KTH Electrical Engineering

Risk Management

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Risk

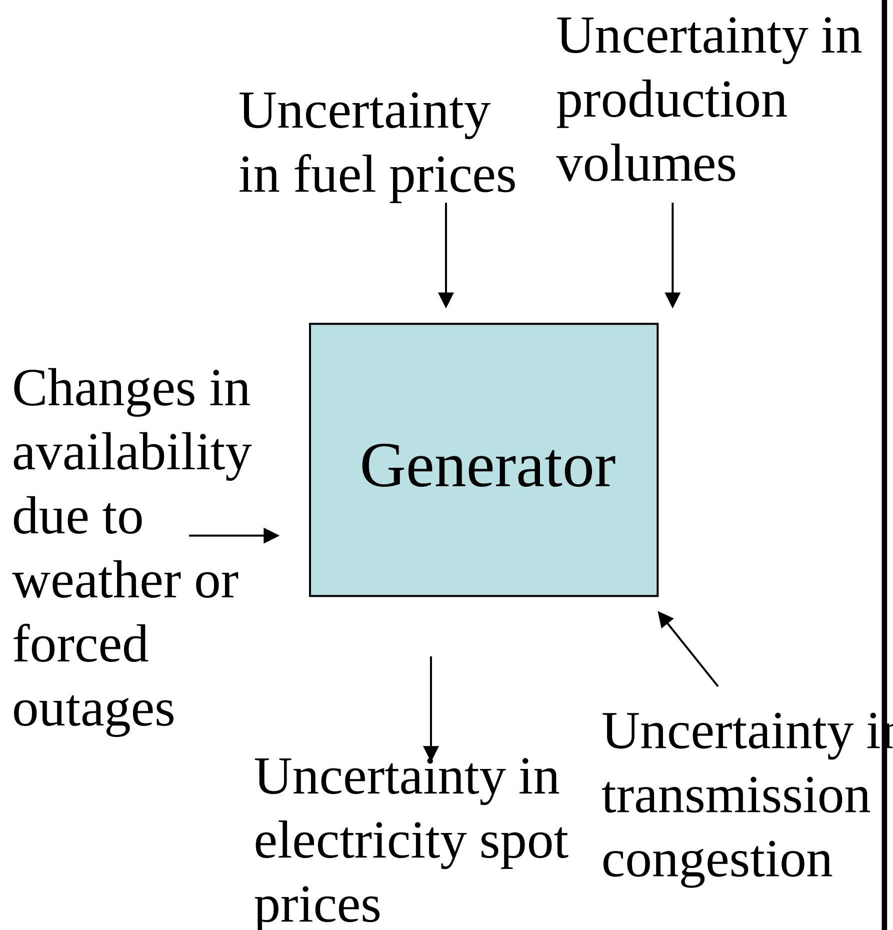
- The wholesale spot price for electricity is notoriously volatile.
  - It can vary every five minutes from $-1000/MWh to the price ceiling (currently $10,000/MWh, rising to $12,500/MWh).
- Investments in generation assets typically require a sunk commitment lasting many years. It is difficult to forecast the spot price accurately on a day-ahead basis, let alone a year ahead, or twenty years in the future.
- Nearly all the participants in the spot market will seek to reduce the wholesale spot price risk to which they are exposed. In other words, participants in the spot market behave as though they are **risk averse**.
  - This could be for two reasons – either because investors reward these firm for reducing their risk and/or because creditors (such as banks) require the firm to maintain a certain level of hedge cover.

Risk

- Firms will not make investments in the electricity industry without some form of assurance as to the long-term revenue they will receive.
  - An efficient active hedge market is essential to achieve efficient investment in electricity generation.
- We would like to answer the following questions:
  - Why do firms hedge the risks they face?
  - How do firms hedge the risks they face?
    - What risks can be hedged and which cannot?
    - What are the instruments available for hedging risks? How do they operate? Who are the buyers and sellers of these products?
    - As we will see there are many different hedge products (swaps and caps etc.) – how do firms choose a portfolio of these instruments?

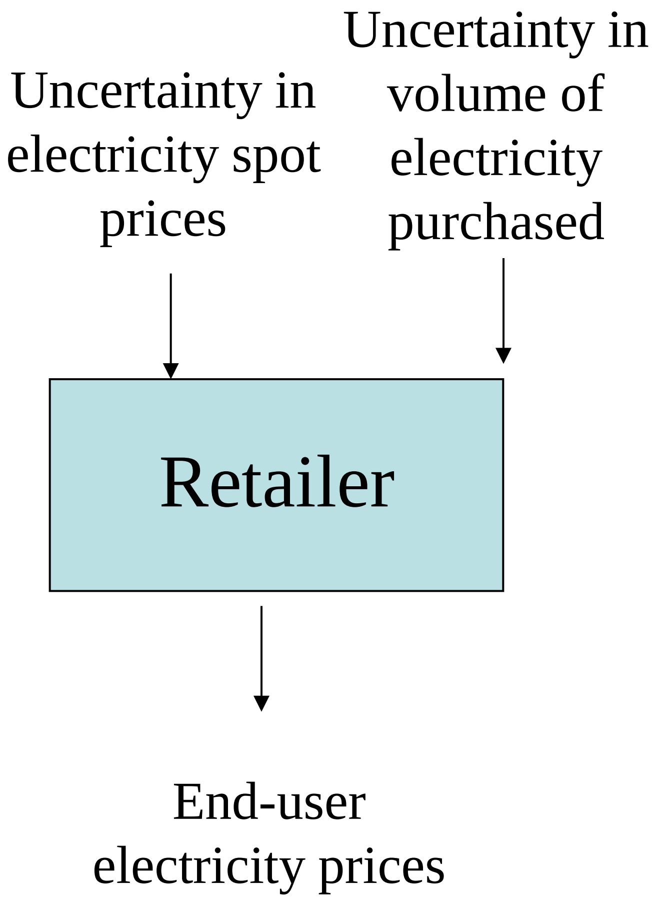
Sources of risk

- Let's start by exploring what risks can be eliminated by arrangements within the electricity industry and what risks must remain to be borne by some party.
- A generator faces many sources of risk
  - Input (fuel) price risk
  - Changes in availability (breakdowns, industrial action, weather)
  - Output (electricity) spot price risk
  - (Transmission congestion risk)
  - Volume risk
- Can the generator pass input price risk upstream through input price contracts with its suppliers? What about wholesale price risk?



Sources of risk

- A retailer also faces risk:
  - Input electricity spot price risk
  - Output (end-user) price risk?
  - Volume risk
- Can a retailer reduce its risk by passing wholesale spot price risk downstream (to end-users?)
- Changes in the wholesale spot price have an opposite effect on the profits of generators and retailers.
  - Contractual arrangements between generators and retailers can mitigate the risks they face.



