The On-Going Co-evolution of Network Energy Markets

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➢ It is now more than 25 years since I first moved to London (in 1988) to help design the first truly (albeit far from perfectly) competitive electricity market, the England and Wales Pool

➢ A few years earlier, FERC had begun encouraging, and in 1992 required, US interstate gas pipelines to unbundle transportation from gas sales to facilitate competition in the gas commodity

➢ The 1990s saw both gas and electricity markets evolve rapidly in a virtual "Cambrian explosion" of new approaches, but along different paths due to different historical, economic and technical factors

➢ Now, gas and electricity markets are increasingly interacting, raising issues of coordination, integration and even convergence

Resolving these issues will require further (r)evolutionary changes in electricity and gas markets, so it is worth reviewing some history, basic concepts/misconceptions and options

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➢ The Fossil Record
  – In the beginning: The First Century (1880s-1980s)
  – The 'Cambrian Explosion' of Markets (1990s)

➢ The Basic Logic of Network Markets
  – A (Displacement) Network's TSO and CEX(s)
  – Three Approaches and Some Examples

➢ Market Design: Gas vs. Electricity
  – Straws, Loop Flow and TSO-Operated Markets
  – Lessons from the Three-Node Networks

➢ Issues for the Future Co-evolution
  – Gas-Electricity Convergence
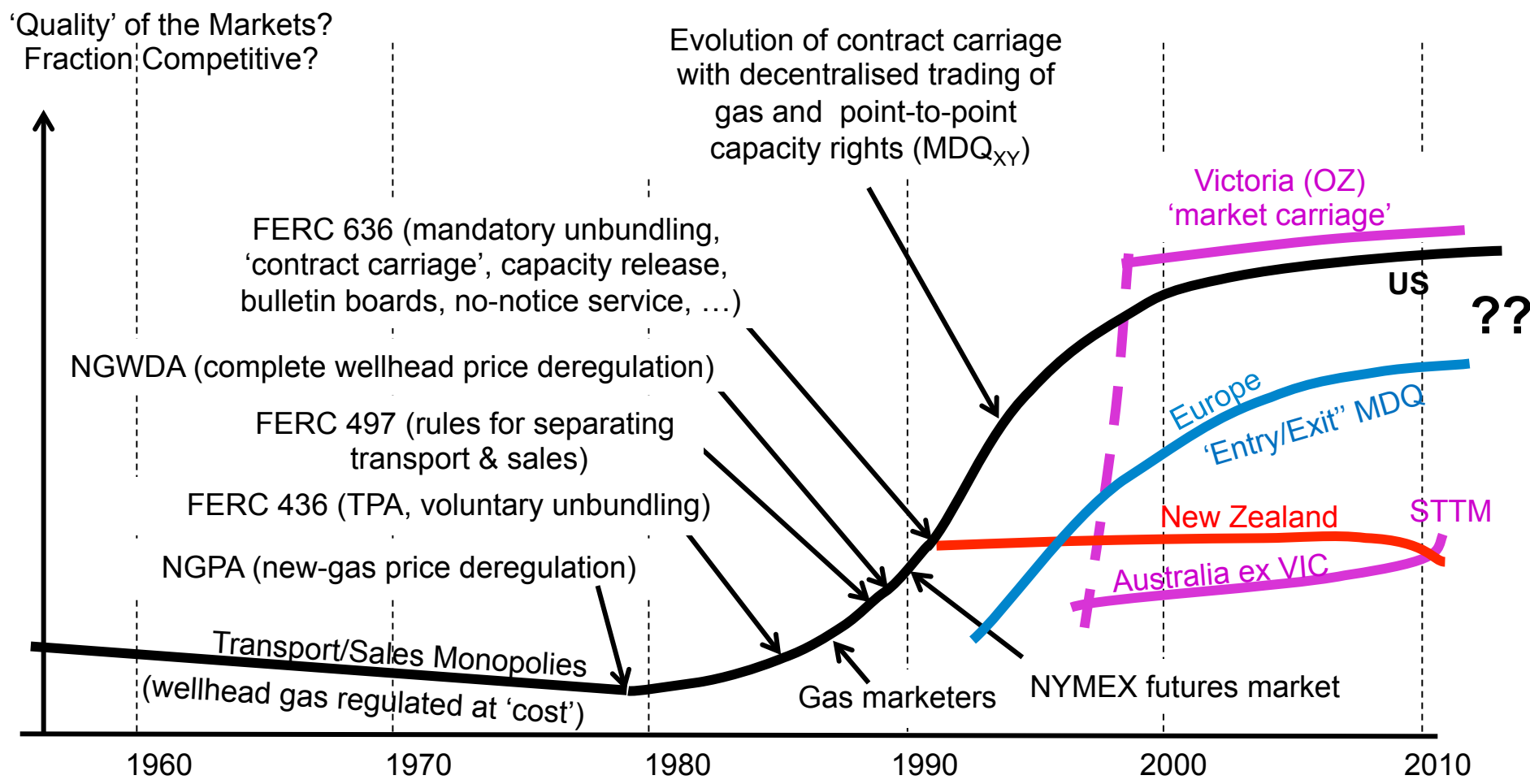 – The Basic Options and Likely Outcome

