A Natural Gas LP Formulation to Enhance Allocation with Market Pricing Mechanisms

S.R. Starkey, E.G. Read and S. Dye
University of Canterbury
New Zealand.
E-mail: stephen.starkey@pg.canterbury.ac.nz
B.J. Ring
Market Reform,
Australia.
W. Pepper
ICF International,
USA.

Abstract

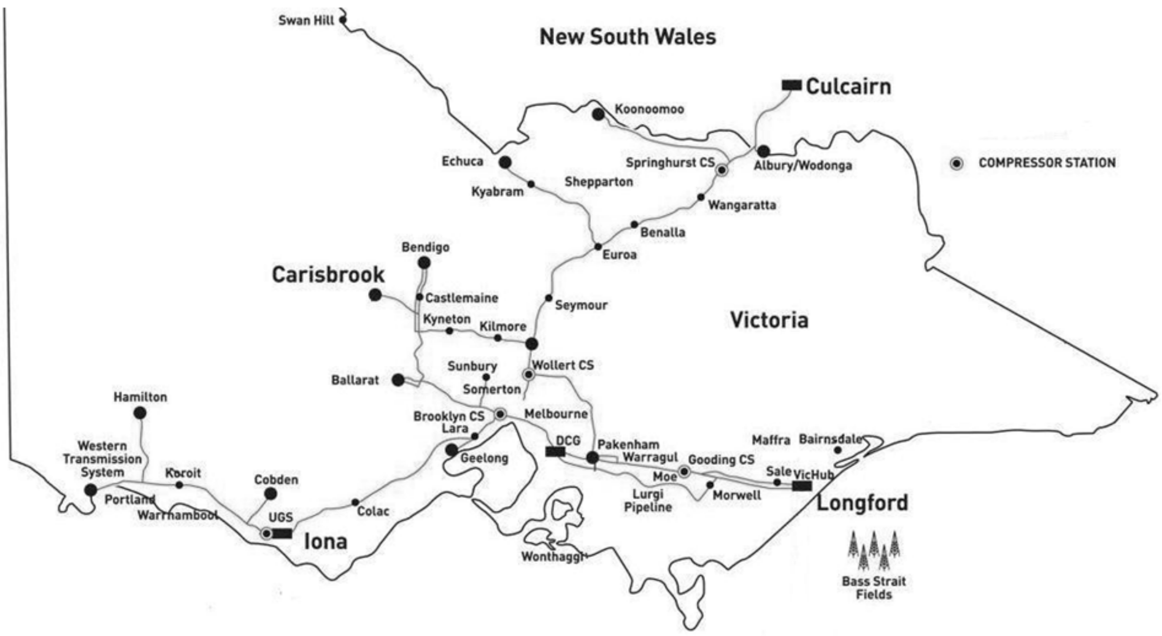
Many electricity markets are now cleared using a Linear Programming (LP) formulation that simultaneously determines an optimal dispatch, and corresponding nodal prices, for each market dispatch interval. Although natural gas markets have traditionally operated in a very different fashion, the same basic concept can be applied. Since 1999, the Australian state of Victoria has operated a gas market designed to operate in this fashion, based on an LP approximation to the underlying inter-temporal non-linear gas flow optimization problem. The simplified formulation presented here covers the key physical relationships defining the flow of gas though the system, along with definition of practical offer and bid forms. The dual variables on key constraints imply prices which vary by location, as for electricity markets, but also by time. But the gas flow equations mean that gas is both delayed and stored within the transportation system itself. This raises a number of operational, pricing, and hedging issues which could be ignored in the case of electricity, but become important when operating this kind of market in a gas supply network. Some of those issues will also be important for the design of markets for other commodities, such as water, where there are delays and storage within the "transportation system", over which the market operates.

Presentation

Outline

1. Victorian Natural Gas System
2. Electricity v Natural Gas
3. Modelling the Market
4. Modelling the Natural Gas Transportation System
5. Prices and their Interpretation
6. Conclusions

1. Victorian Natural Gas System



2. Electricity v Natural Gas

Both transfer bulk quantities over large distances via interconnected networks,

Each unit of the respective commodity seeks path of least resistance through the network,

Electricity transfers energy instantaneously through "on/off" network of lines,

Natural Gas transfers mass through pipes, with:

- Delays and storage in transit
- Greater control, via valves and compressors

3.1 Market Concept

Market Operator clears the market:

- Determining price for each node and period
- Issuing dispatch orders for all participants