Sources of risk

- Contracts between generators and retailers *cannot* eliminate all risk from the industry.
- The industry still bears "residual risk" from
  - Input price risk
  - Changes in availability (outages, industrial action)
  - Volume risk
  - Output (end-user) price risk?
- This residual risk *must* be borne by some party within the industry (or the industry must pay some other party, such as a bank, to bear this risk).
- What is the size of this residual risk?
- The industry profit is the sum of the profit of all the generators and retailers plus the settlement residues. The residual risk is the variability in the industry profit.

Risk management instruments

- In practice the majority of risk-management contracts are arrangements between generators and retailers.
- These arrangements are sometimes specially tailored or custom-made arrangements (especially when the contract is for a longer-term, such as ten-fifteen years).
- Outside these tailor-made contracts most risk-management arrangements fall into standardised contractual forms.
  - The use of standardised contractual forms facilitates transparency in pricing and reduces the transactions costs of trading.
- There are a variety of such contracts:
  - **Swaps** (55-60%), **caps** (10-20%), **floors** (1-2%)
  - **Swaptions** (10-12%), **Asian options** and **collars** (4-6%), etc.

OTC vs exchange-based trade

- These standardised contracts are traded either bilaterally (in what is called the over-the-counter or OTC market), or sometimes in organised exchanges.
  - A key difference between these two markets is that in the OTC market a party knows who the counterparty is and must make arrangements for handling counterparty risk (the risk that the counterparty will not fulfill the contract).
  - In the case of trade on an exchange, the exchange is the counterparty and makes arrangements for handling the risk of non-performance on the contact.
  - Parties will sometimes want to swap an OTC transaction for an equivalent exchange-traded transaction in a process known as "Exchange for Physical"
    - (this can be used to reduce counterparty exposure, to net-off positions, or to allow trading outside exchange hours).

Swaps

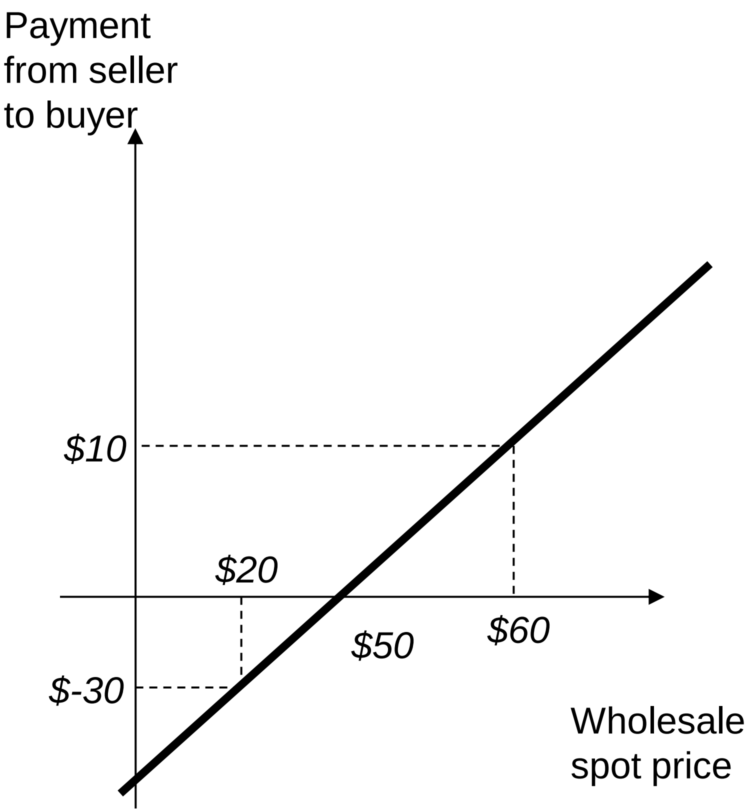
- The simplest hedge contracts are **swap** contracts (also known as **contracts-for-differences**).
- To specify a swap contract you need to specify three pieces of information:
  - The precise dates and times in the future that the swap contract will apply
  - The number of units
  - The price of the contract.
- By convention, with a swap contract, for each date and time that the swap contract applies:
  - the **seller** makes a payment to the **buyer** equal to the difference between the wholesale spot price at that point in time less the contract price times the number of units.
  - (The buyer has "swapped" its exposure to pay a floating spot price for a requirement to pay a fixed price)

Swaps

- In mathematical notation, a swap at a given date and time, with a fixed price *F* and for a fixed quantity *X*, pays the following amount from the seller to the buyer when the spot price is *P*:

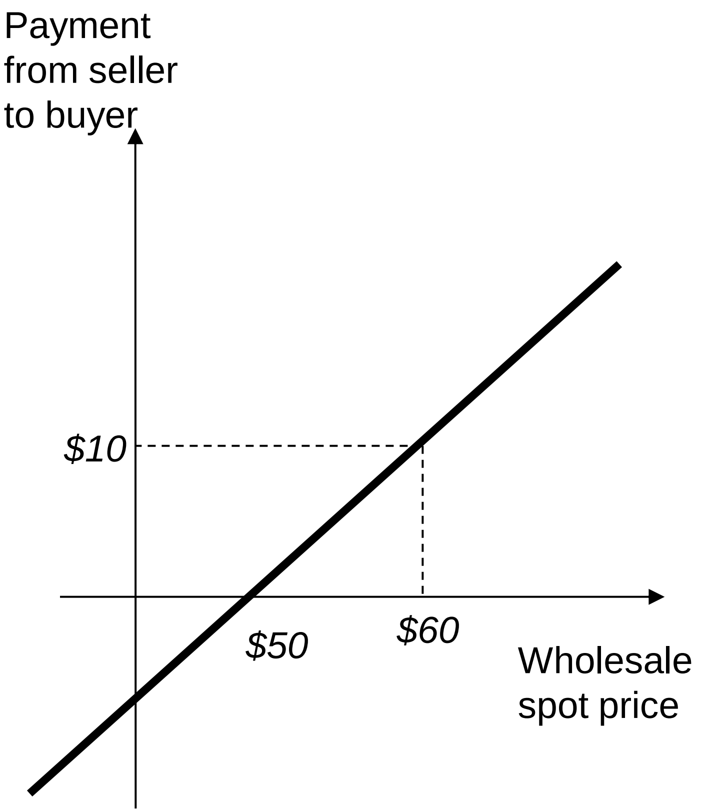
$$Swap(P,X,F)=(P-F)X$$

  - If the contract price is $50, when the wholesale price rises to $60, the seller pays the buyer $10 per contract unit.
  - If the wholesale price drops to $20, the buyer pays the seller $30 per contract unit.



