

Paradoxical Effects of Expansions in an Electricity Market with Fuel Network

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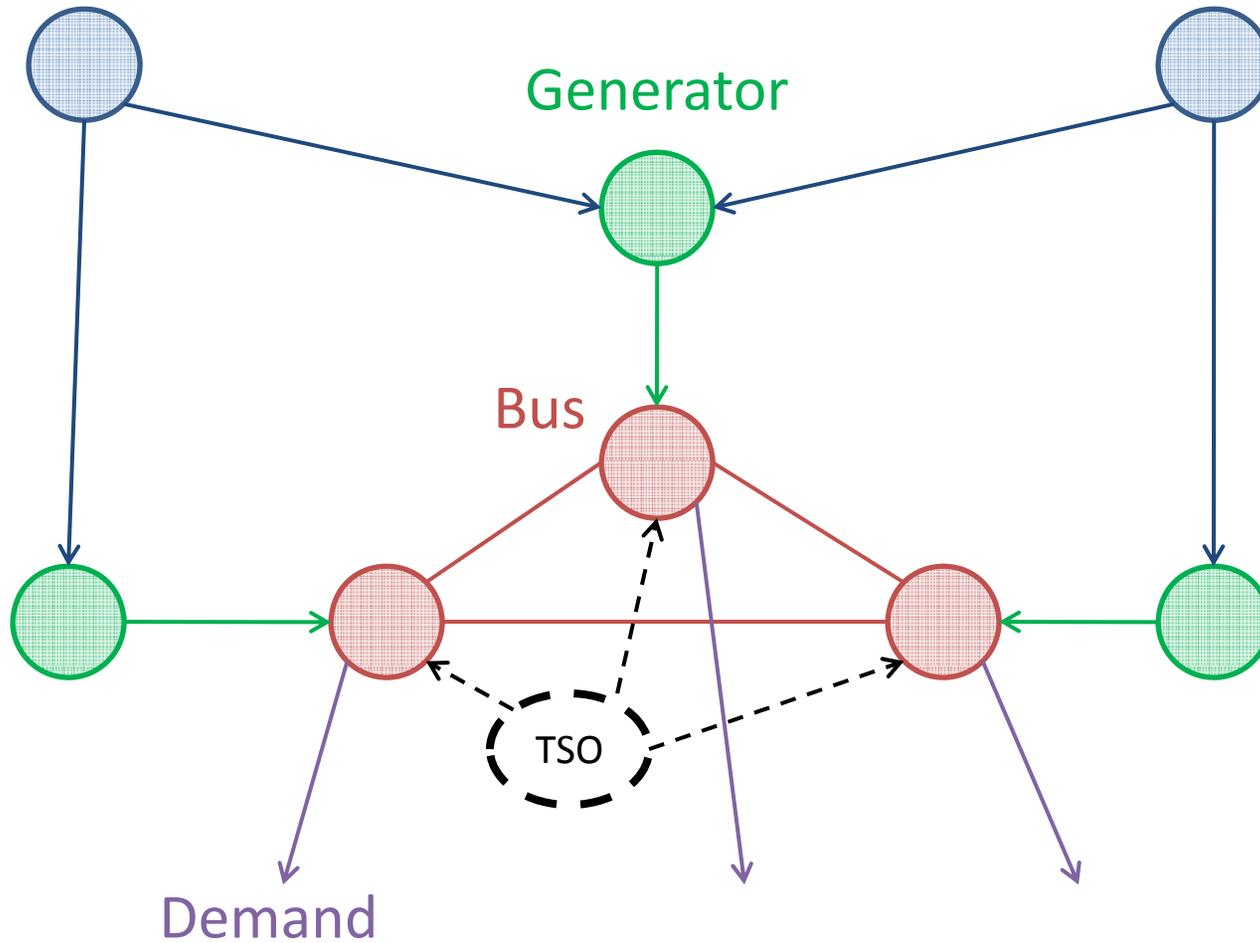
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Outline

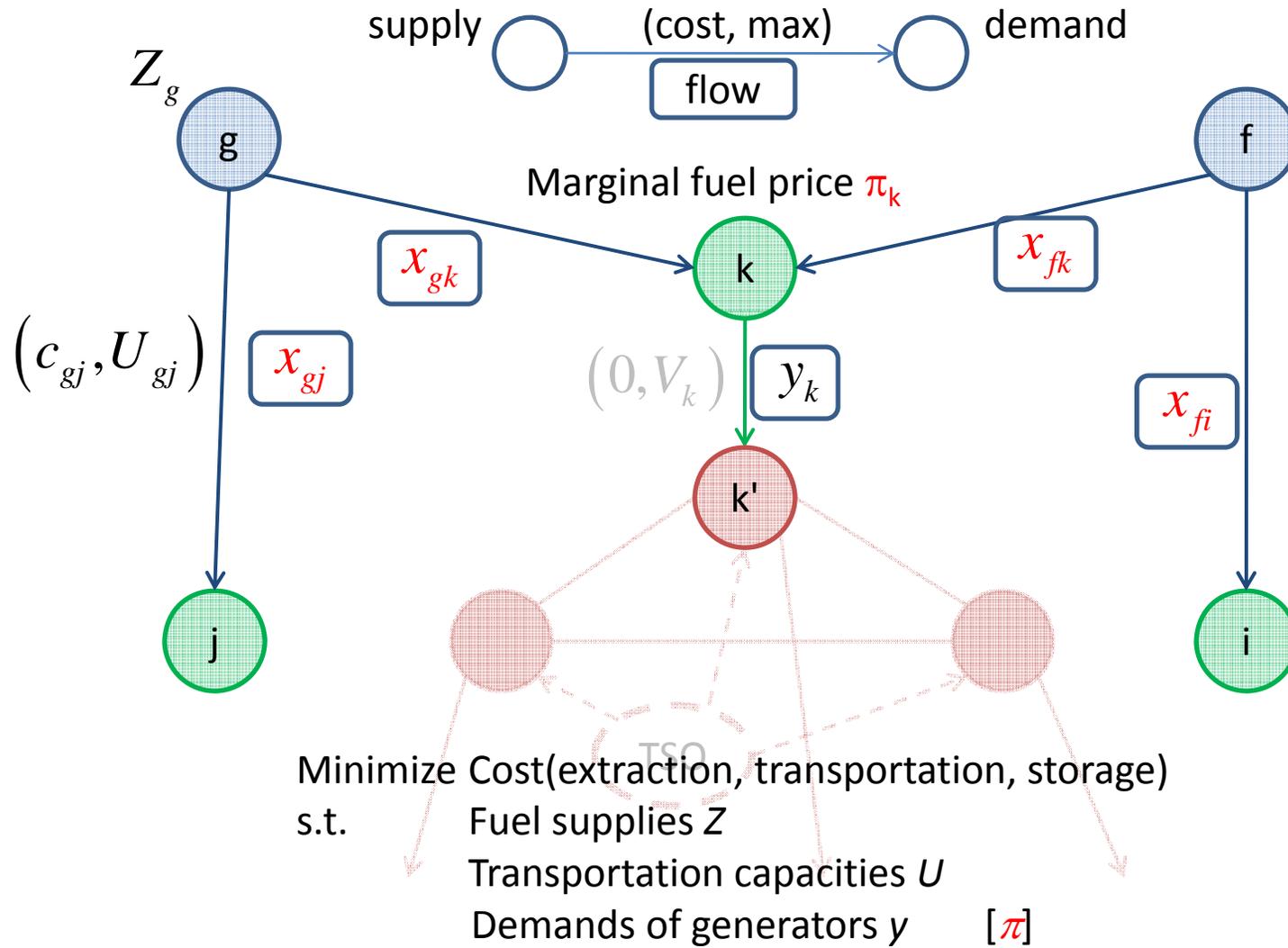
- Integrated market equilibrium model of
 - Fuel supply and transportation
 - Electricity production by strategic generators
 - System operation to meet price sensitive demand
- Paradoxical examples of reduced welfare from increases in
 - Fuel transportation (or generation) capacity
 - Electricity transmission capacity
- Implications for expansion planning models

