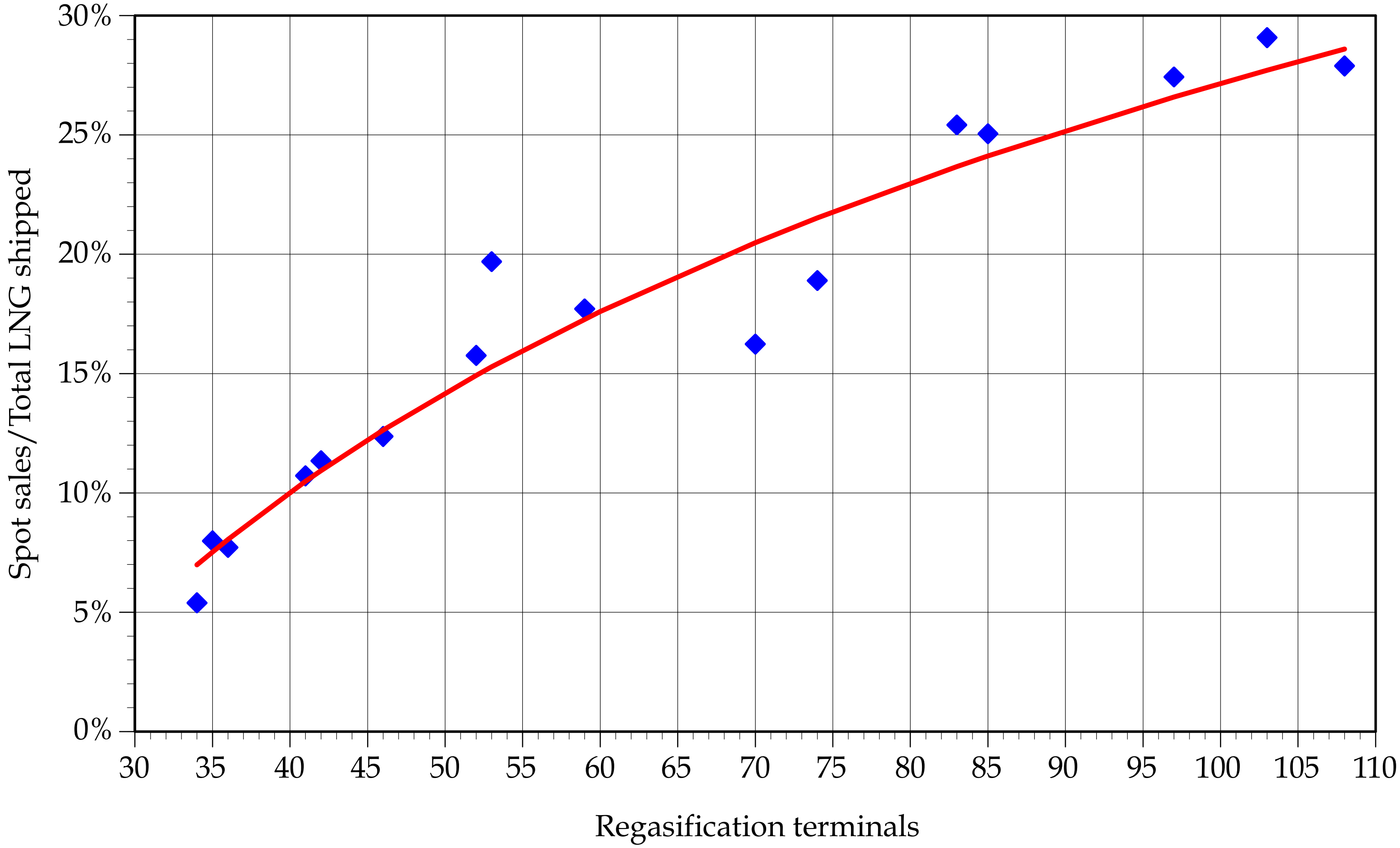
Spot trading is related to the number of importers



$$\text{SpotFrac} = \underset{(0.0130)}{0.187}\ln(\textit{Regas}) - \underset{(0.0532)}{0.590}; \quad R^2 = 0.9370$$