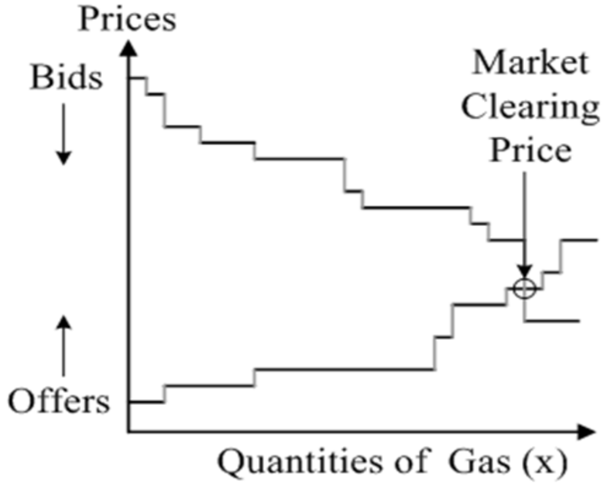
In OR terms, find the optimum solution, while balancing gas over all nodes and time periods, within constraints

Need to model:

- Market clearing at each node and period
- Gas flow dynamics between nodes and periods

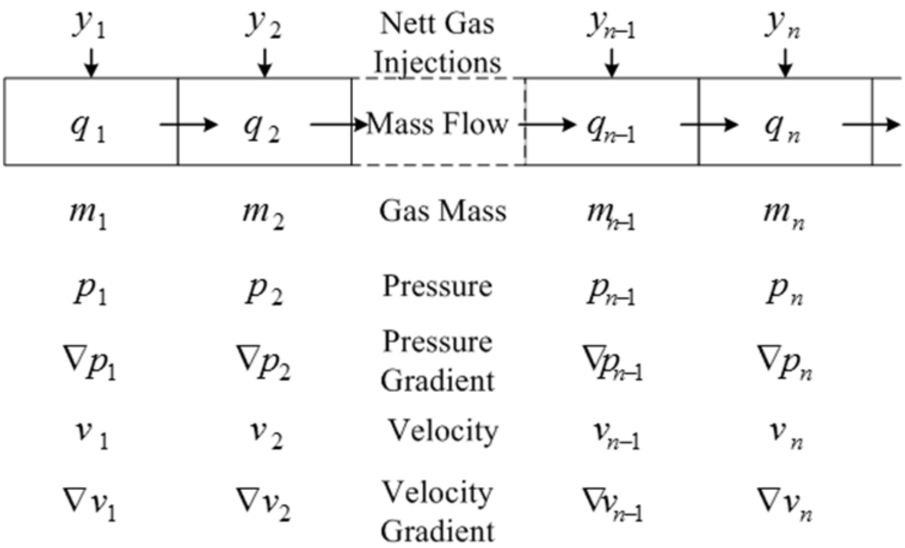
3.2 Market Clearing

$$\sum_{t}\sum_{n}\left(\sum_{d\in Dn}\sum_{i} Bid_{di}^{t}x_{di}^{t}-\sum_{s\in Sn}\sum_{i} Offer_{si}^{t}x_{si}^{t}\right)$$



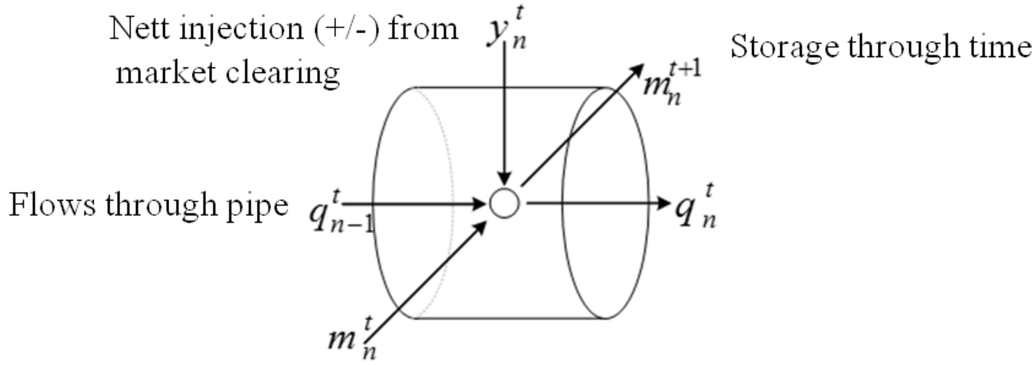
Plus constraints to bound and sum bid/offer tranches