Integrated model of fuel transportation, generation & transmission

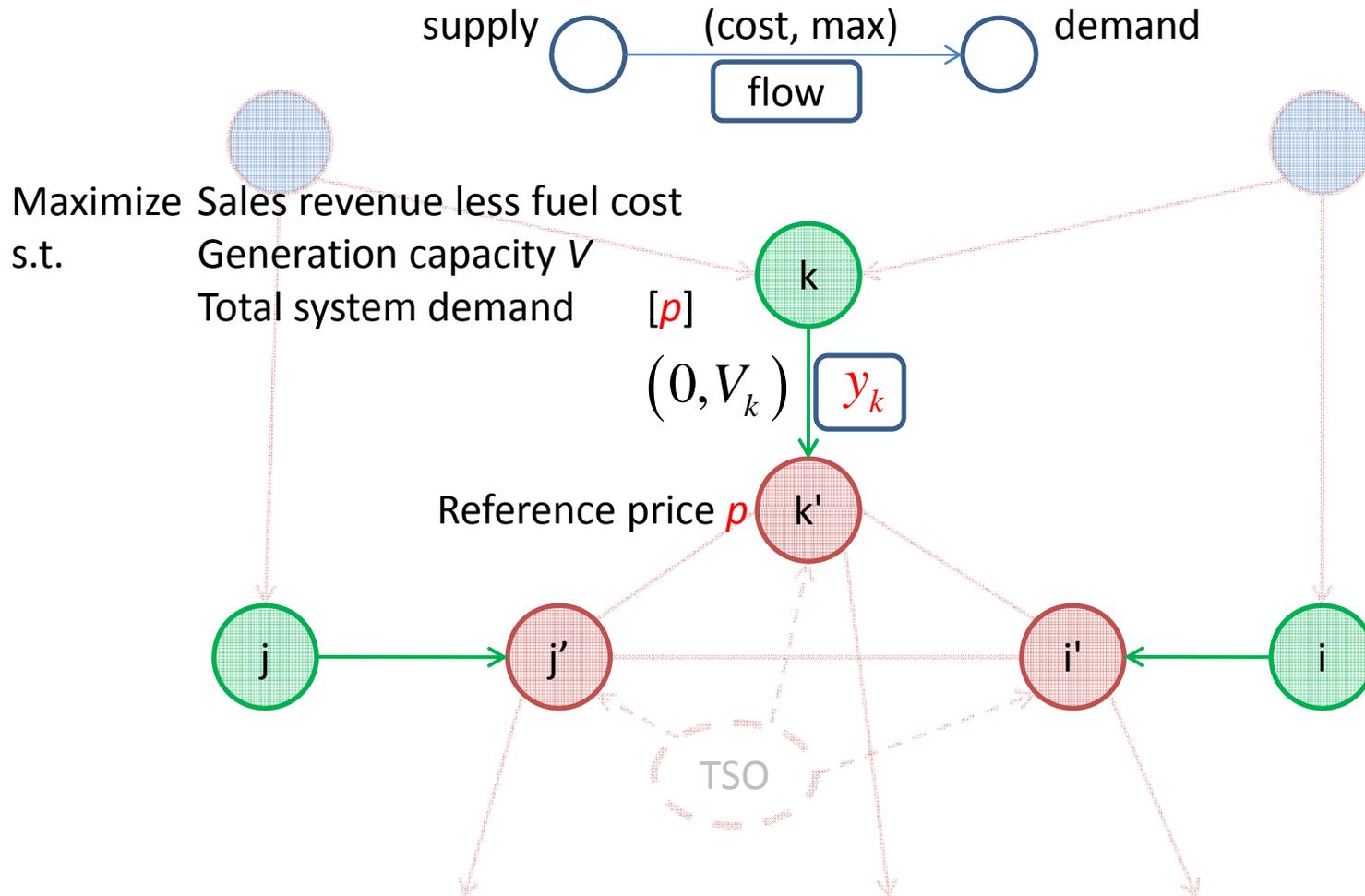
Fuel Source