Swaps

- Swaps are only good for insulating the buyer or seller from wholesale spot price risk **when the buyer or seller faces no volume risk**.
  - For example, suppose a large load knows it will consume at the rate of precisely 100 MW every hour of every day in 2011. It could completely eliminate its exposure to wholesale spot price risk by purchasing a swap.
  - Similarly, a generator which knew it would be producing precisely 1000 MW for every day during Q1 2010 could sell a swap for that quarter.
- But how many generators or loads face no volume risk at all?



Caps

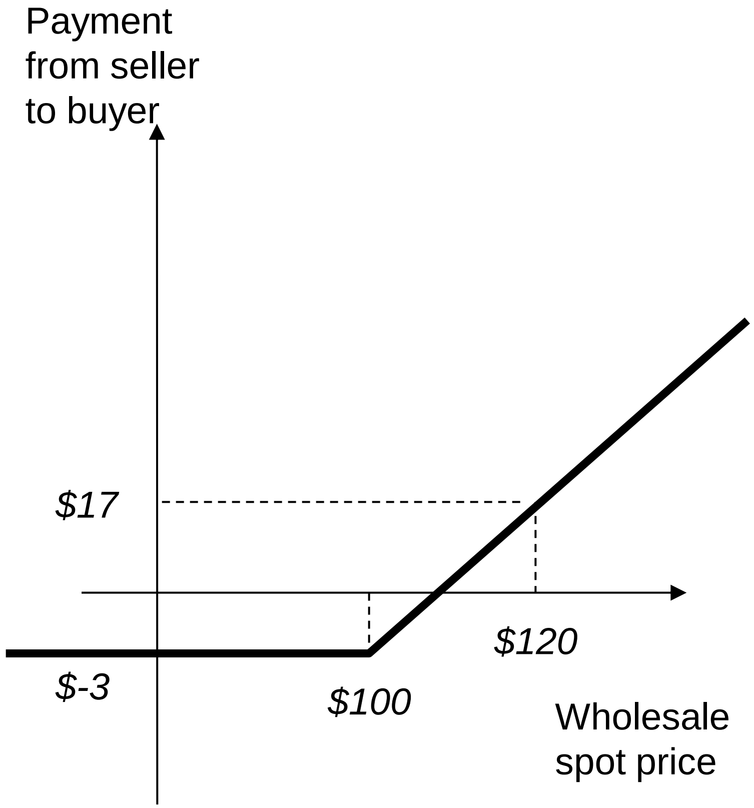
- The next simplest hedge contracts are **cap** contracts.
- To specify a cap contract you need to specify four pieces of information:
  - The precise dates and times in the future that the cap contract will apply
  - The number of units
  - The **strike price** (i.e., the wholesale price above which the contract will be active).
  - The price of the contract.
- By convention, with a swap contract, for each date and time that the swap contract applies:
  - the **seller** makes a payment to the **buyer** equal to the difference between the wholesale spot price at that point in time less the contract price times the number of units – but only when the wholesale spot exceeds the cap strike price.
- Caps allow buyers to place an upper limit (or "cap") on the amount they will pay to buy a certain quantity of electricity.

Caps

- In mathematical notation, a cap at a given date and time, with a strike price *S*, a price *F* and for a fixed quantity *X*, pays the following amount from the seller to the buyer when the spot price is *P*:

  $Cap(P,S,X,F)=(P-S)X-F.X$, if $P \geq S$ and $-F.X$, otherwise

  - For example, if a cap has a strike price of $100, the wholesale spot price is $120, and the cap contract cost $3, the seller would pay the buyer $20-3 = $17 per unit of the contract.
  - If the wholesale spot price was $80, the buyer would pay the seller just $3 per unit of the contract.



Swaps and Caps

- Caps are most useful for hedging risks for which the **volume risk is directly tied to the price risk**.
- For example, suppose we have a generator with a variable cost of $50/MWh and a capacity of 100 MW. Recall that if this generator is a price-taker, the efficient dispatch is for this generator to be dispatched up to 100 MW when the spot price exceeds $50/MWh and not to be dispatched at all when the spot price falls below $50/MWh.
- It is clear that for this generator the volume risk is precisely and directly tied to the price risk.
- This generator could completely eliminate its exposure to wholesale spot price risk by selling a cap with a strike price of $50/MWh and a volume of 100 MW.
  - If the wholesale price rose above $50/MWh the generator would have an obligation to pay the difference less the contract price, but in this case the generator would be producing and would receive wholesale revenue to fund these payments.
  - If the wholesale price fell below $50/MWh the generator would have no obligation to pay and would receive a payment equal to the contract price.

Swaps and Caps

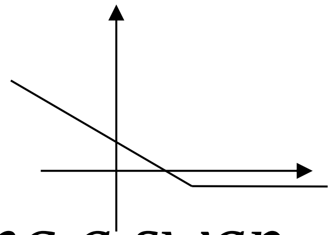
- Cap contracts are useful hedging tools for mid-merit and peaking generators.
- In the same way, a cap contract might be useful to a retailer which needs to hedge a load of say, 1000 MW, which drops to 500 MW if and only if the wholesale spot price rises above $100/MWh.
- This load could be hedged by:
  - The **purchase** of a swap contract with a volume of 1000 MW and
  - The **sale** of a cap contract with a volume of 500 MW.
- Again, the key point is that cap contracts are useful hedging tools **when the volume risk is directly linked to the price risk**.
  - It is worth noting that a *swap is identical to a cap which is always "in the money"* (i.e., which has a strike below the lowest price)
  - Caps with different strike prices should be thought of as different risk management instruments (with swaps just another form of cap)

Floors

- "Floors" are the opposite of caps – they allow sellers to ensure they will be paid at least a minimum price for a given quantity of electricity.

  $Floor(P,S,X,F) = (S-P)X - F.X$, if P<S

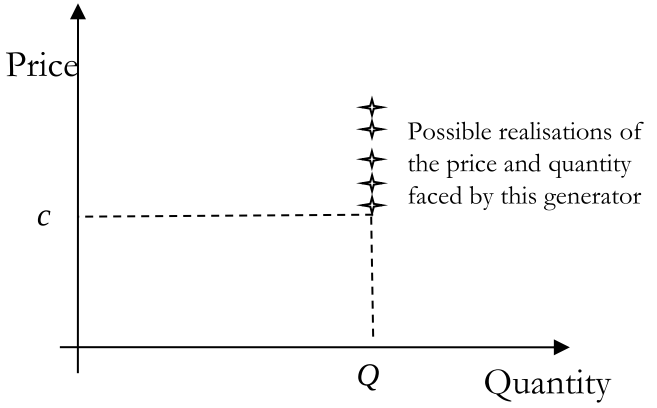
  $-F.X$, otherwise



- For the same strike price and quantity, *selling a swap is identical to selling a cap and buying a floor*
  - Given any two of swap, cap and floor it is possible to construct the other. So we will focus on swaps and caps.
- There are also *collars* which consist of a cap and a floor with different strike prices.