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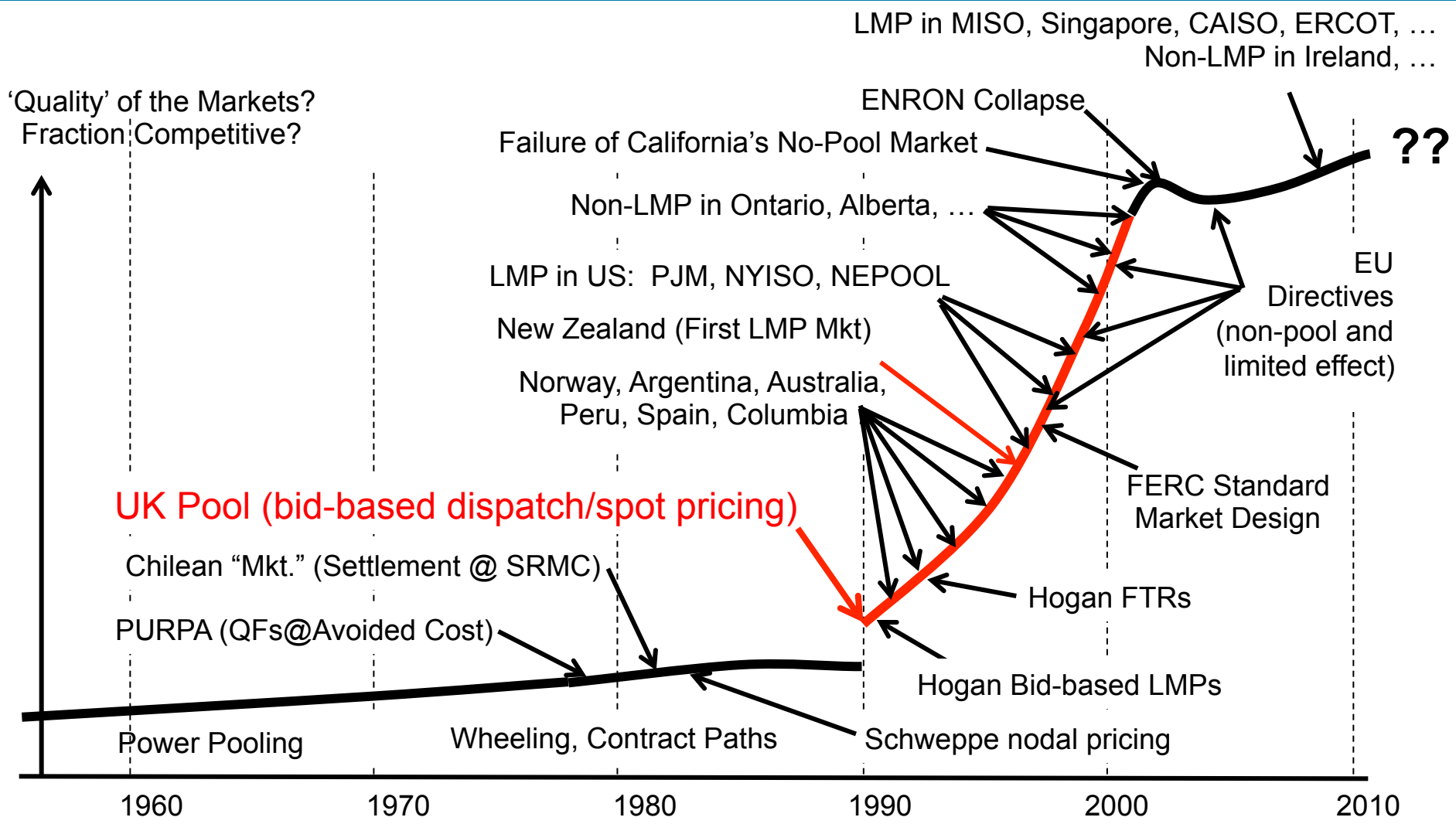
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The First Century … ~1880-1980 (in US)

➢ Initial competition (~1880-1900) and its control (~1900-1930)

– A-to-B gas pipelines were financed on the back of long-term contracts with producers at A and large customers at B; 'destructive' competition was reduced as large, integrated holding companies developed

– Electricity companies used risk capital to build grids integrated into their operations; 'destructive' competition led to state regulation of franchise monopolies and growth of multi-state holding companies

➢ The break-up of holding companies and federal regulation (1930s)

➢ The "golden age" of regulated monopolies (~1940-72)

– Because of (despite?) the 1930s reforms, and improving technology and cheap oil/gas, costs fell and demand grew steadily for 30 years

– Strains appeared in the late 1960s – and then the oil crisis of 1972 began 15+ years of panic, costly mistakes and improvisation

By the mid-1980s, the old ecosystem was weak and discredited, allowing new approaches to evolve

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The 'Cambrian Explosion' in Gas Markets

'Quality' of the Markets?
Fraction Competitive?

Evolution of contract carriage with decentralised trading of gas and point-to-point capacity rights (MDQ_{XY})

Victoria (OZ) 'market carriage'

FERC 636 (mandatory unbundling, 'contract carriage', capacity release, bulletin boards, no-notice service, …)

US

??