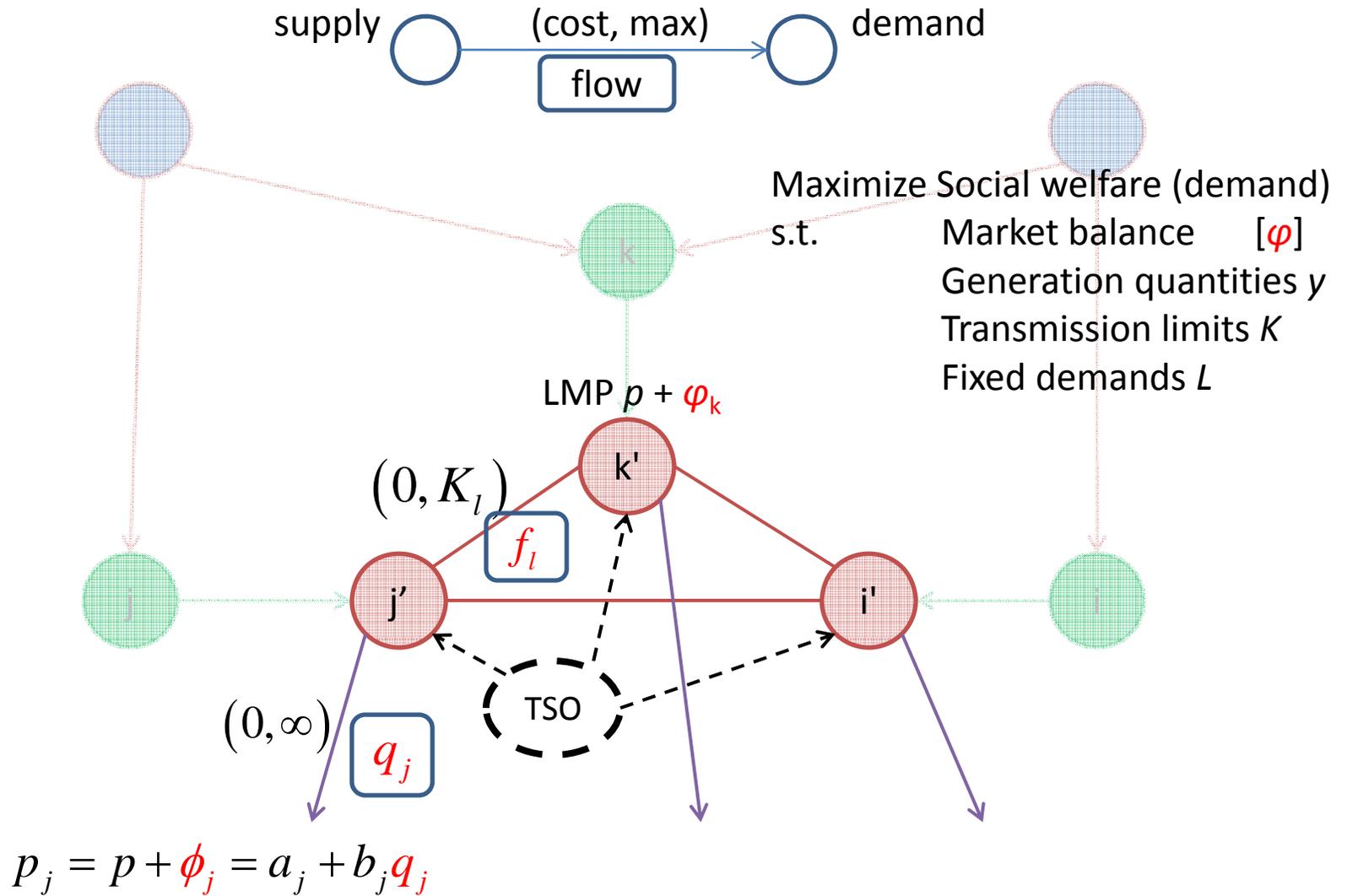
Fuel delivery



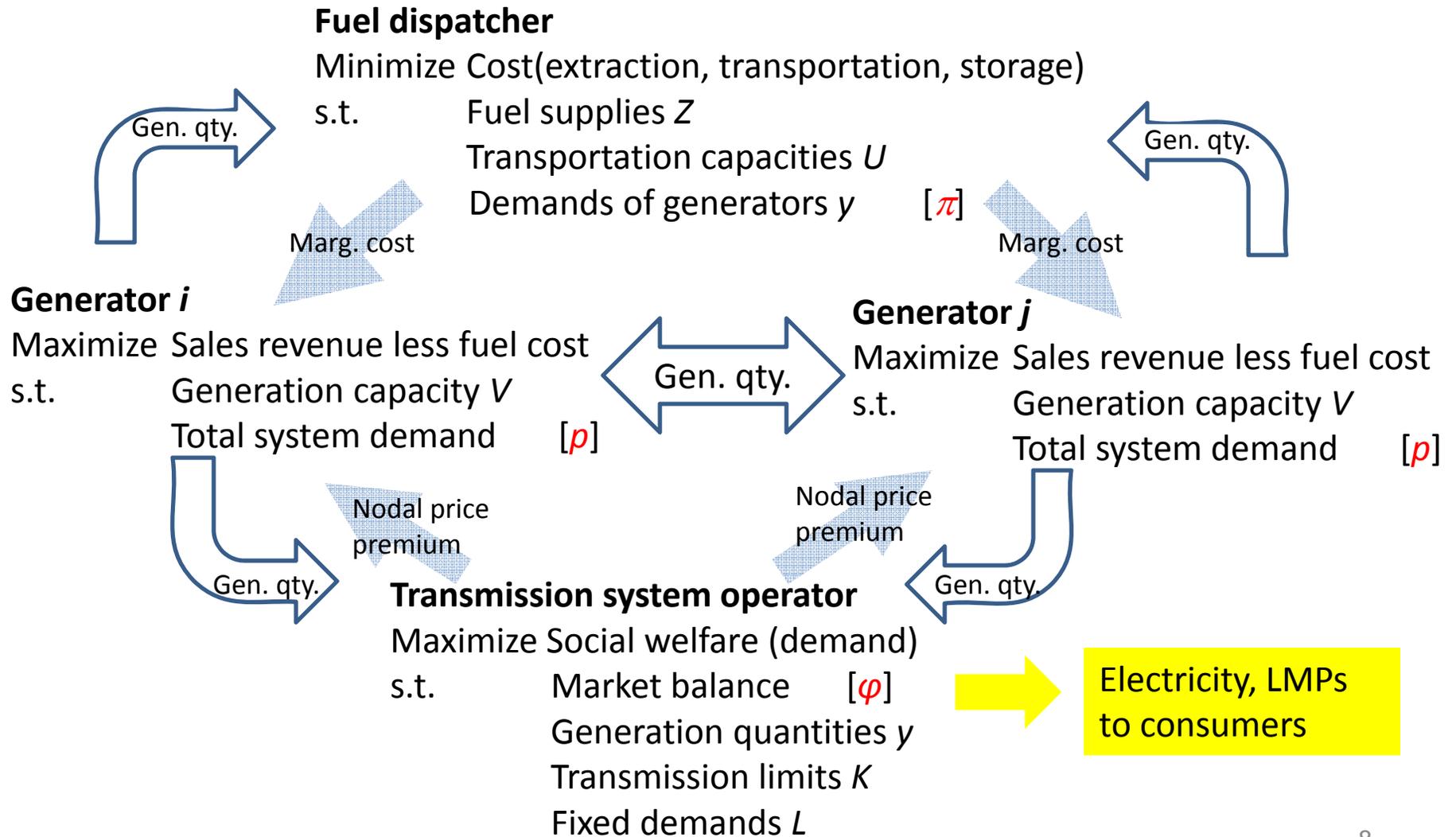
Electricity generation – Cournot competition