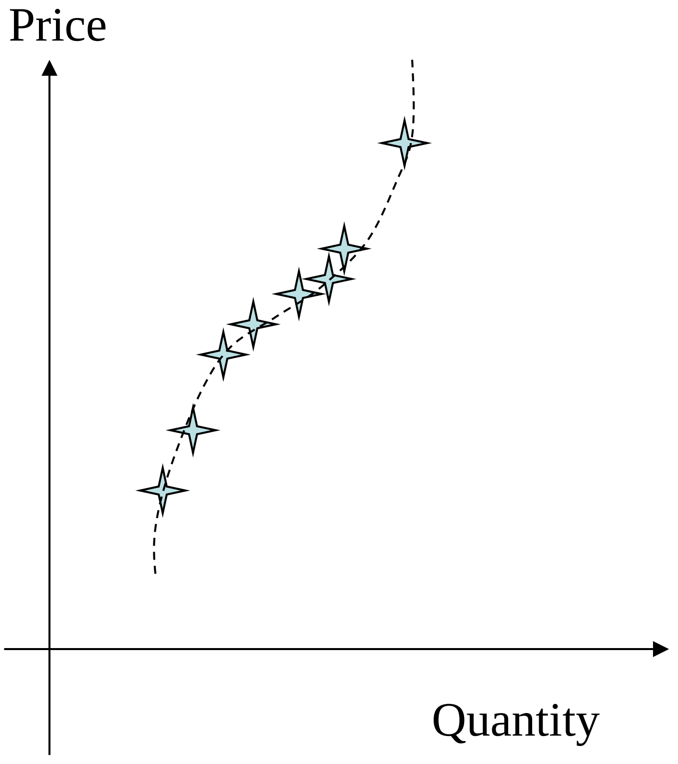
Combining swaps and caps to achieve a perfect hedge when the volume is a monotonic function of the price

- No Volume Uncertainty
- A retailer or a generator which faces no volume risk can achieve a perfect hedge using swaps alone.
- Generator with a single plant
- a generator without market power and with constant marginal cost up to a fixed capacity can achieve a perfect hedge using a cap, with a strike price of the cap equal to the generator's marginal cost and the volume of the cap equal to the total capacity of the generator.



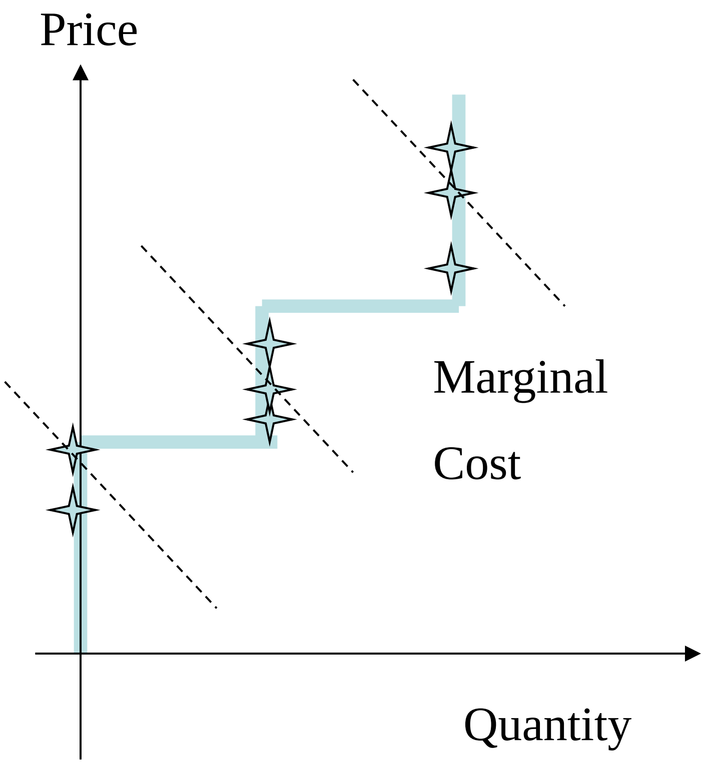
Combining swaps and caps to achieve a perfect hedge when the volume is a monotonic function of the price

- If a generator holds a portfolio of swaps and caps, will the presence of that portfolio change the generator's bidding behaviour?
- In principle, if there were a full range of cap contracts available with different strike prices it would be possible to perfectly hedge any price/quantity risk where the quantity was a simple function of the price.



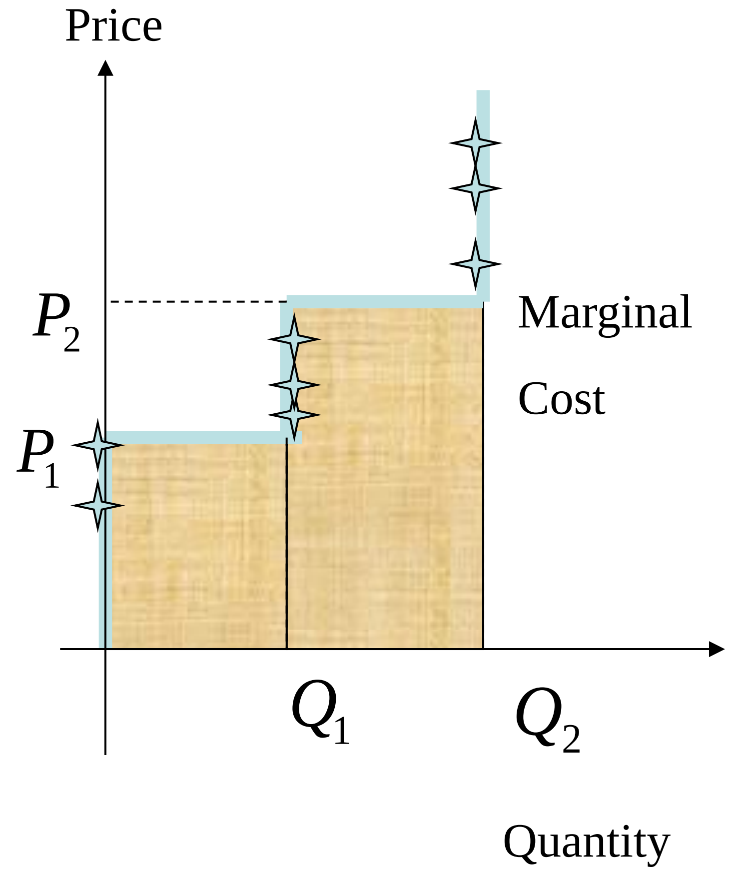
Generator with two plants

- For example, consider the position of a price-taking generator with two generating units both of which are perfectly reliable.
- The price-dispatch relationship for this generator is as given by the diagram.
- Can this price-quantity risk be perfectly hedged using swaps and caps alone?