Source: GIIGNL

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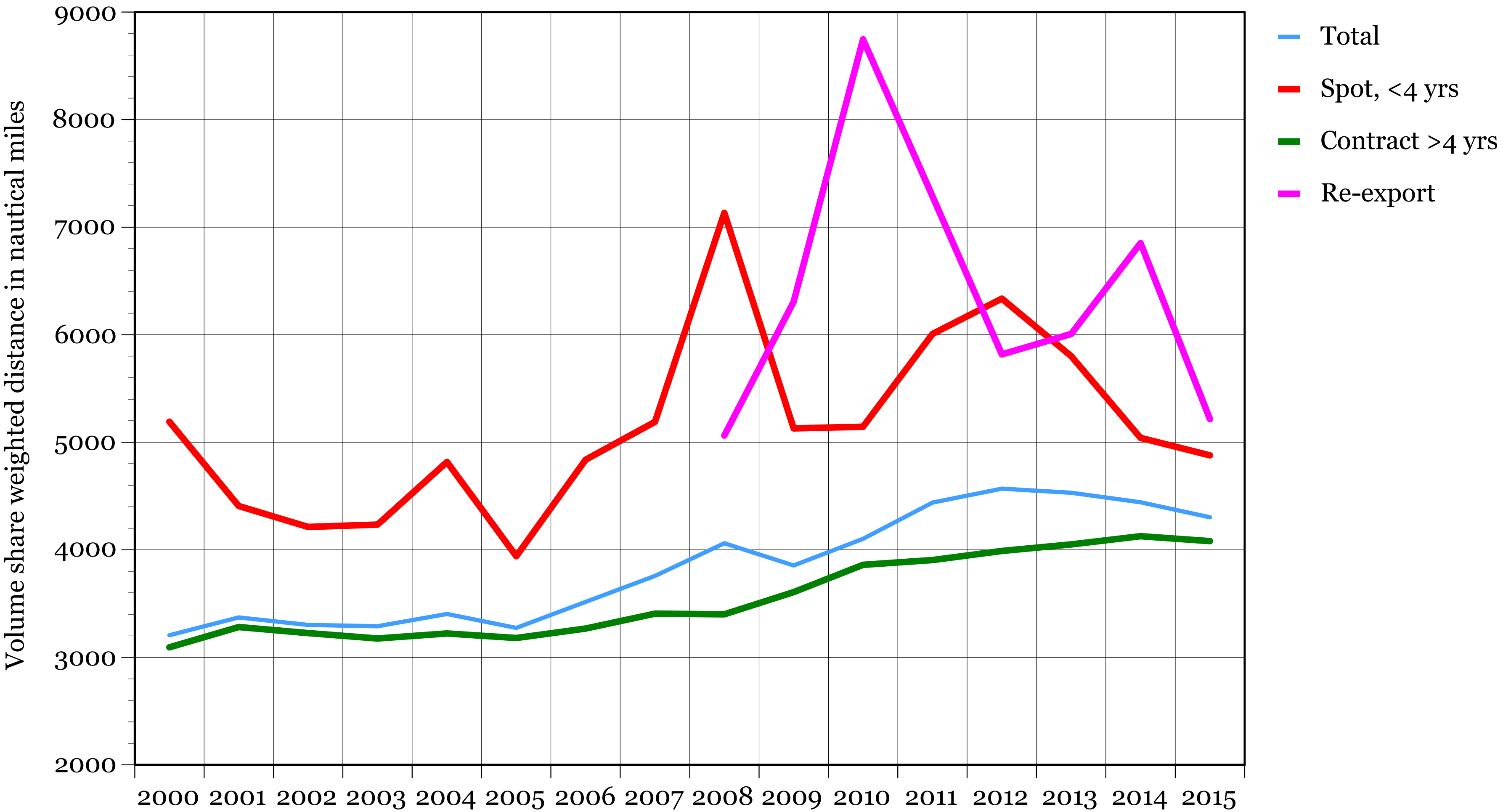
Average LNG shipping distance



Sources: Author calculations based on GIIGNL and VesselDistance.com

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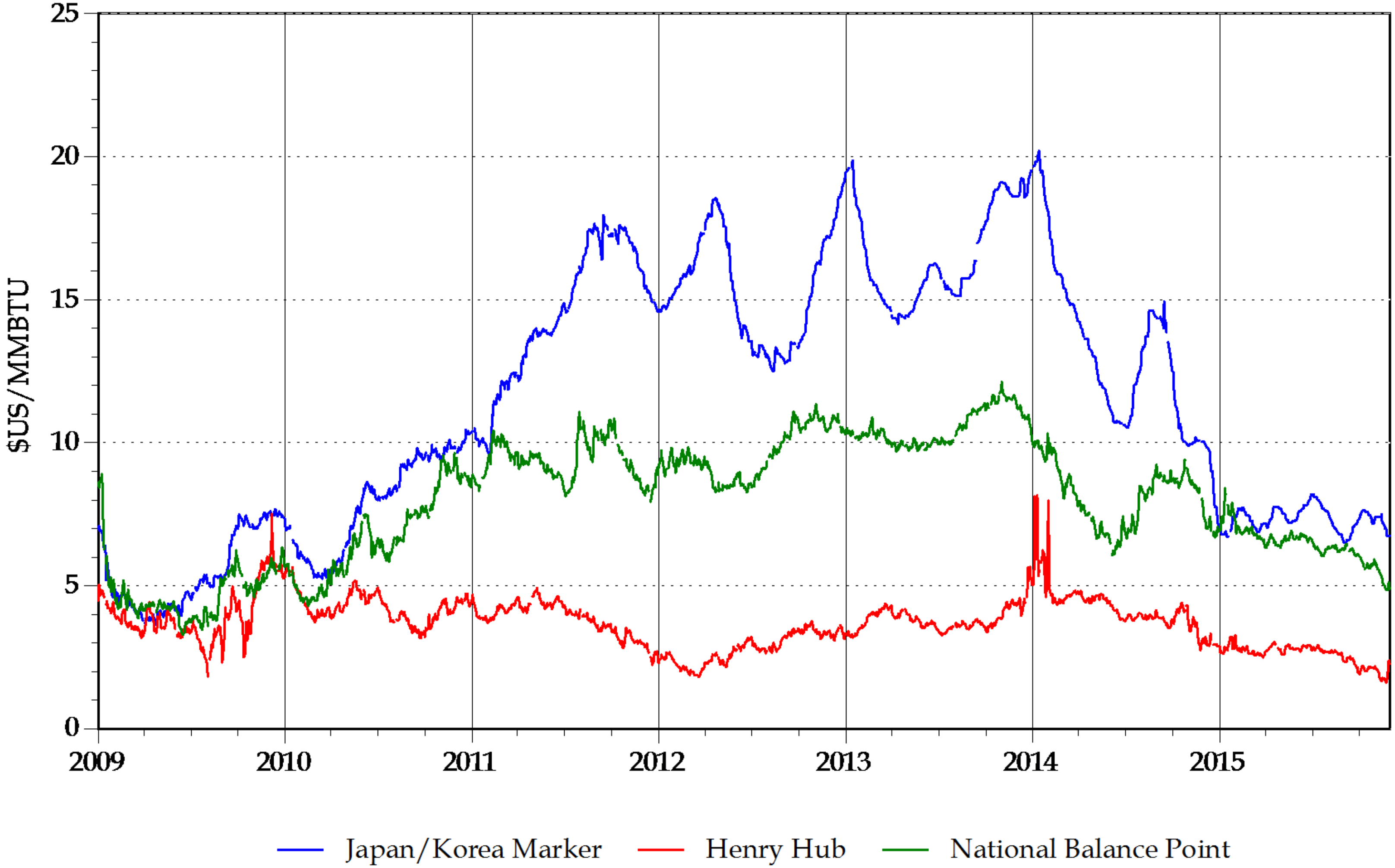
Recent evolution of spot natural gas prices