Transmission & distribution



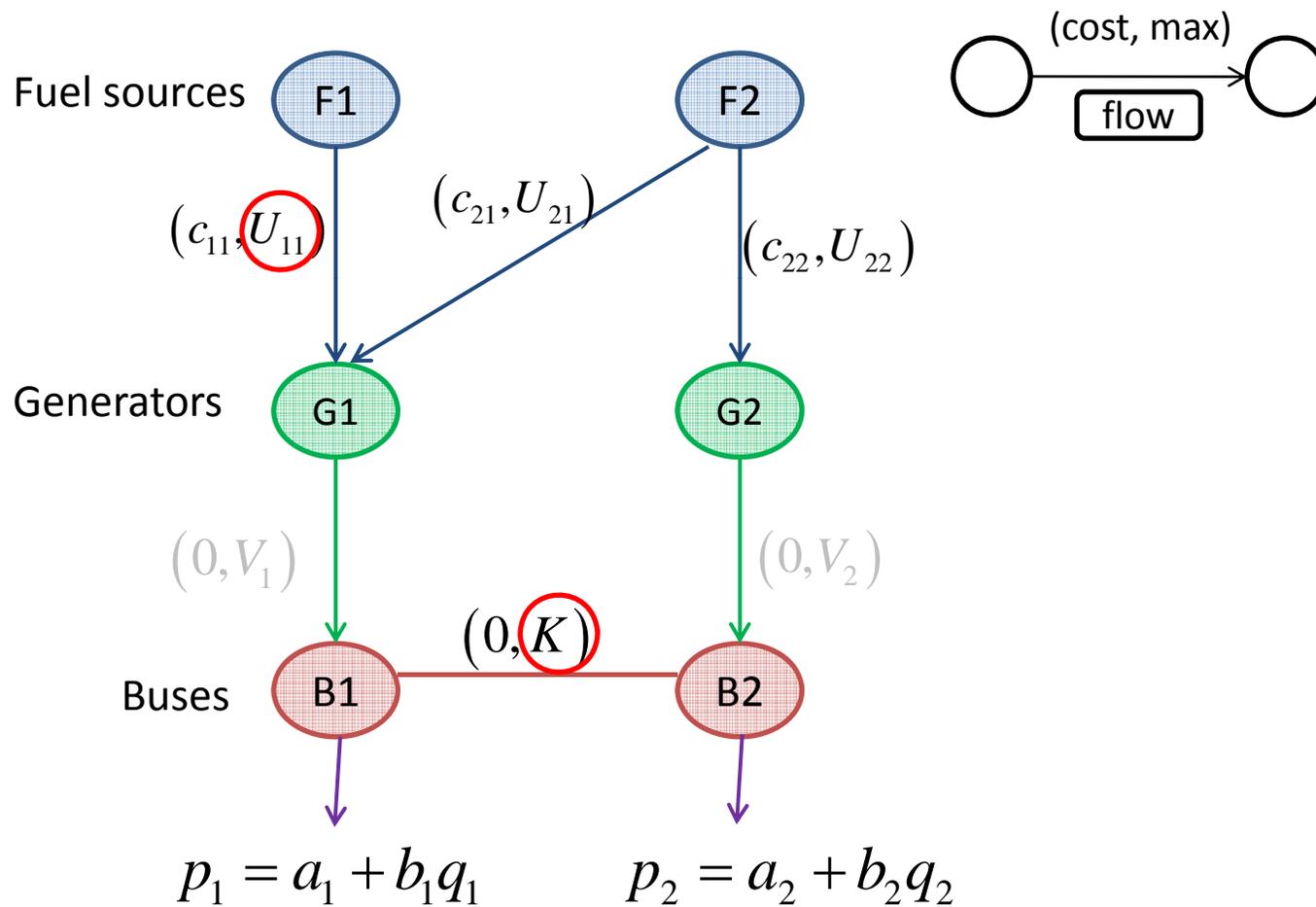
Integrated equilibrium model



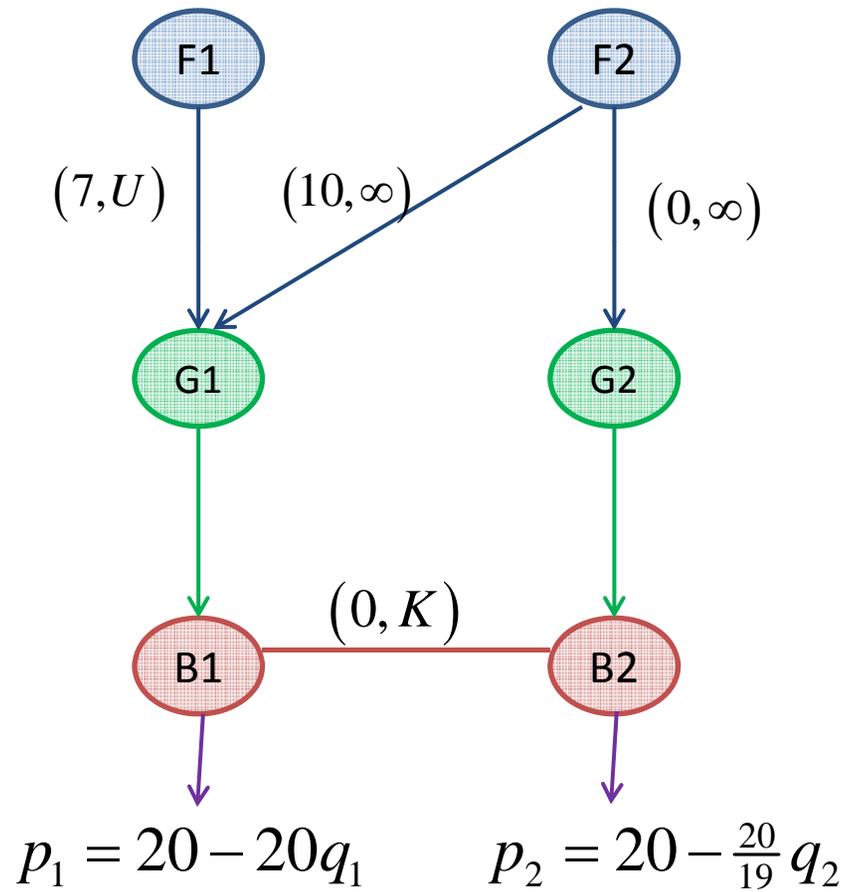
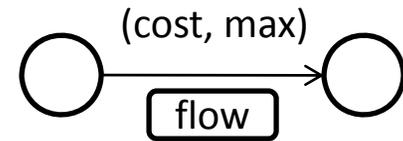
Model properties