NGWDA (complete wellhead price deregulation)

Europe

'Entry/Exit" MDQ

FERC 497 (rules for separating transport & sales)

FERC 436 (TPA, voluntary unbundling)

New Zealand

STTM

NGPA (new-gas price deregulation)

Australia ex VIC

Transport/Sales Monopolies (wellhead gas regulated at 'cost')

Gas marketers

NYMEX futures market

1960   1970   1980   1990   2000   2010

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The 'Cambrian Explosion' in Electricity Markets

LMP in MISO, Singapore, CAISO, ERCOT, …
Non-LMP in Ireland, …

'Quality' of the Markets?
Fraction Competitive?

ENRON Collapse

Failure of California's No-Pool Market

Non-LMP in Ontario, Alberta, …

LMP in US: PJM, NYISO, NEPOOL

New Zealand (First LMP Mkt)

Norway, Argentina, Australia, Peru, Spain, Columbia

EU Directives (non-pool and limited effect)

FERC Standard Market Design

UK Pool (bid-based dispatch/spot pricing)

Chilean "Mkt." (Settlement @ SRMC)

Hogan FTRs

PURPA (QFs@Avoided Cost)

Hogan Bid-based LMPs

Power Pooling

Wheeling, Contract Paths

Schweppe nodal pricing

??

1960   1970   1980   1990   2000   2010

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A Network and Its Transmission System Operator (TSO)

A 'Network'
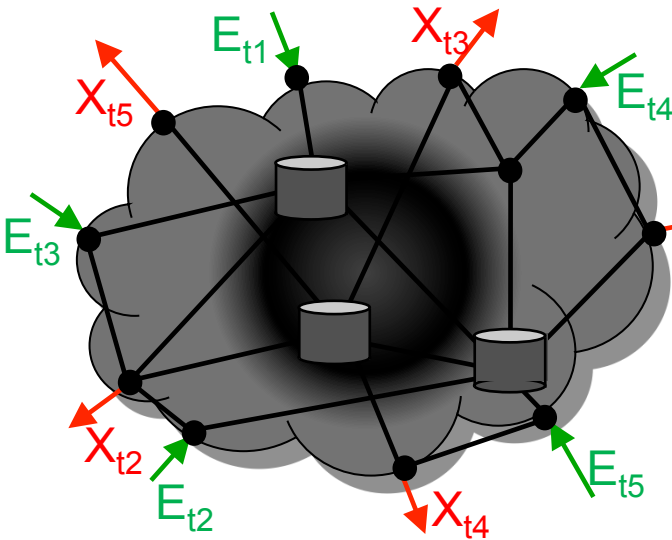
- ➢ A (displacement) energy network:
  - – Is a set of nodes connected by pipes/wires
  - – Has complex physical constraints
  - – Needs a TSO to monitor/control operations
- ➢ In operational period t, commodity amounts:
  - – E_{ti} are injected at entry points i
  - – X_{tj} are withdrawn at exit points j
- ➢ An 'Operational Schedule' (OS_T) is a set of (E_{ti}, X_{tj}) for all i and j in the network and all t in scheduling period T
- ➢ An 'Operational Model' (OM) of the network:
  - – Defines the set of OS_Ts that satisfy the constraints given initial and ending values of state variables (e.g., generation/storage levels etc.)
  - – May include mathematical models, operating protocols, rules of thumb, TSO judgments, etc.
  - – Is known to the TSO but is more or less a black box/cloud to others

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A Network Market and Its Commodity Exchange(s) (CEXs)

A Network Market
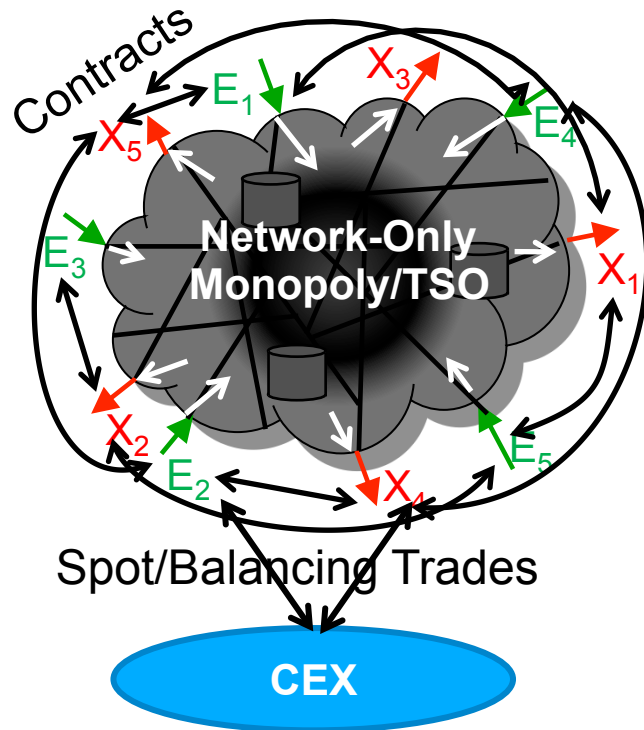
- ➢ A network market is a set of arrangements that lets commodity sellers and buyers:
  - – Trade commodity at different times and places bilaterally and in one or more CEX(s) to determine the 'Market Schedule' (MS)
  - – Pay the independent TSO to implement the MS

- ➢ Before, while and/or after commodity trading determines the MS, the TSO:
  - – Must determine whether the MS does/will satisfy network constraints and if necessary modify it to obtain a feasible OS
  - – May or may not modify the MS if it is feasible but 'only' inefficient

The principal issues in network market design: when/how does the TSO interact with the CEX to manage any 'gap' between the MS and an OS that satisfies network constraints; and what, if anything, does the TSO do if the MS is 'only' inefficient?