Source: Platts

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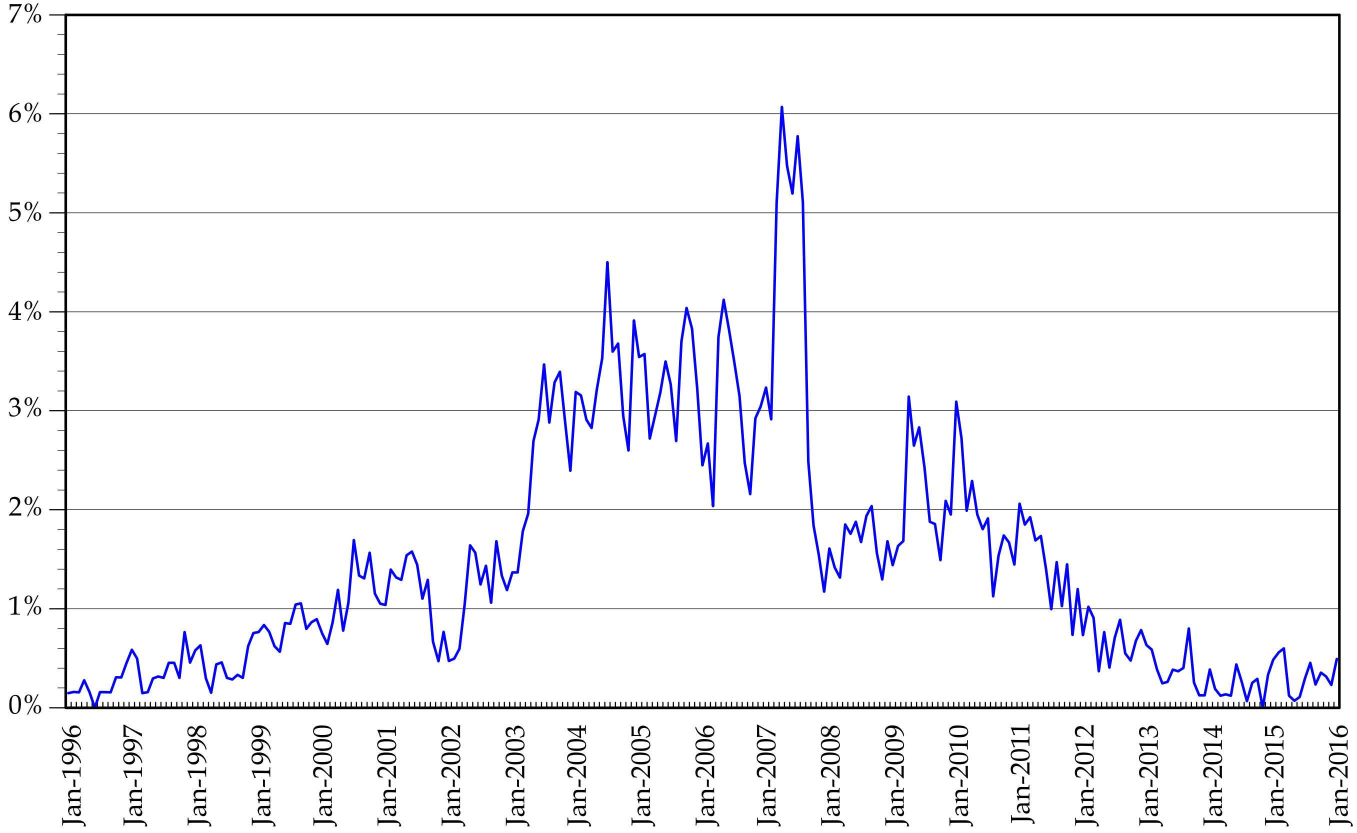
US LNG Imports/Marketed production



Source: US Energy Information Administration (EIA)