- An equilibrium exists – unique in all the examples to follow (Ryan et al. 2010)
- Equilibrium can be computed efficiently by off-the-shelf software
- Integration of fuel supply, generation, and transmission allows view of how constraints interact to affect LMPs and welfare
- Outcomes have been validated against computational agent simulation of wholesale power market platform design (generators submit supply function bids) (Ryan 2009)
- Can incorporate partly fixed demands (Ryan 2010)

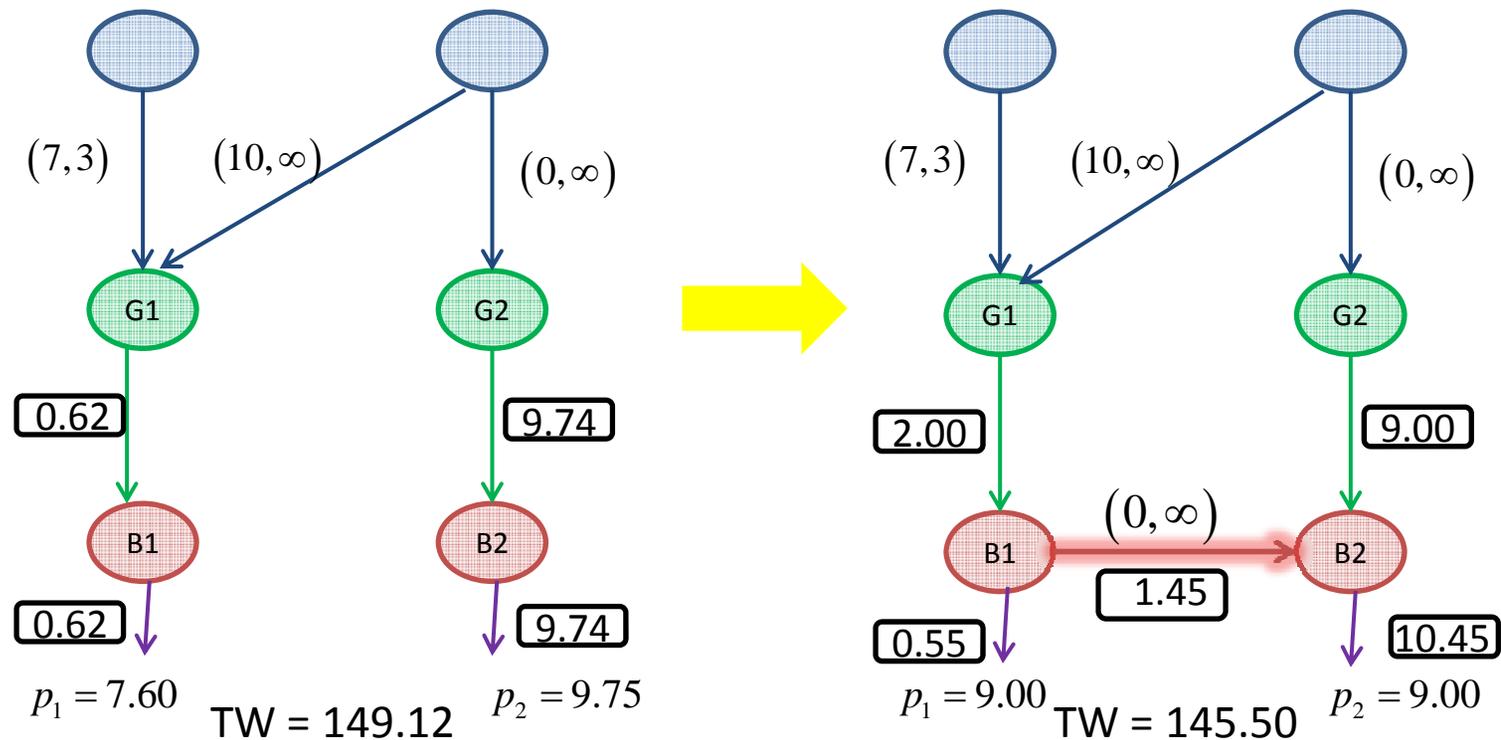
Simple examples – before and after expansion