(The?) Three Basic Options for a Network Market

➢ There are basically three ways network constraints can be included (or not) in commodity trading, each with implications for the roles of the TSO and CEX(s) and for efficiency; network constraints can be:

1. ***Ignored*** in commodity trading: The TSO must provide enough physical capacity that the 'unconstrained' MS is 'almost always almost feasible' and/or actively manage any physical congestion outside the market

2. ***Commoditized*** as simple, stable capacity rights (e.g., MDQ_{xy}): The TSO must choose a combination of (1) restricting the supply of MDQ and living with or actively managing 'contractual congestion' and/or (2) providing more MDQ and actively managing physical congestion

3. ***Dynamically priced and allocated*** in a complex commodity market constrained by the 'actual' capacity (i.e., by an accurate/complex OM): The TSO must provide the OM, closely supervise (or even operate) the market, and manage any (presumably small) residual 'gap' between the OM-constrained MS and a feasible OS

The Trade-Off: The more the TSO helps the market price network constraints the smaller the MS/OS gap and the less the need for 'excess' capacity and/or TSO actions to modify the MS

Some Non-US Examples

➢ In the UK, the gas and electricity TSO (National Grid Company) has virtually full discretion in managing operations

- Electricity trading ignores network constraints, and gas trading is constrained only by highly simplified 'entry/exit' capacities

- NGC operationally 'balances' the systems by active contracting and trading, with a lot of discretion in deciding what to do and financial regulatory incentives to improve 'efficiency' (somehow defined)

- NGC is criticized by some for being arbitrary and opaque, but praised by others for being business-like and efficient

➢ In Victoria (OZ), the gas TSO uses a rules-defined, network-constrained spot market to manage operations

- Buy/sell offers are used five times a day to find a least-cost network-constrained OS and a network-unconstrained MS and settlement price

- Offer-based ancillary payments compensate shippers for following model-generated instructions that close the MS/OS gap at least cost

There are many ways to skin the network market cat, each with different implications for TSO and CEX roles, for economic efficiency, and for competition

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'Contract Straws' in Gas vs. 'Contract Paths' in Electricity

➢ The evolution of network markets began on US gas pipelines ~1985
  – Historically, integrated gas pipelines had purchased gas at A and delivered gas to B subject to contractual MDQ_Bs
  – When customers/shippers started buying the gas at A for delivery to B, the gas MDQ_Bs were 'simply' converted into tradeable transport MDQ_{AB}s
  – A pipeline with multiple A and B was, in effect, modeled in the market as though it were a fixed bundle of fixed-capacity A-to-B 'contract straws'

➢ Analogous 'contract paths' were tried in electricity but failed
  – Tradeable MH(ourly)Q_{AB}s were set at the maximum flow on a specific physical path from A to B, called the 'contract path'
  – But 'loop flow' meant that power flowing from A to B took many parallel paths, and power from many other X-to-Y transactions flowed on parts of the A-to-B contract path, making the MHQ_{AB} uncertain/unreliable
  – Electricity TSOs must model the entire system, and many use such models to operate network-constrained commodity/capacity spot markets

The failure of contract paths and the 'need' for TSO spot markets in electricity are commonly attributed to loop flow – implying no need/value for TSO spot markets in gas

The 'Capacity(ies)' of a 3-Node Power Grid

No flow controls or losses
Equal-impedance links

$Q_B + Q_C$

$F_{AB} \leq MAX_{AB}$

$F_{AC} \leq MAX_{AC}$

Q_B

Q_C
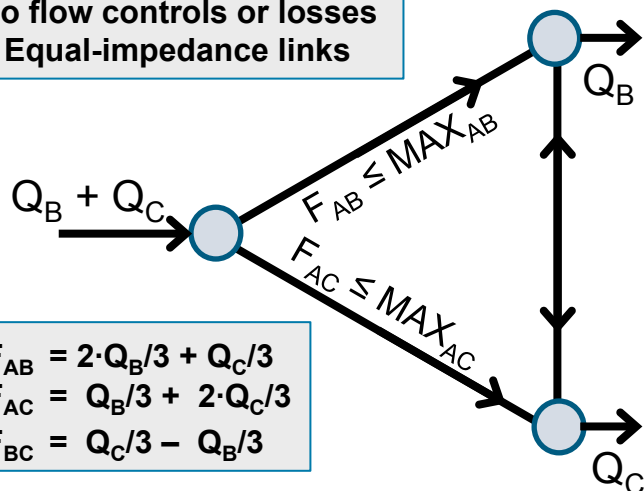
$F_{AB} = 2 \cdot Q_B/3 + Q_C/3$
$F_{AC} = Q_B/3 + 2 \cdot Q_C/3$
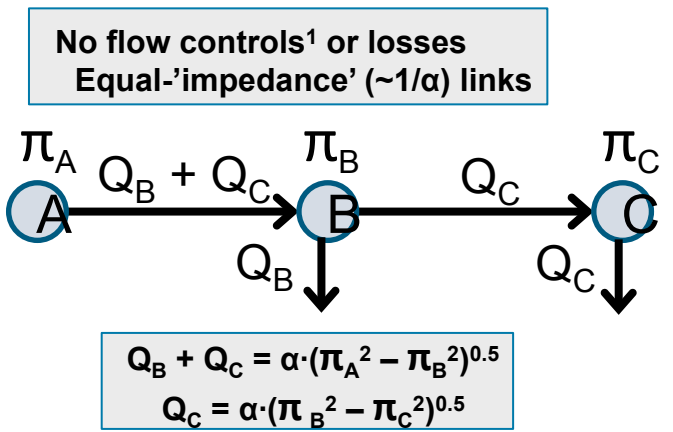$F_{BC} = Q_C/3 - Q_B/3$