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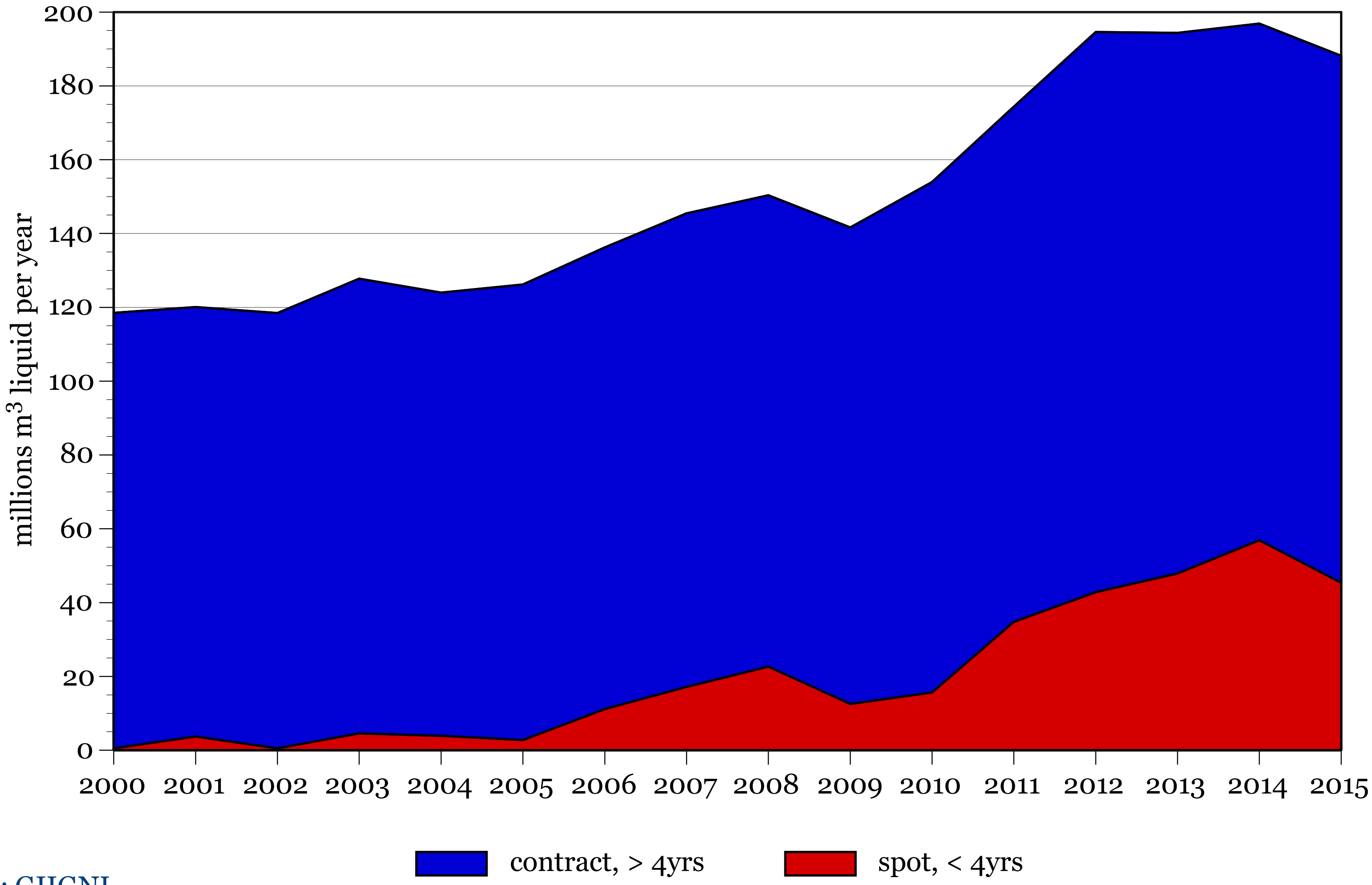
Japanese LNG imports: Long-term contract and other



Source: GIIGNL

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Other recent developments

- LNG swaps and other spot trades increasingly exploit arbitrage opportunities
- Many regasification terminals are adding storage capacity to support arbitrage
- Expiration of long-term contracts for some early liquefaction developments has created spare capacity and without a need to finance large investments
  - More of their output is being sold short-term and spot
- Many recent contracts have greater volume flexibility, destination flexibility, and less than 100% off-take commitments by buyers
- After the EU restructuring directive of 1998 (promoting competition in EU gas markets), the Commission found destination clauses anti-competitive in 2001
  - This stimulated re-export of cargoes and increased destination flexibility
- Growth of "branded LNG" sourced from many sellers and sold to many buyers

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Effects of US developments on LNG trade

- The first few US terminals are proposing exports under a tolling arrangement
  - Typical feed gas price 115% of Henry Hub and liquefaction fee $3–3.50/mmbtu
  - Several buyers will add the LNG to their global portfolio
- Some proposed facilities are smaller and more modular than traditional trains
  - For example, Elba Island (which also has output assigned to Shell's global portfolio)
  - LNG Ltd Lake Charles terminal using a more energy efficient less capital intensive process
- Future co-location of regasification and liquefaction facilities in the US with pipeline connections to a deep market will facilitate short-term arbitrage

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Summary comments on recent developments

- More elastic natural gas supply and demand curves will reduce price volatility
- Intermediaries providing hub services and having access to storage will allow more effective price arbitrage, further reducing price variability
- The gap between spot prices available to importers and exporters also will decline as market liquidity rises
- Spot market trades from parties to contracts should continue to increase
- Greater use of spot and short-term trading may favor lower capital cost projects
- Growth in spot trading may reduce volumes under contract and raise spot market participation, further raising spot market liquidity
- Long-term contracts will also become more flexible to allow parties to better exploit the optionality of spot and short-term trades
- There are compelling reasons for retaining oil prices as the main indexing variable for long-term contracts, but limited use of gas price indexes from deep natural gas markets might provide some risk diversification benefits