Example 1

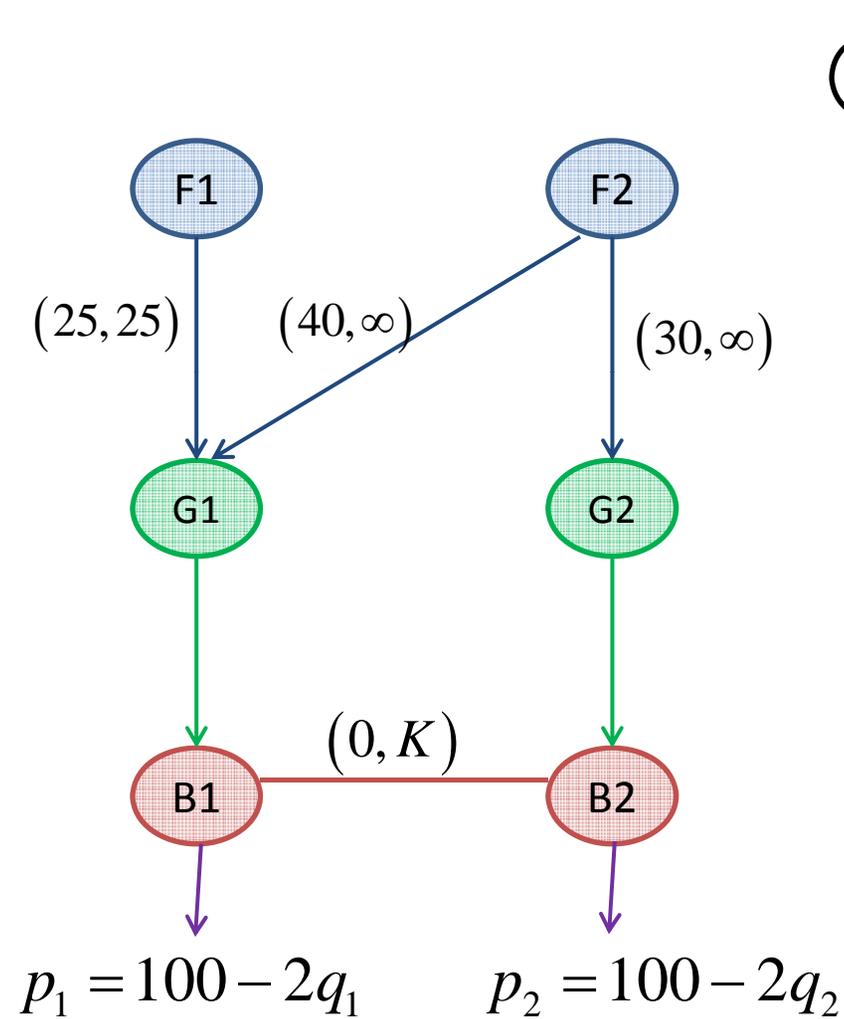


Example 1 – transmission capacity

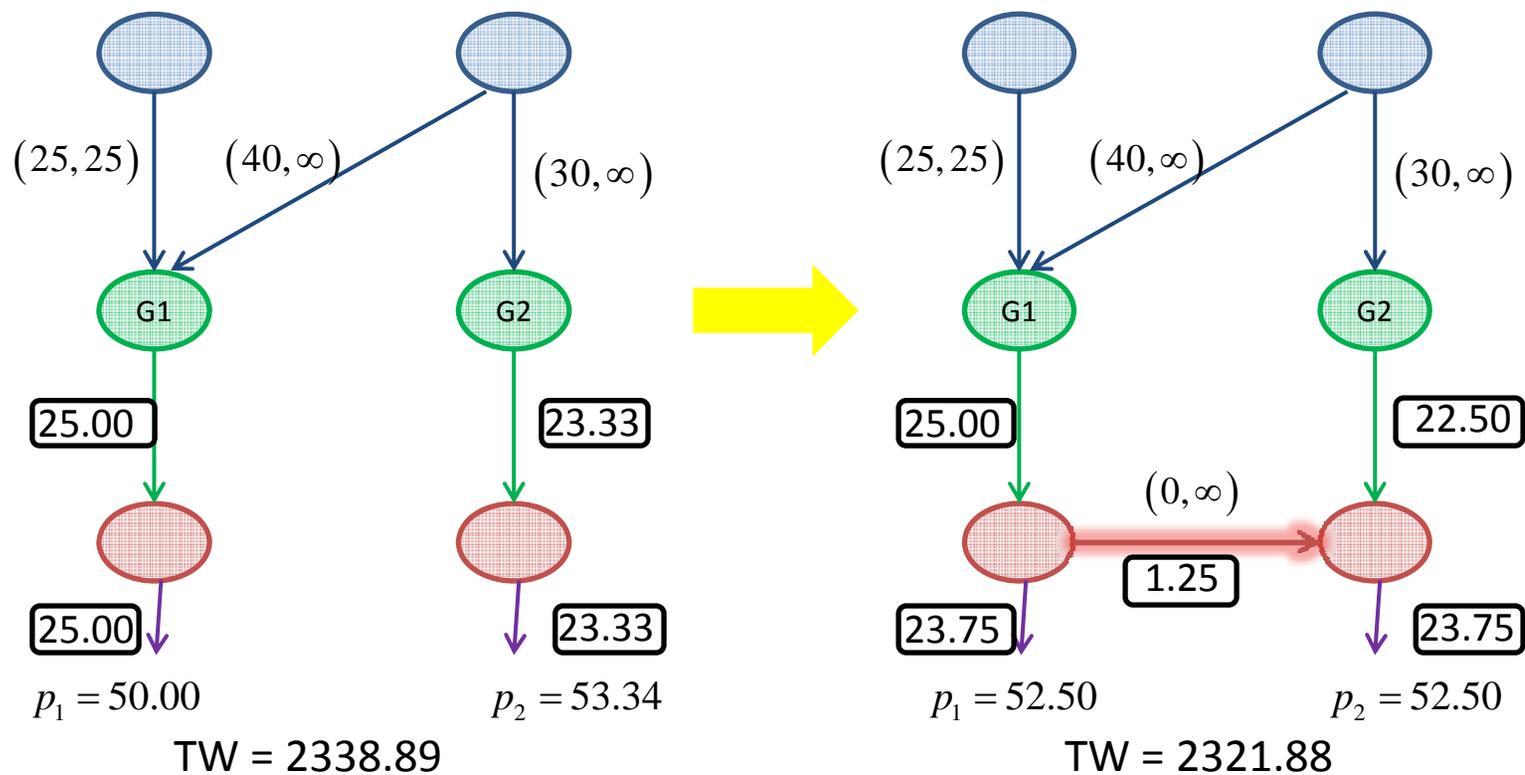


Asymmetric demand: Ability to transmit increases production by higher-cost generator 1. Increase in consumer surplus outweighed by loss of producer profit.