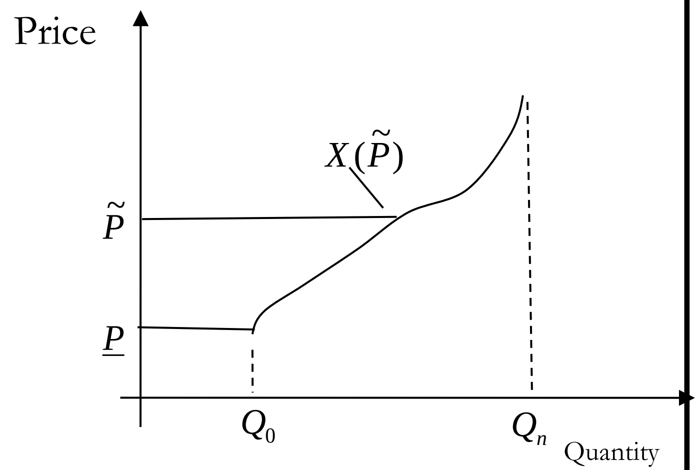
Hedging risk using swaps and caps

- This price-quantity risk cannot be hedged with swap contracts alone
- But it can be hedged using a portfolio of caps – in this case by buying a cap with strike price P_1 and quantity Q_1 and a cap with strike price P_2 and quantity Q_2-Q_1



Generalising to an arbitrary portfolio of cap contracts

- When the profit of a retailer or generator can be expressed as a function of the price alone, it is possible to obtain a perfect hedge using a portfolio of caps where the portfolio is chosen in such a way that the level of cover at any realisation of the market price is equal to the profit function at that price.

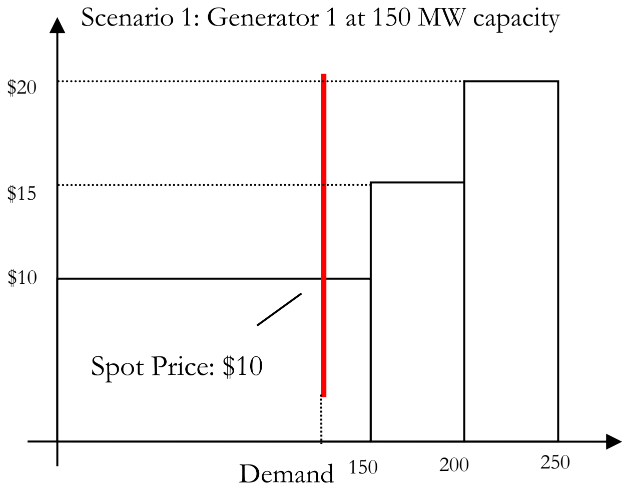


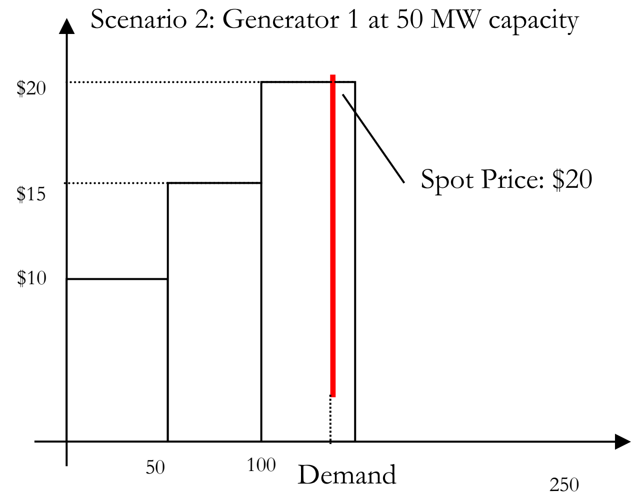
$$\int_{\underline{Q}}^{S^{-1}(\tilde{P})} (\tilde{P} - S(x)).dx - \int_{\underline{Q}}^{\overline{Q}} F(S(x)).dx$$

$$\int_{\underline{P}}^{\tilde{P}} X(s)ds - \int_{\underline{P}}^{\overline{P}} F(s)X'(s)ds$$

$$\pi(\tilde{P}) - \int_{\underline{P}}^{\tilde{P}} X(s)ds + \int_{\underline{P}}^{\overline{P}} F(s)X'(s)ds \qquad \pi'(\tilde{P}) = X(\tilde{P})$$

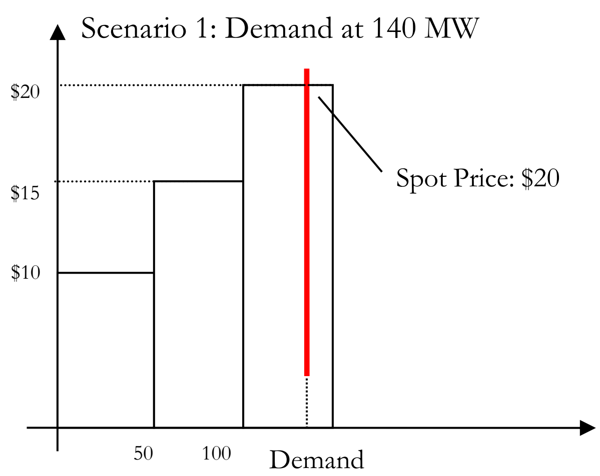
Uncertainty in generator cost functions: Generator performance insurance