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TOPIC 7

The value of long-term LNG contracts in an uncertain environment

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Explanations for long-term contracts

- We focus on two main explanations for the desirability of long-term contracts:
    1. The hold-up problem
    2. Securing a lower cost of finance by reducing cash flow variability
- Commercial parties emphasize the risk sharing benefits of contracts, but the academic literature has focused on the hold-up problem
- The academic literature has also focused on the efficiency benefits of take-or-pay clauses in long-term contracts

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The hold-up problem

- This can occur when trading partners make large up-front investments dedicated to the trade partnership
- Once investments have been made, the counter-party has an incentive to bargain for prices that cover operating costs but do not yield a competitive return on the capital
  - This can also apply to re-negotiating an indexation formula
- The problem can become more acute if some information is known only to one party, so the rents associated with the relationship are not public knowledge
- Contracts often allow more quantity adjustments than price adjustments
  - Price adjustments are zero-sum, while quantity adjustments leave the other party with alternative avenues for making up lost profits

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Rent in the contracting relationship

Best spot prices for buyer p_M

Contract price p

Best spot prices for seller p_X

- Parties in a long-term contract tend to be better matched to each other than to outside parties
- The next best price for the buyer p_M and the next best price available to the seller p_X will vary randomly
- While the two contracting parties generally are better off trading with each other that may not always be true
- The contract price will tend to be toward the top of the p_X distribution and the bottom of the p_M distribution

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Take or pay clauses

Contract price p

Best spot price for buyer p_M

Best spot price for seller p_X

- In the situation illustrated, the importer would prefer to buy spot rather than honour the contract
- But it would be efficient to buy from the exporter since they would both be better off trading at a price between p_X and p_M than both using the spot market
- A take-or-pay clause requires the importer to make the exporter "whole", that is pay pay $p - p_X$ to the exporter, if the contracted volume is not taken
- Then the buyer would choose to *not* take delivery only when $p_M < p_X$ in which case this is efficient
- But the take or pay clause also leads to a transfer from the buyer to the seller in situations like the one illustrated

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Long-term LNG contracts and project financing

- Long term contract is "bankable" because it makes cash flows less volatile
- This in turn allows increased leverage, and reduces the cost of project finance
  - We assume the net benefits of debt are approximated by corporate tax benefits alone
- The total amount of debt is limited by a "value at risk" type constraint:
  - After-tax cash flows to importing and exporting parties are random
  - The constraint requires an upper bound on the probability that the after-tax cash flow will not be sufficient to service the debt in any given year
- Key findings:
  - Contracts can allow trade where it would not otherwise be supportable
  - General increases in spot prices are indexed 85–90%
  - Contracts are more valuable when there is "rent" in the relationship
  - Parties may limit long term contract volumes to allow more flexibility to exploit profitable spot market trades
  - Increased spot price variability generally raises the benefits of long-term contracts

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TOPIC 8

Indexing in long-term LNG contracts

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Indexing in long-term contracts

- Energy *relative* prices tend to be much more stationary than the prices of individual energy commodities
  - For demand, energy content is the dominant determinant of value, although energy density, ease of handling, environmental effects and other attributes are relevant
  - For supply, resources that can be used to produce natural gas in particular can also be used to produce oil and relative output shifts in response to relative prices
- Many studies have shown that *oil* prices tend to be the *most exogenous* energy price in markets where both prices are free to fluctuate independently
- *Natural gas* prices are the *most volatile* fossil fuel price (next slide)
- US natural gas prices have looked more attractive recently because the foreign exchange value of the $US has affected the oil/gas price ratio
  - After US LNG is traded, US gas prices may be a less attractive index to Asian buyers
- Other spot natural gas markets need to become sufficiently deep and liquid to reduce risks to investors in these large capital intensive projects
- Indexing to natural gas hub prices may exchange geographical basis differentials for commodity basis differentials