➢ Even with given **path** capacities MAX_{AY} on each A-to-Y path (for Y = B, C), there are no unique **network** capacities MHQ_{AY}

  – The maximum **network** flow from A to B depends on the total network flow from A to C at the same time, and vice versa

  – In particular, setting $MHQ_{AB} = MAX_{AB}$ and $MHQ_{AC} = MAX_{AC}$ would (if $MAX_{AB} \neq MAX_{AC}$) overload the weaker line whenever shippers tried to use both MHQ_{AB} and MHQ_{AC} fully

➢ The inability to base an electricity market on tradeable MHQ_{XY} defined by physical contract paths was/is widely thought to be:

  – A primary justification for a TSO-operated spot market in electricity

  – Due to loop flow, and hence not an issue for gas markets

In fact, loop flow per se was not why markets based on MHQ_{XY} failed in electricity and is not a good justification for a TSO-operated spot market

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The 'Capacity(ies)' of a 3-Node Gas Pipeline

No flow controls[1] or losses Equal-'impedance' (~1/α) links

π_A $Q_B + Q_C$ π_B Q_C π_C

A — B — C

Q_B Q_C

$$Q_B + Q_C = \alpha \cdot (\pi_A^2 - \pi_B^2)^{0.5}$$
$$Q_C = \alpha \cdot (\pi_B^2 - \pi_C^2)^{0.5}$$

[1]The US gas system has ~18,000 nodes and only ~1,400 compressor stations, or ~13 nodes/station
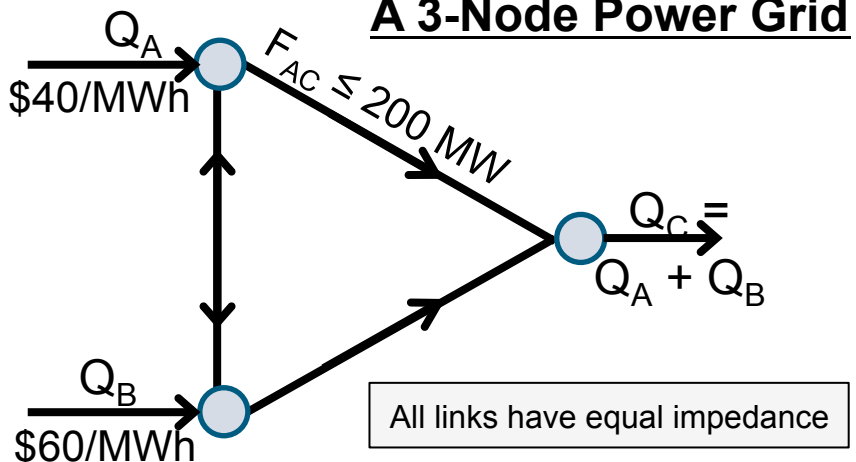
➢ The 'Fundamental Equation' of (steady-state) gas flow on a pipeline says:

- The flow on a link depends on the pressures (π) at the nodes at each end
- Specifically, $\text{Flow}_{XY} = \alpha \cdot (\pi_X^2 - \pi_Y^2)^{0.5}$, where α depends on pipeline properties
- For an X-to-Y 'contract straw', MAX_{XY} depends on $\text{MAX}\pi_X$ and $\text{MIN}\pi_Y$

➢ So what are the capacities MDQ_{AB} and MDQ_{AC} of the two parallel 'contract straws' that take gas from A to B and from A to C?