4.1 Gas Flow Variables



All variables assumed to be at middle of cells

4.2 Mass Balance



$$m_n^{t+1} = m_n^t + y_n^t + q_{n-1}^t - q_n^t$$

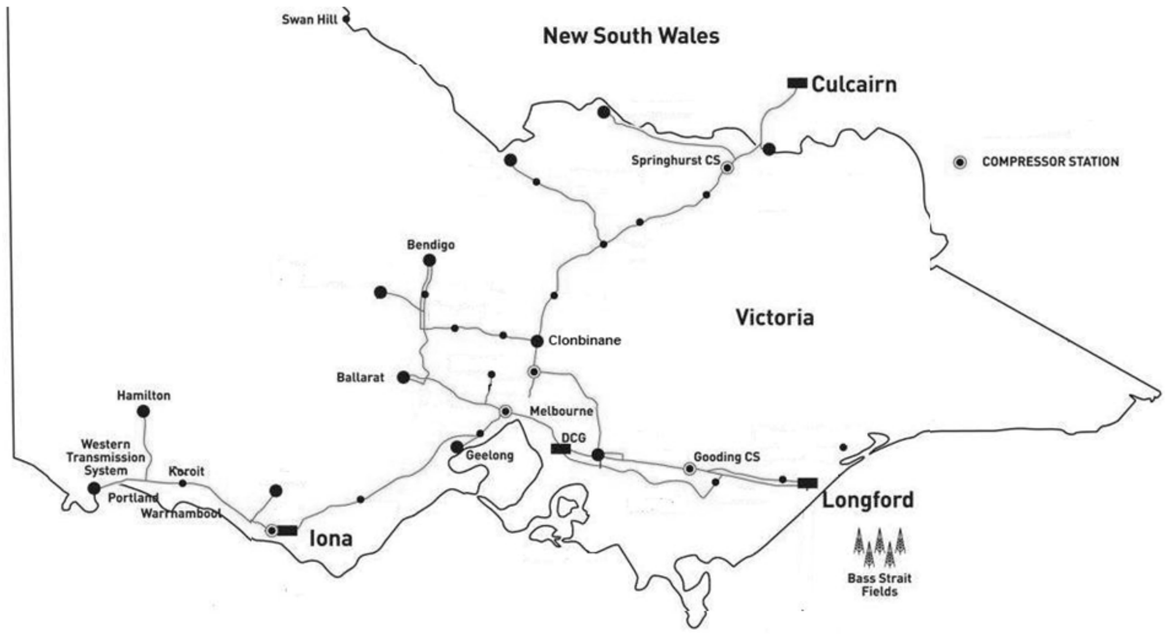
As for electricity networks:

- Except gas flows through time and space

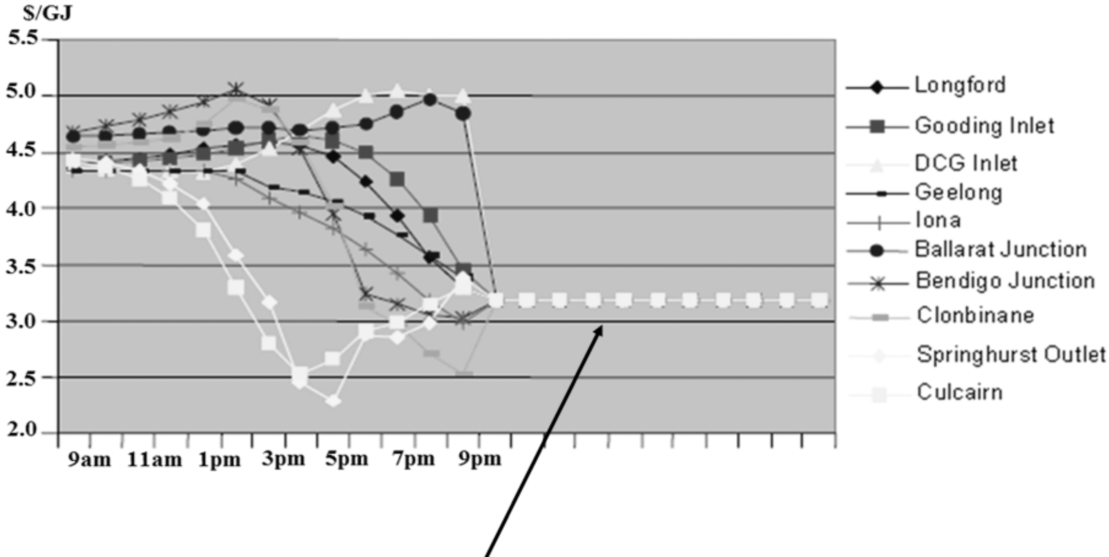
As for water networks:

- Except gas is compressible so storage and flow are both driven by pressurisation

5.1 Victorian System

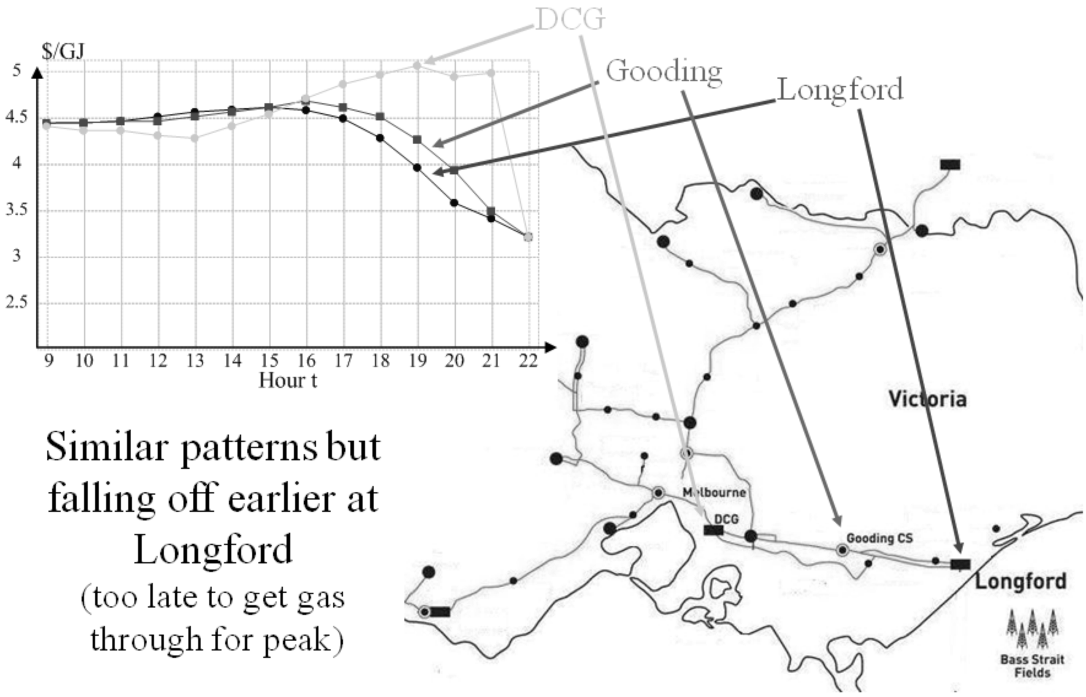


5.2 Price Scenario: General Relationships



Prices all equal because end-of-day gas assumed to be the same price everywhere, due to system "re-set"