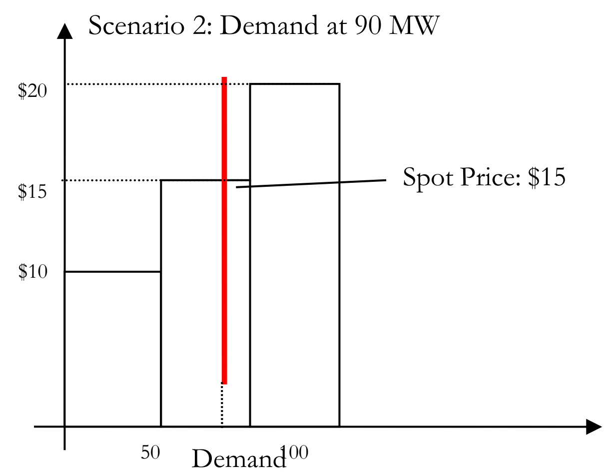




	Scenario 1: Gen 1 at full capacity			Scenario 2: Gen 1 at half capacity		
	Price	**Dispatch**	**Profit**	**Price**	**Dispatch**	**Profit**
Gen 1	$10	140	$0	$20	50	$500
Gen 2	$10	0	$0	$20	50	$250
Gen 3	$10	0	$0	$20	40	$0
Retailer	$10	140	$(P^R - 10) \times 140$	$20	140	$(P^R - 20) \times 140$
Total Industry Profit			$(P^R - 10) \times 140$ $= 140P^R - 1400$			$(P^R - 20) \times 140$ $+ 750 =$ $140P^R - 2050$
Diff						-$650

Uncertainty in generator cost functions: Generator performance insurance

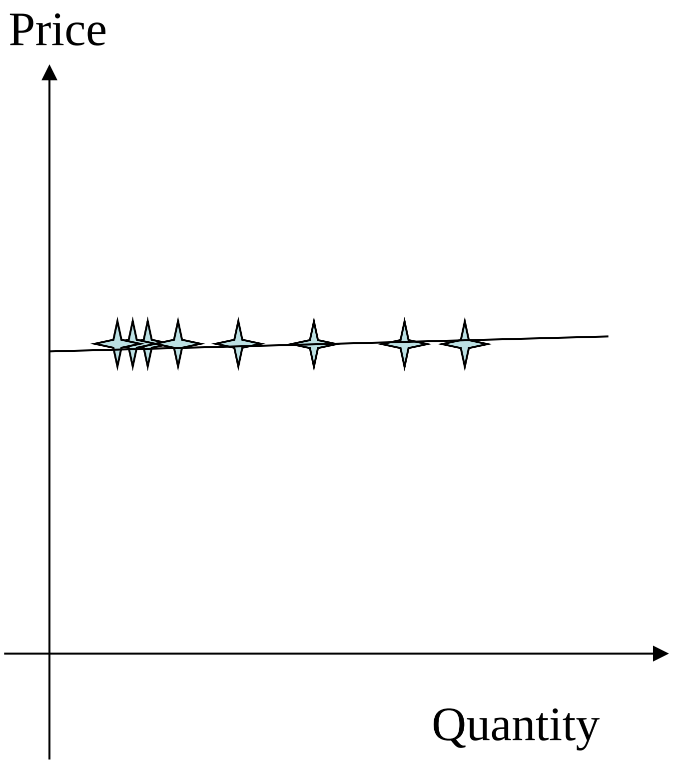




	Scenario 1: Demand at 140 MW			**Scenario 2: Demand at 90 MW**		
	Price	**Dispatch**	**Profit**	**Price**	**Dispatch**	**Profit**
Gen 1	$20	50	$500	$15	50	$250
Gen 2	$20	50	$250	$15	40	$0
Gen 3	$20	50	$0	$15	0	$0
Retailer	$20	140	$700	$20	140	$900
Industry Profit			$1450			$1150
Difference						-$300

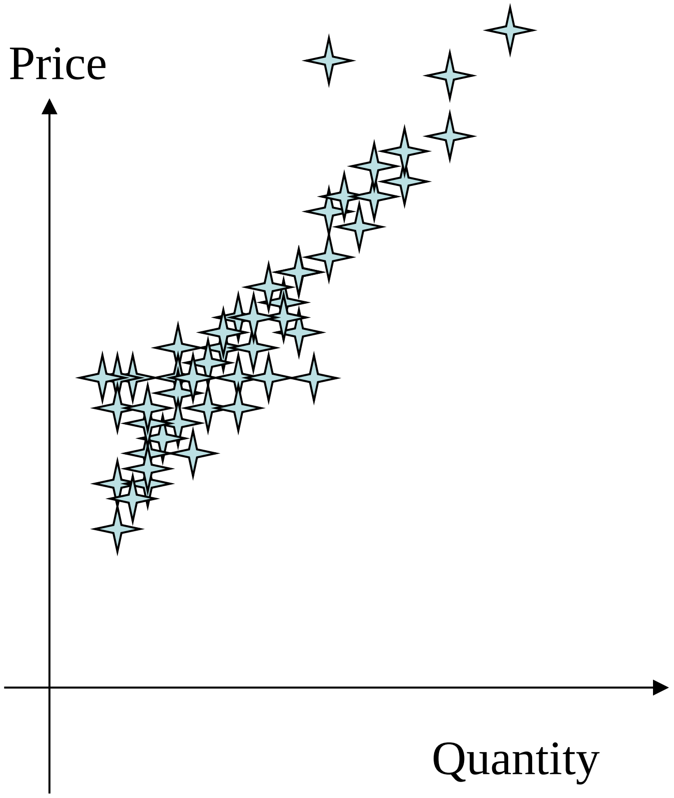
Hedging risk using swaps and caps

- It is important to recognise that not all risks can be hedged using swaps and caps.
- This applies, in particular, when the quantity can not be expressed as a function of the price.
- In the simplest case in which price is fixed and volume is varying *swaps and caps can have no effect on the risk at all!*



Hedging risk using swaps and caps

- More generally, when the quantity cannot be expressed as a function of the price…
- …we can't look for a perfect hedge, only a hedge which minimises total risk
  - (i.e., a hedge which minimises the variance of the firm's profit)



Financial Transmission Right

- **Firm Financial Transmission Right (FFTR)**: The FFTR is a financial instrument which for a given pair of nodes and a given date and time in the future, makes a payment which is proportional to the difference in the nodal prices at the two nodes.

- In mathematical notation, if $\tilde{p}_i$ and $\tilde{p}_j$ are the nodal prices at nodes *i* and *j*, respectively, then a firm financial transmission right with a quantity of *X* units, and a price F_{ij} has the following payment:

$$FFTR_{ij}(\tilde{p}_i, \tilde{p}_j, X, F_{ij}) = (\tilde{p}_j - \tilde{p}_i)X - F_{ij}X$$

- **Definition:** For a given pair of nodes and a given date and time in the future, a firm financial transmission right or ("FFTR") is a financial instrument which, in the future, makes a payment which is proportional to the difference in the nodal prices at the two nodes.

Financial Transmission Right

- **FFTRs and settlement residues**: Some advocates of FTRs argue that certain market participants should have an entitlement to a given level of FTRs (without having to pay for them).The **revenue** needed to support these FTRs would come from the **settlement residues**.