Example 2: symmetric demand

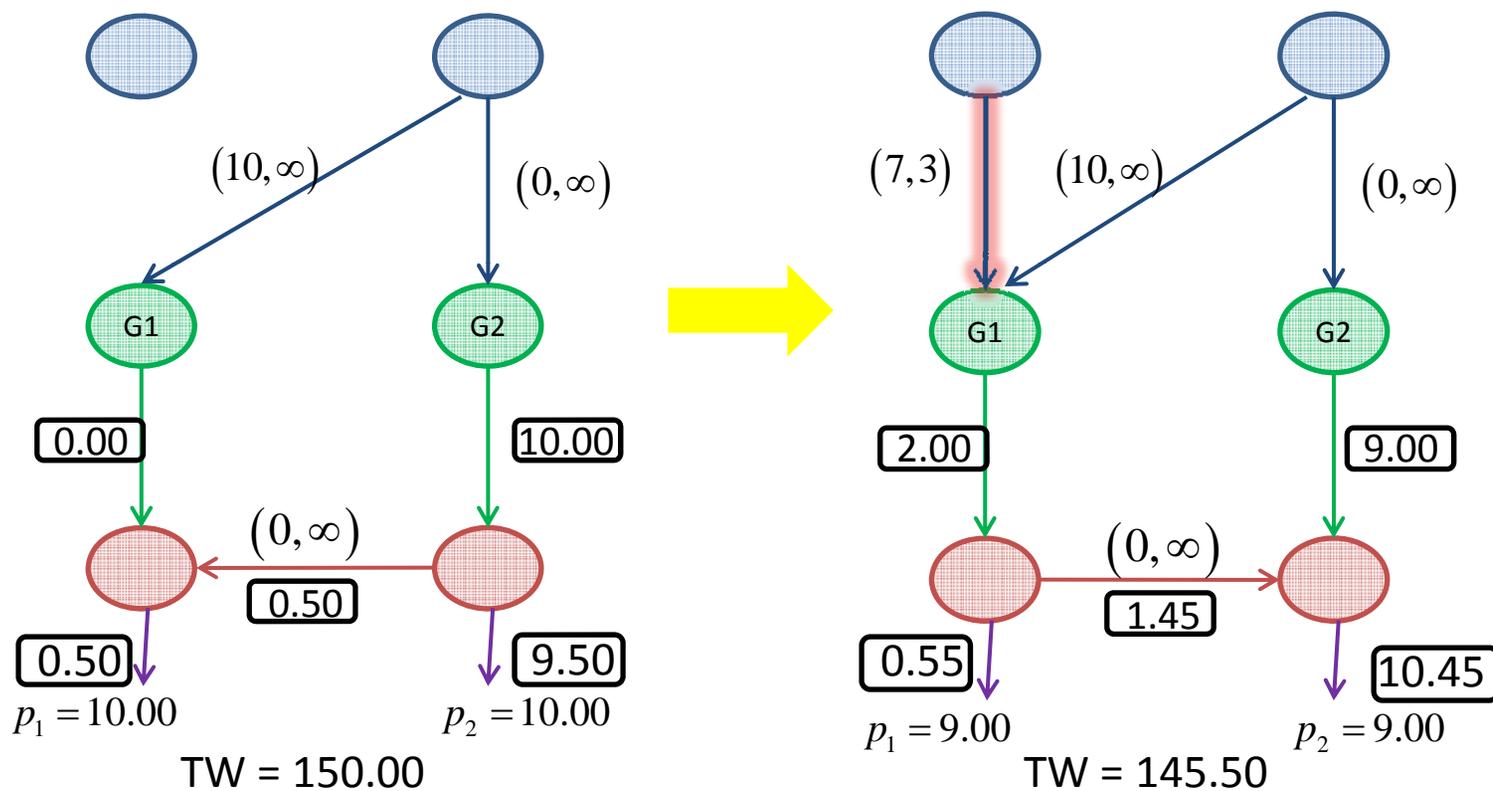


Example 2 – transmission capacity



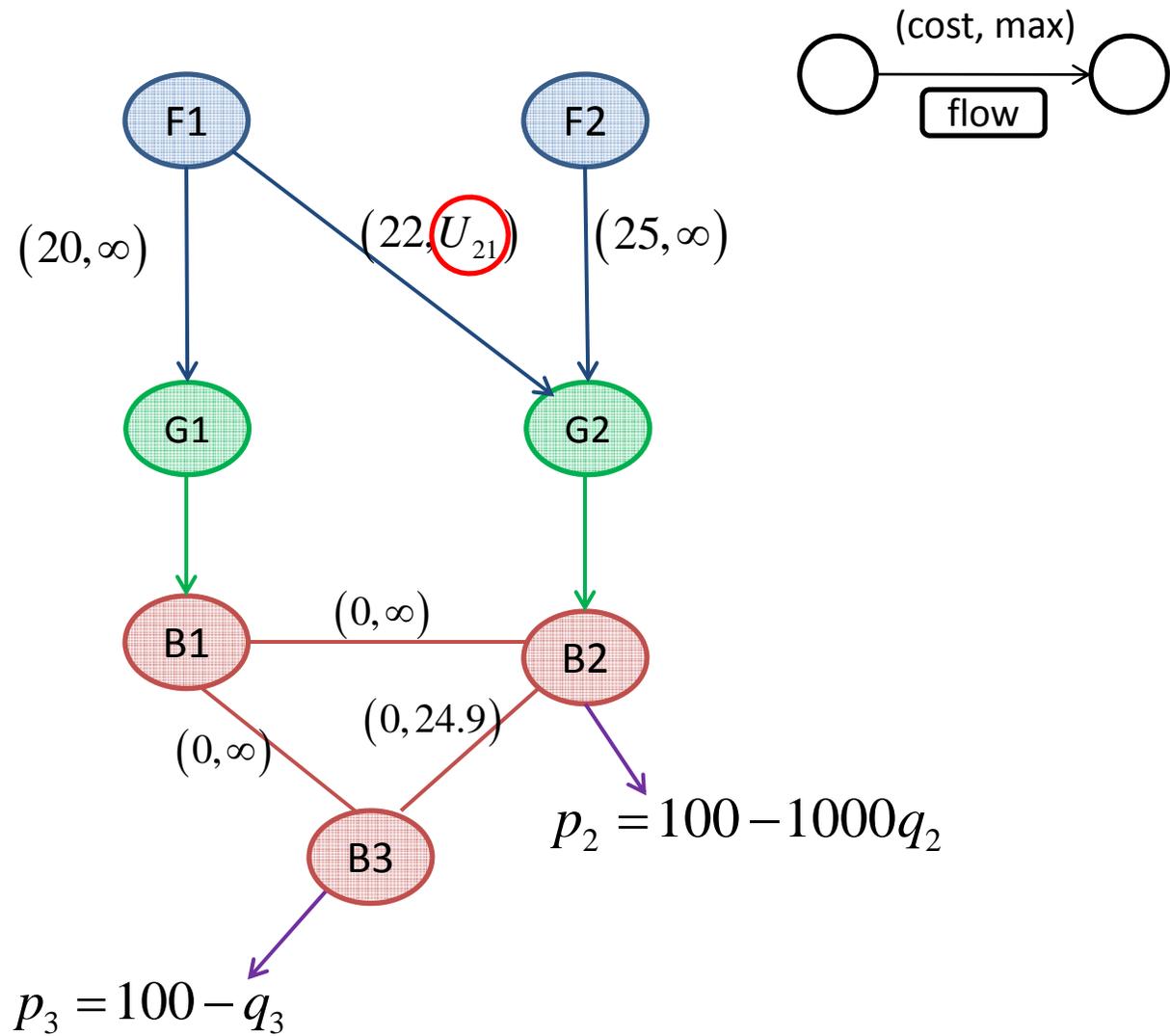
Cost structure: With ability to transmit, incentive for G1 to increase production does not outweigh the jump in its marginal cost