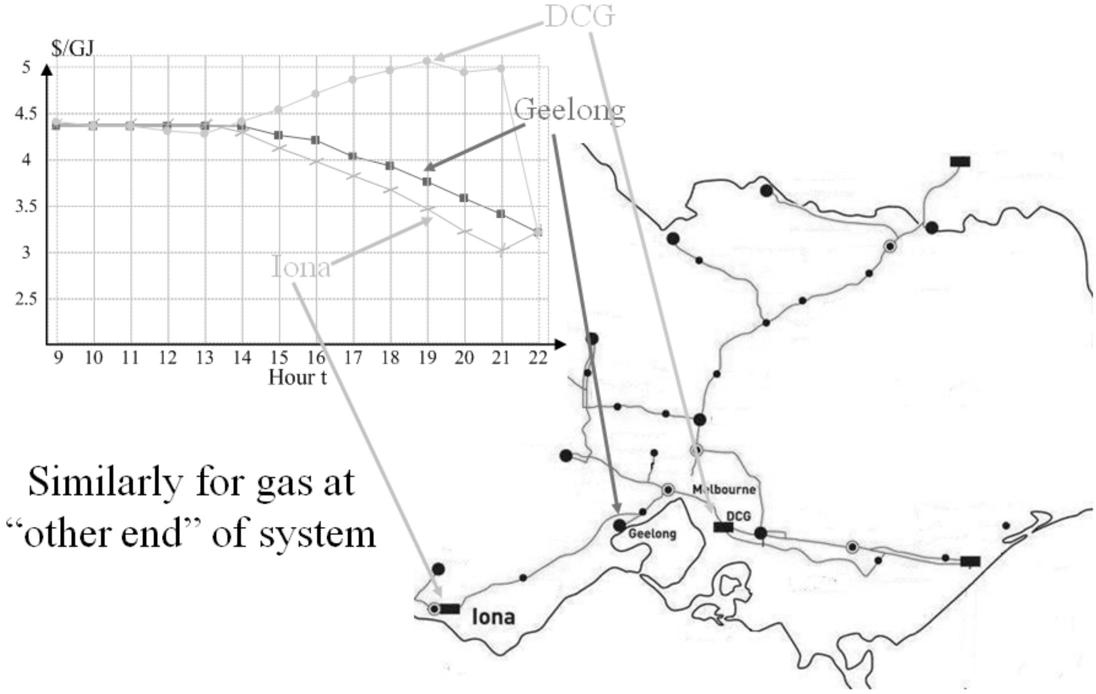
5.3 South-East Price Relationships



Similar patterns but falling off earlier at Longford

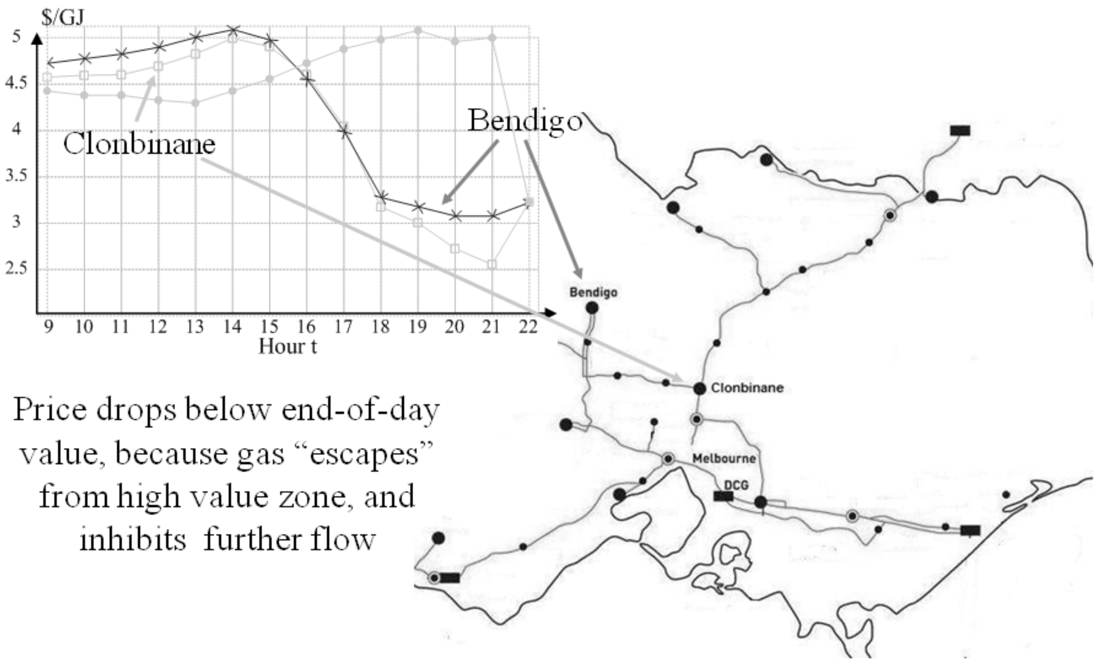
(too late to get gas through for peak)