- Mathematically, it is written as

$$FFTR_{ij}(\tilde{p}_i, \tilde{p}_j, X_{ij}) = (\tilde{p}_j - \tilde{p}_i) X_{ij}$$

- This raises the question of how to determine what quantity of FTRs can be allocated while still allowing the allocated FTRs to be supported by the settlement residues?

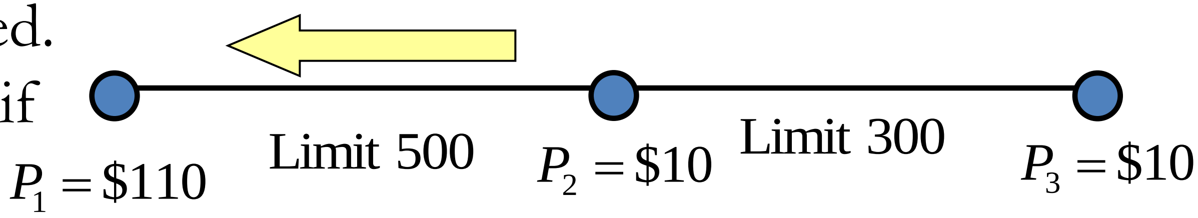
Simultaneous feasibility

- How much of the different point-to-point FTRs should the system operator sell? How does the system operator know whether it will receive enough revenue in the merchandising surplus to fund all the FTRs it sells?
  - This is the problem of ensuring that the FTR obligation is **revenue adequate**.
- Theory provides an answer:
  - The full set of FTR obligations provided by the system operator correspond to a set of hypothetical flows or net injections on the network. If those hypothetical flows are within the physical limits of the network, (i.e., are simultaneously feasible") the merchandising surplus is always less than or equal to the revenue obligations on the system operator.
- In effect, the system operator must run the dispatch process in two stages.
  - In the first stage, for the purpose of selling hedging instruments, the system operator forecasts the network configuration in the future, takes bids and offers for different point-to-point FTRs and then finds an allocation of FTRs (and prices) which clear the market, consistent with the forecast network limits at that time.
  - In the second stage, which is the wholesale spot market, the system operator takes bids and offers and finds the dispatch and nodal prices which clear the market, consistent with the actual network limits at the time.

Nodal pricing / FTRs

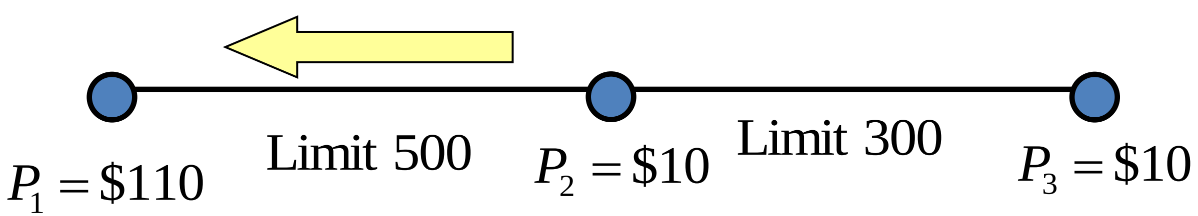
- The following is a feasible allocation of FTRs in this market:
- Now suppose the prices in the spot market are as below.
- The total residues are \$50,000 and the total FTR payments are \$50,000, so the mechanism is revenue adequate as required.
- But what happens if there is a network outage?

FTR	Alloc	Pay-out
2-1	600	600 x \$100 = \$60,000
3-1	-100	-100x \$100 = \$10,000
2-3	-400	-400 x \$0 = \$0
Total		\$50,000



Nodal pricing / FTRs

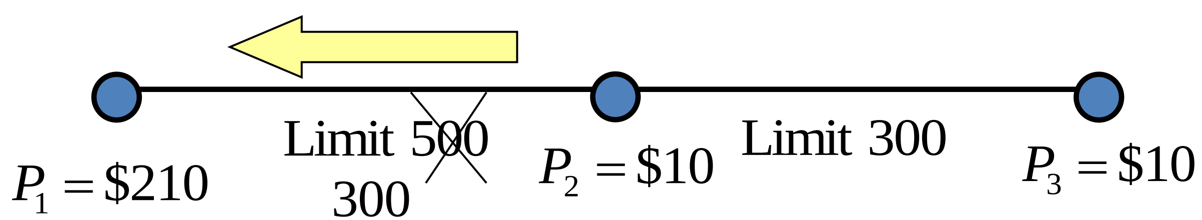
- A core issue in the design of an FTR mechanism arises from the timing.
- Since FTRs are used for hedging, the FTR auction has to be held well in advance of the spot market – probably many years in advance.
- But what happens if, on the day of the spot market, the network cannot carry the flows corresponding to the FTRs that were sold in advance (i.e., if the FTRs are no longer simultaneously feasible)?
- Now the system operator faces a risk of a revenue shortfall.
- In practice this is addressed in one of two ways:
  - "Scaling back" all of the FTRs to the point where the scaled back FTRs are simultaneously feasible on the network, or
  - To not offer FTRs up to the full forecast capability of the network (so that there is some additional surplus in normal times to offset the revenue shortfall in times of network outages).
  - Should the TSO be held financially responsible for the deficit, as an incentive mechanism?



Nodal pricing / FTRs

- Now suppose an outage drops the limit on the first line to 300 MW. The total residues are now \$60,000 but the FTR obligations are \$100,000.
  - There is now a net residue deficit of \$40,000.
  - One approach is simply to scale back all the FTRs equally (by 0.6 in this case).
  - But now the FTRs are not a firm hedge.