Example 1 – fuel/generation capacity

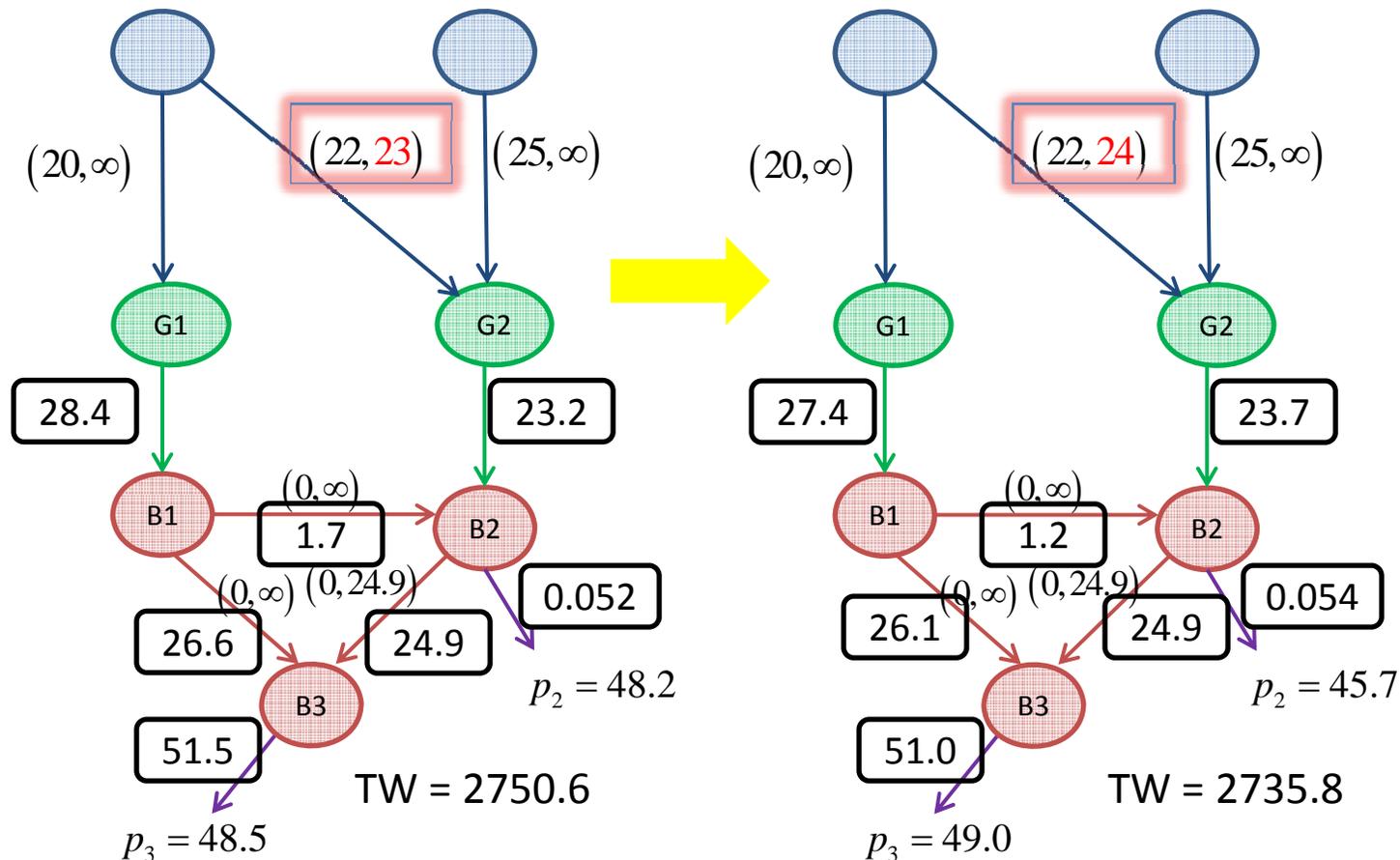


Asymmetric demand: Lower costs for G1 shift some production away from lowest-cost G2. Gain in consumer surplus is outweighed by loss of producer profit.

Example 4



Example 4 – fuel/generation capacity



Loop effects: Higher capacity of lower cost generation at node 2 shifts some production there; transmission congestion causes overall production to decrease.

Contributors to paradoxical effects

- Uneven demand sensitivity to price
- Generator strategic behavior
- Discontinuous marginal cost induced by the fuel supply network or generator switching
- Transmission constraints and loop effects
- See also the Braess paradox in transportation networks:
“If every driver takes the path that looks most favorable to him ... an extension of the road network may cause a redistribution of the traffic that results in longer individual running times.” (Braess 1968)

Implications for expansion planning

Numerical optimization is like mountain-climbing in a fog



Possible mitigation of paradoxical effects

- Paradoxical instances appear to be rare (Sauma and Oren 2006)
- Expansions occur in large increments that may “bridge the crevasses”
- Multiple simultaneous expansions may avoid them
- Different models of generator rationality and strategy exhibit different effects

References

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- Sauma, E. E. and S. S. Oren. Proactive planning and valuation of transmission investments in restructured electricity markets. *Journal of Regulatory Economics* 30: 261-290, 2006.

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