5.4 South-West Price Relationships



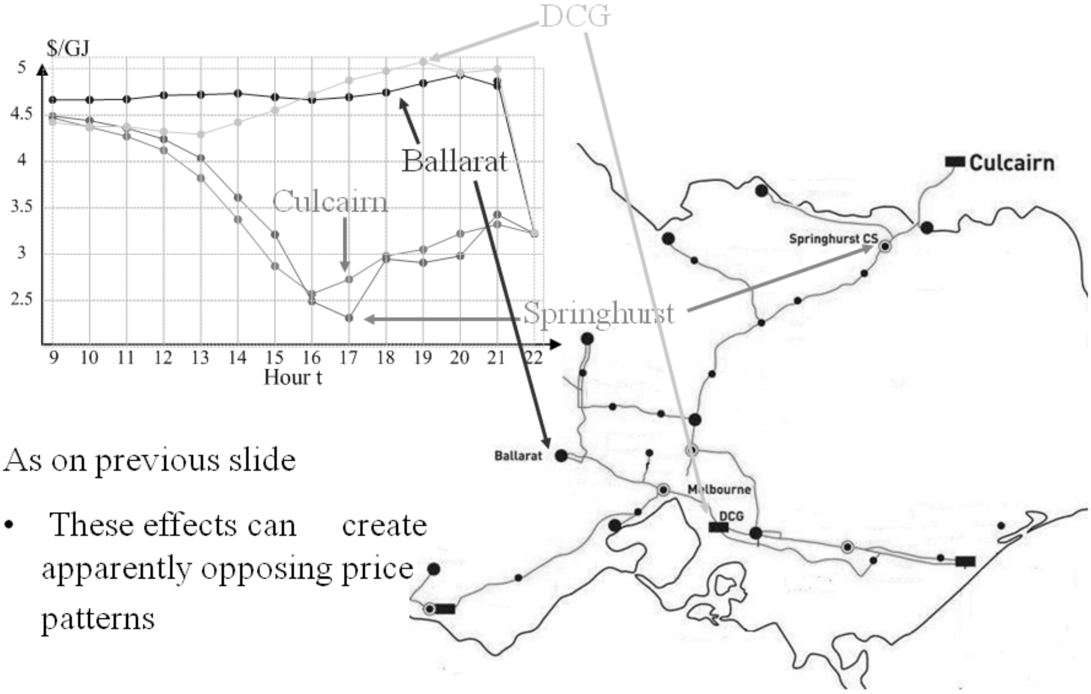
Similarly for gas at "other end" of system

5.5 North-Central Price Relationships



Price drops below end-of-day value, because gas "escapes" from high value zone, and inhibits further flow

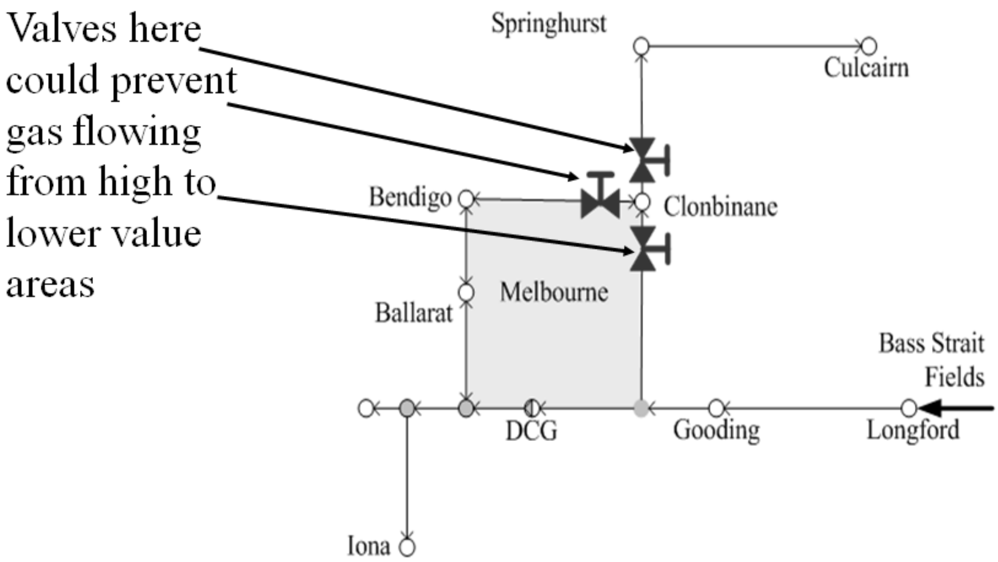
5.6 Central v North-East Price Profiles



As on previous slide

- These effects can create apparently opposing price patterns

5.7 Example Price Information Use



Price information can allude to enhancing system control to better manage flows as the gas transmission network evolves

6. Conclusions

For the gas market in Victoria:

- Congestion can generate significant price signals
- But it is rare enough that actual market is highly simplified to 1 node and 6 (re-)pricing periods
- Detailed model is used for operational dispatch though

For gas markets elsewhere:

- The LP formulation works, and can be applied
- Significant benefits likely where congestion occurs

For similar markets with system delay and storage:

- Transferable knowledge to other systems such as water