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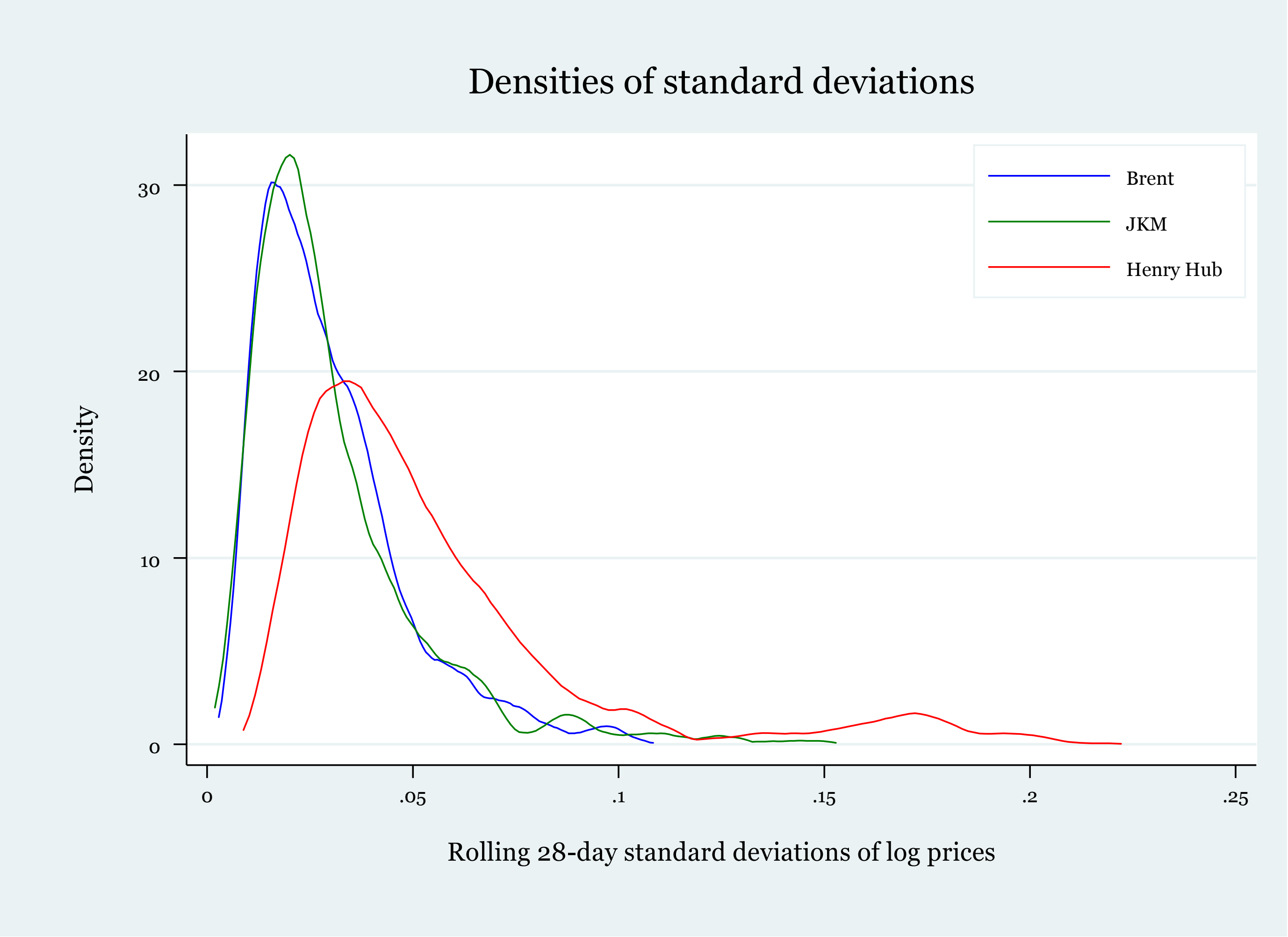
Relative volatilities of Henry Hub and Brent



Source: Author calculations based on data from the US Energy Information Administration (EIA)

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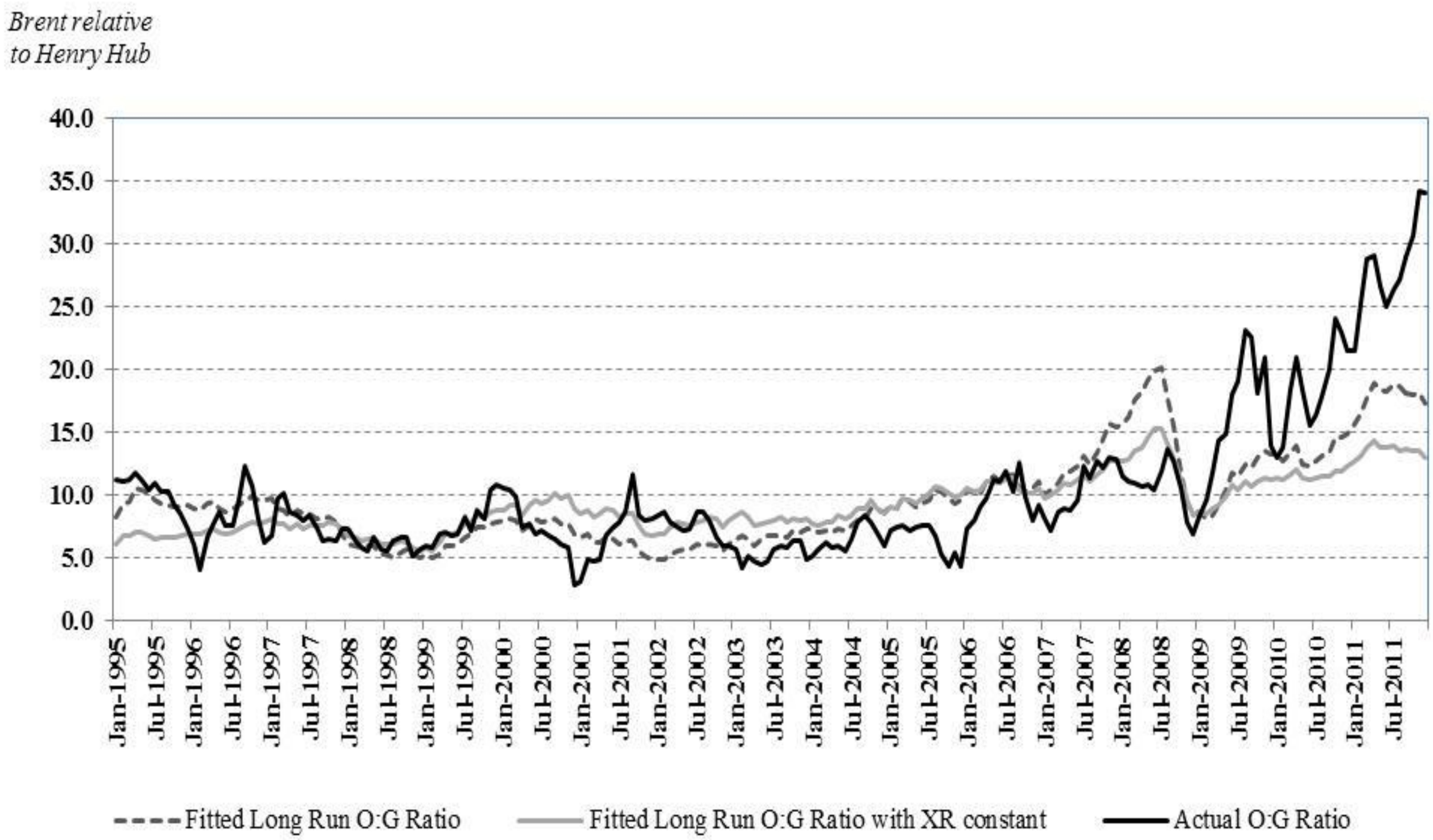
Influence of exchange rate on Brent/HH price