- Just as on the 3-node power grid, the maximum flow from A to B depends on how much is flowing from A to C at the same time
- In particular, if $\text{MDQ}_{AB} = \text{MAX}_{AB}$ and $\text{MDQ}_{AC} = \text{MAX}_{AC}$, the pipeline could not deliver both MDQ_{AY} simultaneously
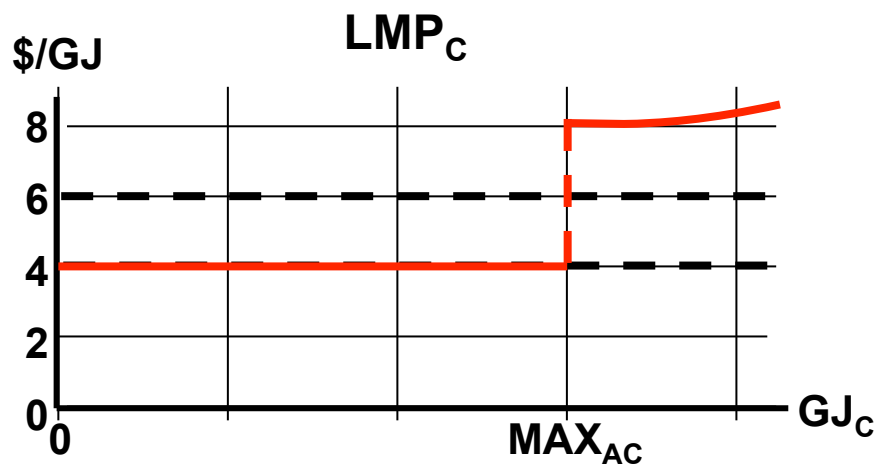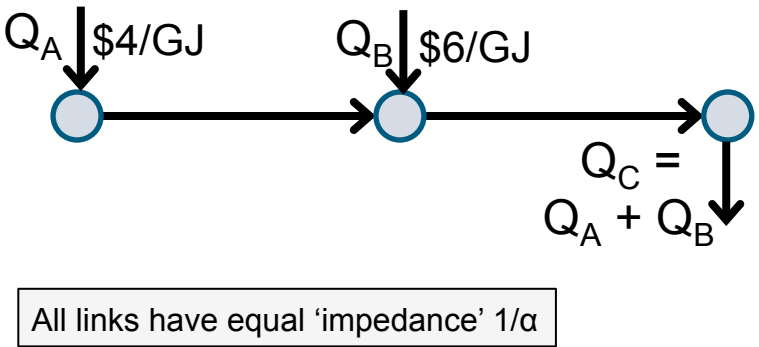
Even without loop flow, X-to-Y network capacities MDQ_{XY} cannot be set at the MAX_{XY} on specific X-to-Y 'contract straws' – and (more fundamentally) cannot be set independently!

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What About the Effects of Loop Flow on Nodal Prices?

A 3-Node Power Grid

Q_A
$40/MWh

$F_{AC} \leq 200$ MW

$Q_C = Q_A + Q_B$

Q_B
$60/MWh

All links have equal impedance

LMP$_C$

$/MWh

| 80 |
| 60 |
| 40 |
| 20 |
| 0 |

0   100   200   MAX$_{AC}$ 400   MW$_C$

A 3-Node Gas Pipeline

Q_A $4/GJ

Q_B $6/GJ

$Q_C = Q_A + Q_B$

All links have equal 'impedance' $1/\alpha$

LMP$_C$

$/GJ

| 8 |
| 6 |
| 4 |
| 2 |
| 0 |

0   MAX$_{AC}$ GJ$_C$
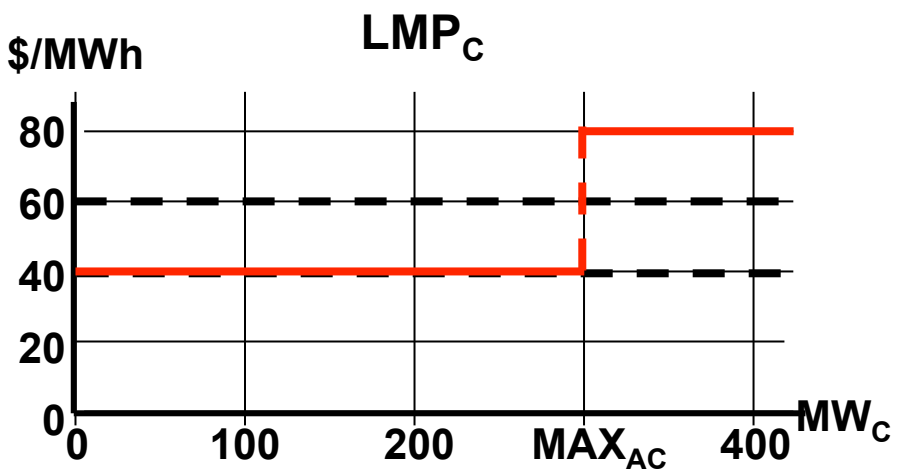
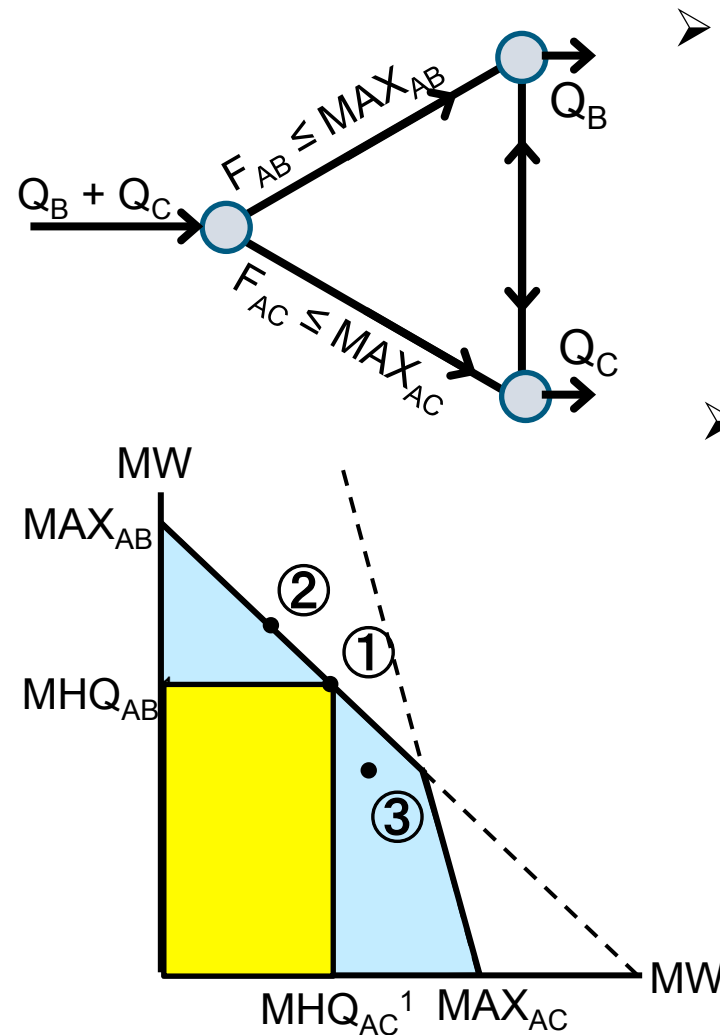*Loop flow externalities and gas flow externalities have essentially the same economic and market design implications*