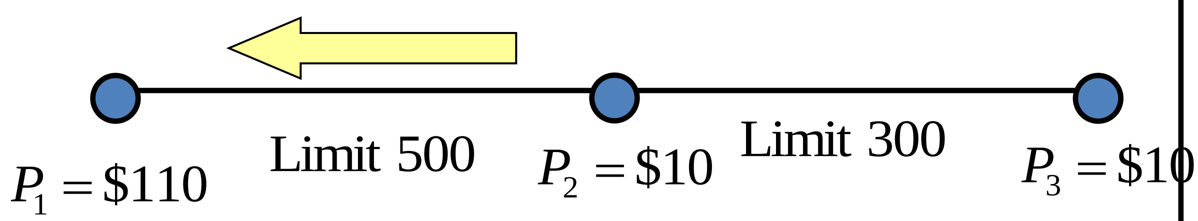
FTR	Alloc	Scaled	"Raw" Pay-out
2-1	600	360	360 x \$200 = \$72,000
3-1	-100	-60	-60x \$200 = -\$12,000
2-3	-400	240	-240 x \$0 = \$0
Total			\$60,000



Nodal pricing / FTRs

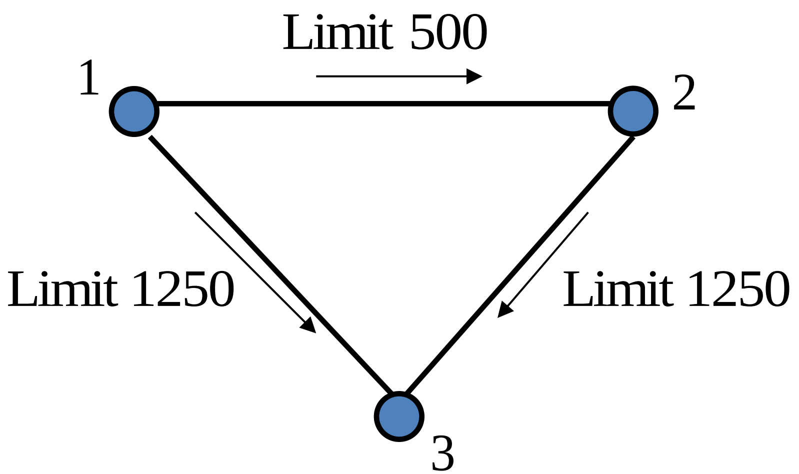
- An alternative approach is to not offer FTRs up to the full capability of the network. For example, suppose that the system operator only offered a capacity equal to 450 MW on the first link.
- Now there is a surplus of $50,000 under system normal conditions (and a residue deficit of $30,000 under outage conditions). If outages are rare enough this approach could be revenue adequate.
- But some traders cannot obtain the full system normal hedges they need?

FTR	Alloc	Pay-out with reduced alloc
2-1	600	600 x $100 = $60,000
3-1	-150	-150x$100 = $-15,000
2-3	-450	-450 x $0 = $0
Total		$45,000



Nodal pricing / FTRs

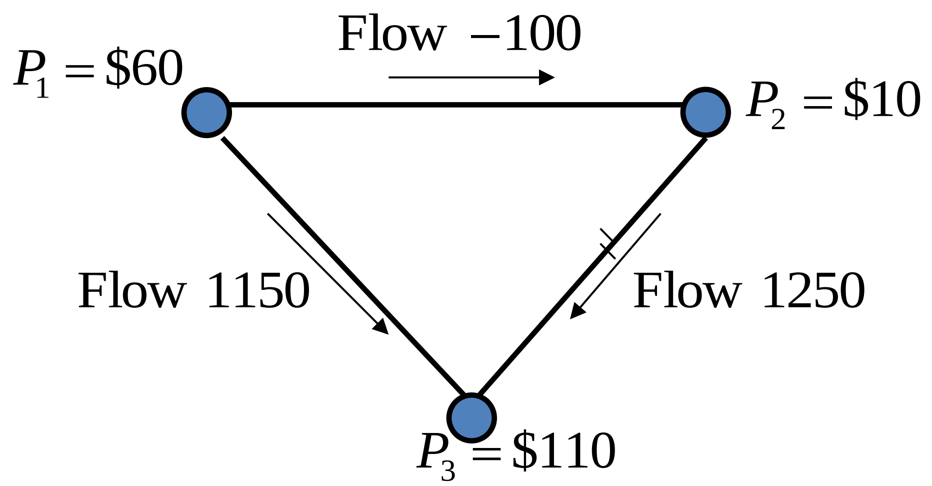
- Let's now repeat the exercise for a meshed network:
- In this network, the following allocation of FTRs is simultaneously feasible.
  - The net injections implied by these allocations are consistent with all of the limits on this network.



FTR	Alloc
1-2	-250
2-3	1000
1-3	1500

Nodal pricing / FTRs

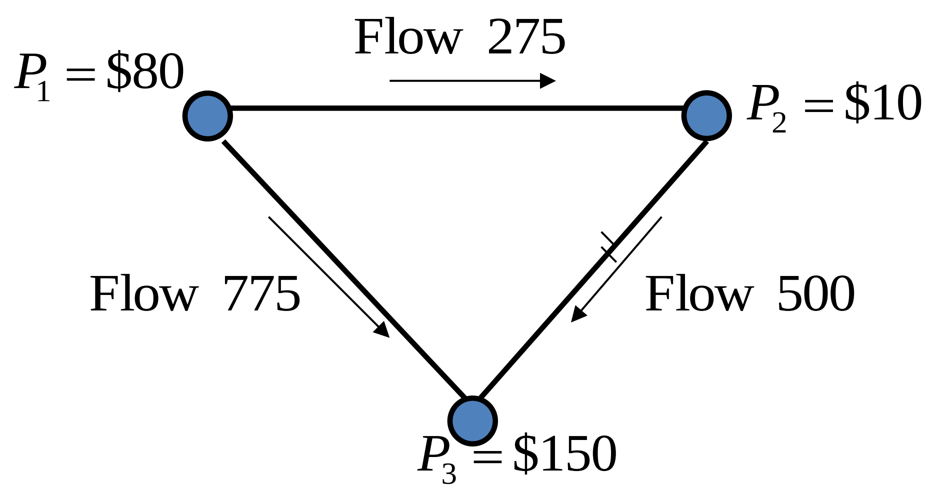
- Now suppose the prices and limits are as shown.
- The total residues in this market are \$187,500 but the total FTR obligations are only \$150,000.
- So the FTRs are firm and the mechanism is revenue adequate as required.



FTR	Alloc	Payout
1-2	500	500x\$-50 = \$-25,000
2-3	1000	1000x\$100=\$100,000
1-3	1500	1500x\$50=\$75,000
Total		\$150,000

Nodal pricing / FTRs

- Now suppose that an outage reduces the limit on the 2->3 line down to 500.
  - Prices change as shown.
- The total residues in this market are now $105,000 but the total FTR obligations are $210,000.
- As before, the FTR allocation could be scaled back proportionately (by a factor of half).
  - As before, the FTRs are no longer fully firm.



FTR	Alloc	Scaled	Payout
1-2	500	250	250x$-70 = $-17,500
2-3	1000	500	500x$140=$70,000
1-3	1500	750	750x70=$52,500
Total			$105,000

References

1. D. Biggar, The Economics of Electricity Markets, Course Slides, Australian Energy Regulator and Australian Competition and Consumer Commission

2. D. Biggar, M. Hesamzadeh, The Economics of Electricity Markets, Book in Press, IEEE and John Wiley Publisher