- Long-run relationship requires relative heat rates and the foreign exchange value of the $US to be included to be stable

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Within sample fit of dynamic model

- Adjustment to long-run error is approximately 6% per month
- Unexpected inventory changes have about 2x the effect on prices as expected ones
- HDD and CDD deviations and major hurricanes have expected effects on $\Delta\ln(p_{NG})$

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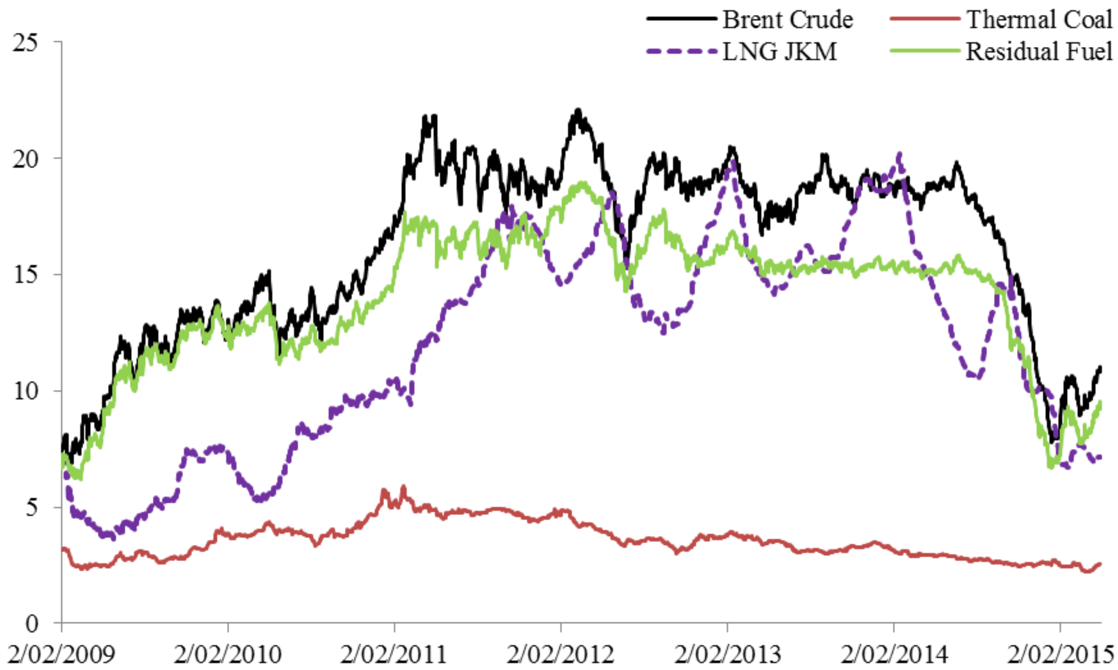
Relationship of JKM to other fuel prices



Data sources: Platts and EIA

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The co-integrating (long-run) coefficient β								
	LNG_{t-1}	RFO_{t-1}	$coal_{t-1}$		$Brent_{t-1}$		CONST	
Unrestricted								
ec1(t-1)	1	0	0.145	(0.631)	–1.874	(–9. 547)	2.602	(5.709)
ec2(t-1)	0	1	–0.096	(–1.729)	–0.813	(–17.178)	–0.268	(–2.441)
Restricted long-run equations								
ec1(t-1)	1	0			–1.806	(–10.991)	2.581	(5.678)
ec2(t-1)	0	1			–0.857	(–21.64)	–0.254	(–2.319)

Endogenous variable	The Speed-of-adjustment coefficients α: ec1(t-1)		ec2(t-1)		Further restrictions on: Long-run coefficient β	Short-run dynamic coefficients	Log Likelihood	Number of parameters
A Full Model								
ΔLNG	–0.006	(–5.74)	–0.006	(–1.03)	N	N	27864.51	160
ΔRFO	–0.001	(–1.05)	–0.017	(–2.99)				
Δcoal	–0.000	(–0.44)	0.003	(0.61)				
ΔBrent	0.002	(1.45)	0.014	(2.00)				
B Restricted long-run equations								
ΔLNG	–0.006	(–5.71)	–0.006	(–1.09)	Y	N	27864.00	158
ΔRFO	–0.001	(–0.93)	–0.012	(–2.34)				
Δcoal	–0.001	(–0.54)	0.000	(0.08)				
ΔBrent	0.002	(1.58)	0.017	(2.63)				
C Restricted long-run equations with speed-of-adjustment coefficients also restricted								
ΔLNG	–0.006	(–5.84)			Y	N	27862.81	154
ΔRFO			–0.010	(–2.13)				
Δcoal								
ΔBrent	0.003	(2.10)	0.018	(2.83)				
D Fully-restricted model								
ΔLNG	–0.006	(–6.09)			Y	Y	27833.10	65
ΔRFO			–0.009	(–2.12)				
Δcoal								
ΔBrent	0.003	(2.27)	0.020	(3.19)				