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So Why Is a TSO Spot Market So Useful in Electricity?

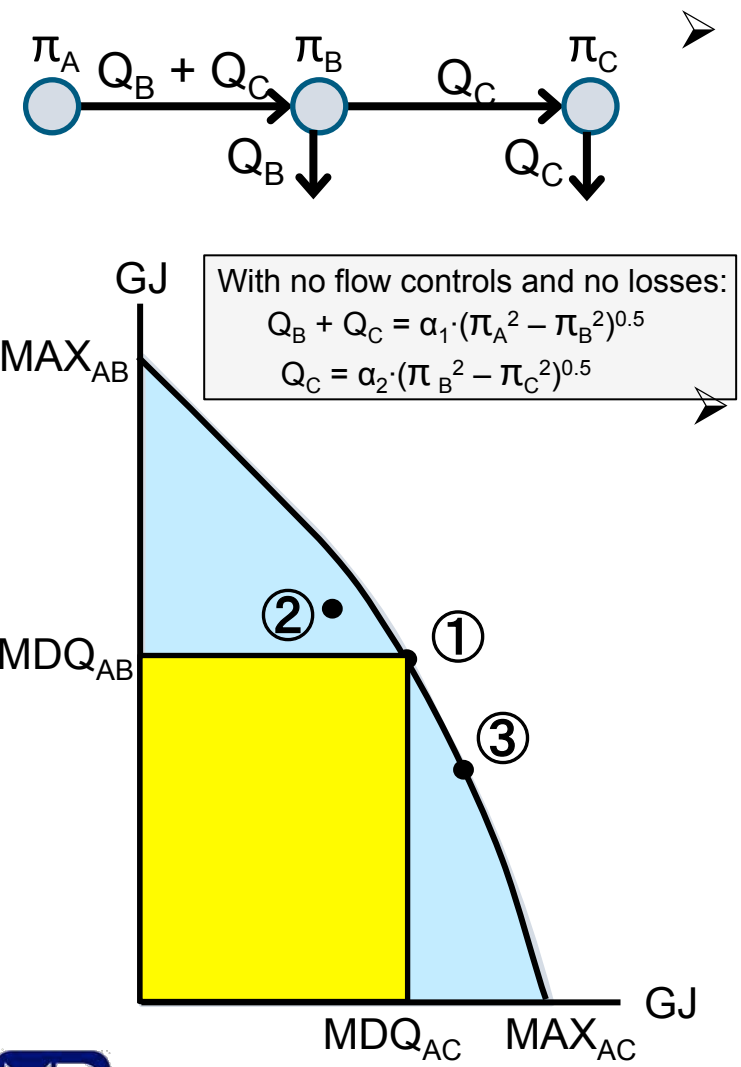➢ Loop flow externalities on a power grid mean that X-to-Y network capacities MHQ_{XY}:

  – CANNOT be set individually at the maximum flow on some physical X-to-Y 'contract path'

  – COULD be set at anything, as long as all are simultaneously feasible, i.e., in the blue area

➢ Thus, even with loop flow, the TSO:

  – Could base a market on tradeable MHQ_{XY}, using (e.g.) an auction to find/allocate and then enforce, the most valuable simultaneously feasible mix, say at ①

  – Would have no need to operate a spot market – **as long as the optimal use of the physical capacity stayed in the yellow box**

Thus, a TSO spot market is needed, not because of loop flow, but because optimal (peak) flows change, e.g., to ② or ③

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And When Might a TSO Spot Market Be Useful in Gas?

π_A $Q_B + Q_C$ π_B Q_C π_C

Q_B Q_C

GJ

With no flow controls and no losses:
$$Q_B + Q_C = \alpha_1 \cdot (\pi_A^2 - \pi_B^2)^{0.5}$$
$$Q_C = \alpha_2 \cdot (\pi_B^2 - \pi_C^2)^{0.5}$$

MAX_{AB}

② •

①

MDQ_{AB}

③

MDQ_{AC} MAX_{AC} GJ

➢ Gas flow externalities on a pipeline mean that X-to-Y network capacities MDQ_{XY}:
  – CANNOT be based on the capacities of physical X-to-Y 'contract straws'
  – CAN be set jointly so that all are simultaneously feasible, i.e., in the blue area

➢ As long as optimal (peak) flows do not change much or often, the TSO:
  – Can find the most valuable feasible set of MDQ_{AB}, say at ①, and simply enforce these
  – Has no need to reconfigure the MDQ_{XY} if optimal peak flows remain in the yellow box
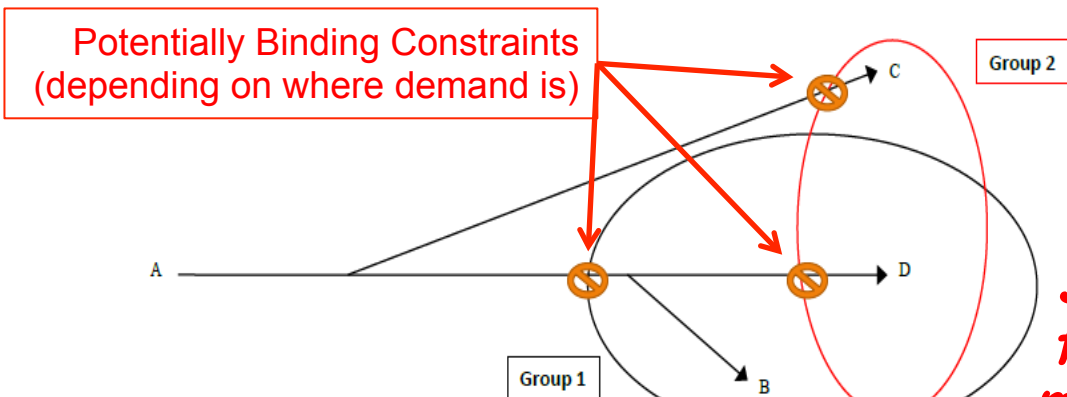
Gas markets based on fixed MDQ_{XY} 'worked' historically, not because there was no loop flow, but because (or as long as) optimal peak gas flows did not change much or often

Gas TSOs Must Increasingly Reconfigure MDQ$_{XY}$

One of 24 examples from the Northern Natural Gas website illustrating how requests for within-day reconfiguration are handled under different situations

Redirect Flowing Rights in Multiple Delivery Groups

Two separate paths: Each path changed from one Physical Delivery Point to a new Physical Delivery Point, two separate allocated Groups involved; No change to nomination volume

Potentially Binding Constraints (depending on where demand is)

> In practice, gas TSOs must/do dynamically reconfigure MDQ$_{XY}$ as market conditions change – but in ad hoc, inefficient, non-market ways

Such situations cry out for TSO-operated spot markets – because EVEN WITHOUT LOOP FLOW, the optimal use of physical capacity, and hence the optimal configuration of MDQ$_{XY}$, change often

Group 2

Group 1

- Group 2 will be allocated before Group 1 in the allocation sequence
- Group 1 capacity = 60; Group 2 capacity = 40

Cycle	Receipt Point	Delivery Point	Nom Volume	Delivery Rank	Allocatable Volume	Total Scheduled	Redirect Flowing Rights
T (Group 2)	A	C	100		100	40	40
T (Group 1)	A	B	100		100	60	60
E (Group 2)	A	D	200		40-F; 160-I	40	
E (Group 1)	A	D	40		40 -F		

F = Flowing
I = Incremental

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Gas-Electricity Convergence

➢ Both gas and electricity markets will have to continue (co)evolving to meet the new challenges they share

  – Gas demand and supply are becoming more diverse and dynamic economically and geographically, as gas plays a larger role in power generation (particularly to back up renewables) and 'fracking' expands

  – Electricity grids are adding flow-control capability analogous to the gas compressors and valves that once (supposedly) made gas different

➢ Dealing efficiently with the increasingly diverse, dynamic and interdependent nature of both gas and electricity will require:

  – Much more fundamental changes for both gas and electricity than (e.g.) tinkering with the timing of scheduling processes

  – Gas pipelines to reduce their historic reliance on fixed MDQ_{XY} both in operations and in investment

Gas will become more like electricity more than the converse, not because pipelines are developing loop flow (which was always a red herring), but because optimal pipeline flows are becoming more dynamic

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The Fundamental Issue and Likely Outcome

➤ The most fundamental issue is whether increasingly dynamic and interdependent electricity and gas systems are best managed by:

- – Developing increasingly sophisticated, complex, rules-based markets operated by independent, mostly non-profit and self-regulated monopoly TSOs – think PJM on steroids; or

- – Developing increasingly powerful, discretionary, opaque, independent, profit-seeking (or state-owned) monopoly TSOs controlled primarily by incentive regulation – think NGC on steroids; or

- – Letting existing institutions and processes muddle along and living with the inefficiencies, i.e., inefficient utilization of physical capacity, arbitrary, non-market TSO processes for reconfiguring capacity, etc.

Given the size, history and complexity of gas and electricity markets, muddling along is the most likely, and maybe even the best, approach in the (perhaps very long) short run; but even muddling should be based on a good understanding of the logic of network markets and the ways in which gas and electricity are, and are not, really different

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