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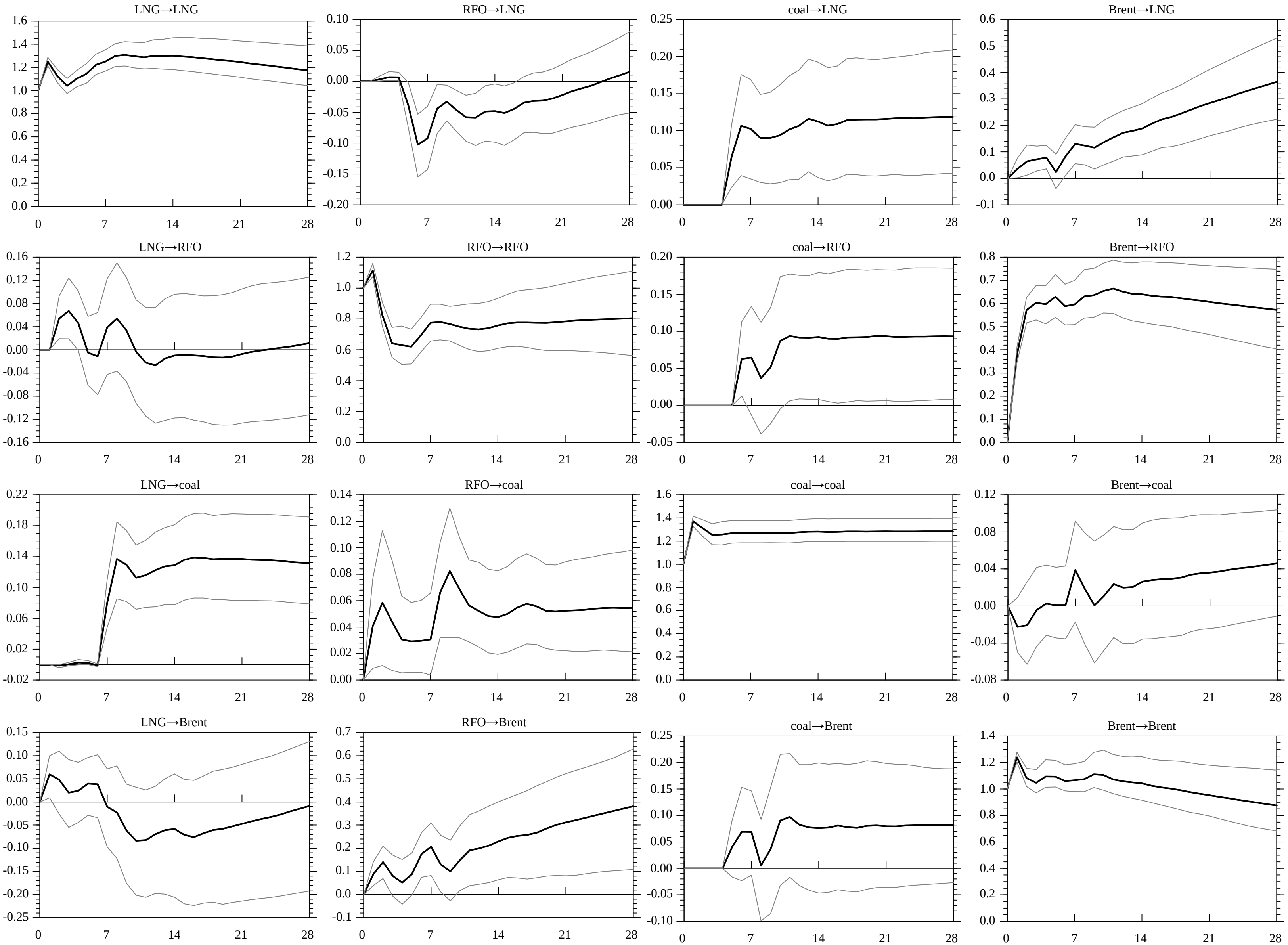
Impulse response functions: Model D



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Concluding remarks

- Energy is of fundamental importance for economic growth
- The energy industry has experienced tremendous technological change and this has kept fossil fuels as the lowest cost energy source for a long time
- The transition to alternative energy sources is costly and will take time
  - Forcing it with subsidies and mandates is imposing substantial welfare costs
  - We should distinguish subsidizing research into new technologies versus subsidies/mandates for the deployment of new technologies that are not yet competitive
- Natural gas is a favored fuel in the short and intermediate run
- LNG is growing relative to pipeline gas supplies, but the LNG market is also undergoing rapid change as it makes natural gas more of a globally traded good
- The capital intensity of LNG projects leaves a role for long-term contracts but spot and short-term trading, and flexibility in contracts, are all increasing
- While there are good reasons for indexing to oil prices, other indexes are possible and have some desirable features