Australian Government
Productivity Commission

Integrating Partial Equilibrium and CGE modelling frameworks

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Background and context

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- The objective is to improve the policy insights from modelling certain policy issues
  - Case study: Renewable Energy Target
  - Electricity sector detail is important
  - General equilibrium aspects are important
  - Policy, theory and interactions are important
- Achieved by combining partial equilibrium and CGE into a single model

Background and context

- Model is hypothetical and illustrative
  - Principles for integrating and solving the model
  - Insights from the approach
- Insufficient detail to evaluate the RET properly
  - Only one renewable technology (wind)
  - No uncertainty in the supply availability of wind
  - Economy roughly the size of Victoria
  - Only 5 load blocks and 2 transmission links

Background and context

- A prerequisite for developing such policy oriented models is the capacity to apply
  - inequality constraints in mathematical programming models
  - the associated Karush-Kuhn-Tucker conditions (complementary slackness conditions)
  - endogenous prices and quantities as variables

A bit of history

1952 Samuelson
- Linear D & S functions
- Linear programming

1964-1971 Takayama & Judge
- Quadratic programming
- Quantity formulation (primal)
- Price formulation (dual)
- *Net social revenue formulation (primal – dual) with price and quantity variables*

1989-1992 Takayama & MacAulay
- *Generalised to non linear programming (NLP)*

2000s Mixed complementarity problem solvers
- Solve non-linear programming problem
- Solve problem with inequality constraints and no objective function (MCP)

1992 CGE solved in levels
- Using nonlinear programmimg
- Solvers (feasibility optimalisation)
- Dummy objective function

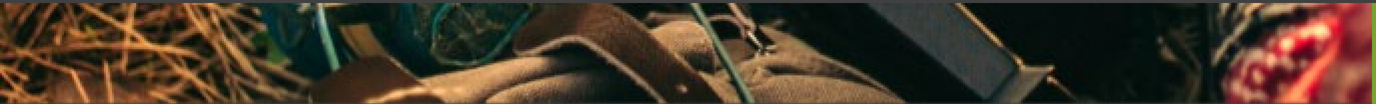
1960 Johanson
- CGE model
- Square system of linear equations in change form

Dixon et al (IAC)
- ORANI model
- CES, CET etc.
- Multi step solutions

Today
- Large applied
- Recursive dynamics
- Linear
- Equalities, cont.

Background and context

- Can the theory from spatial equilibrium models be incorporated into CGE models?
- Can such models be formulated as NLP problems with a single objective function?
- The answers are yes!




Combining models

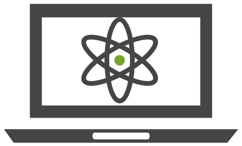
A spectrum of options for linking models

- No linking

- Humans iterate

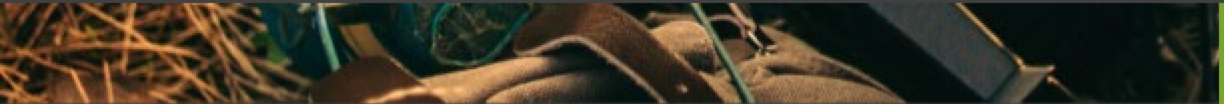
- Models iterate

- Single model



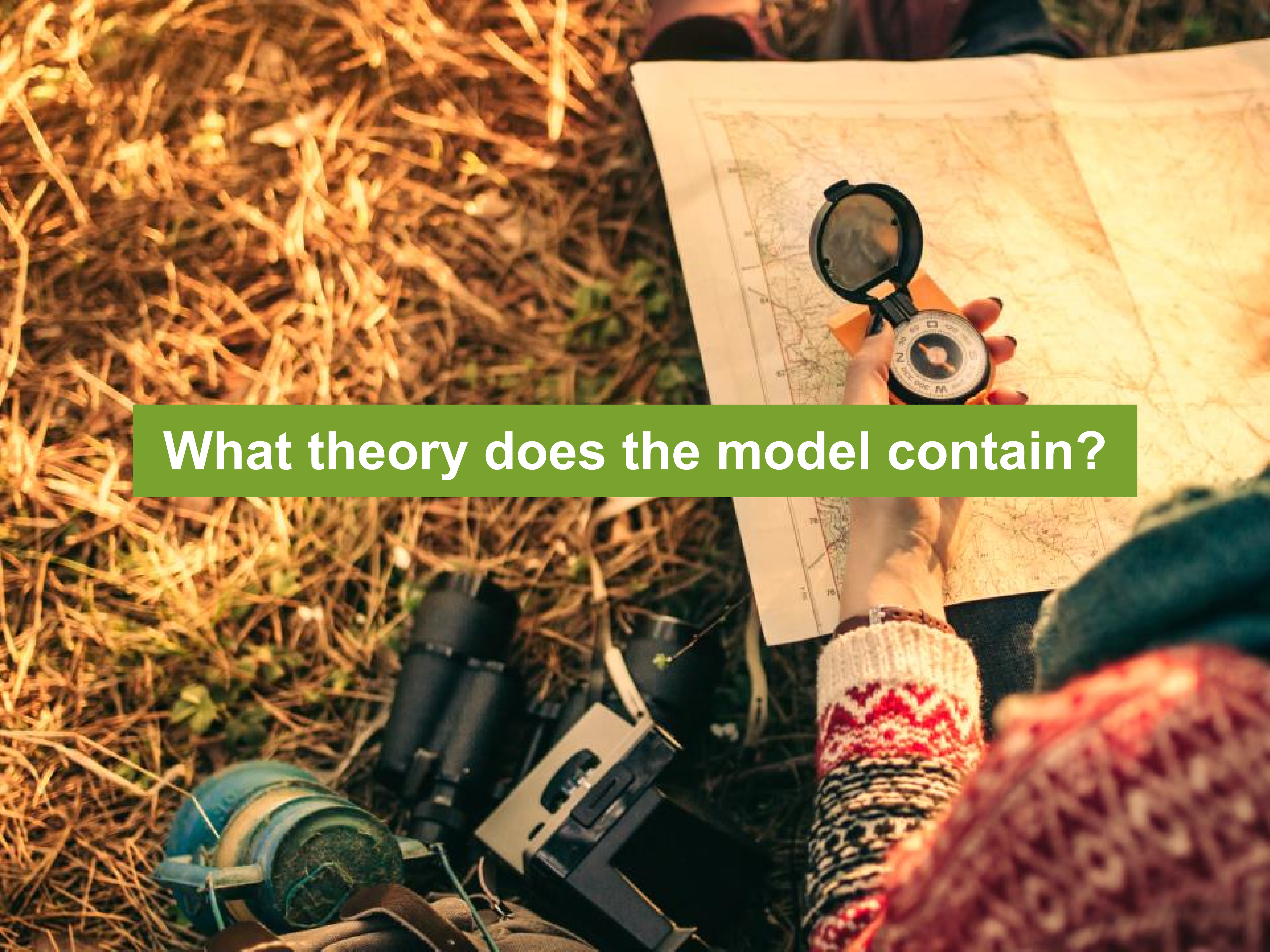
Combining the models as MCPs

- Models combined through their first order conditions for economic equilibria
  - Consistent theory and data
  - The energy components (industries and outputs) come from the PE theory
  - The energy components are re-linked to the CGE industries and final demands
- Naturally get a MCP formulation
- We prove that for this type of model, can also solve as an NLP



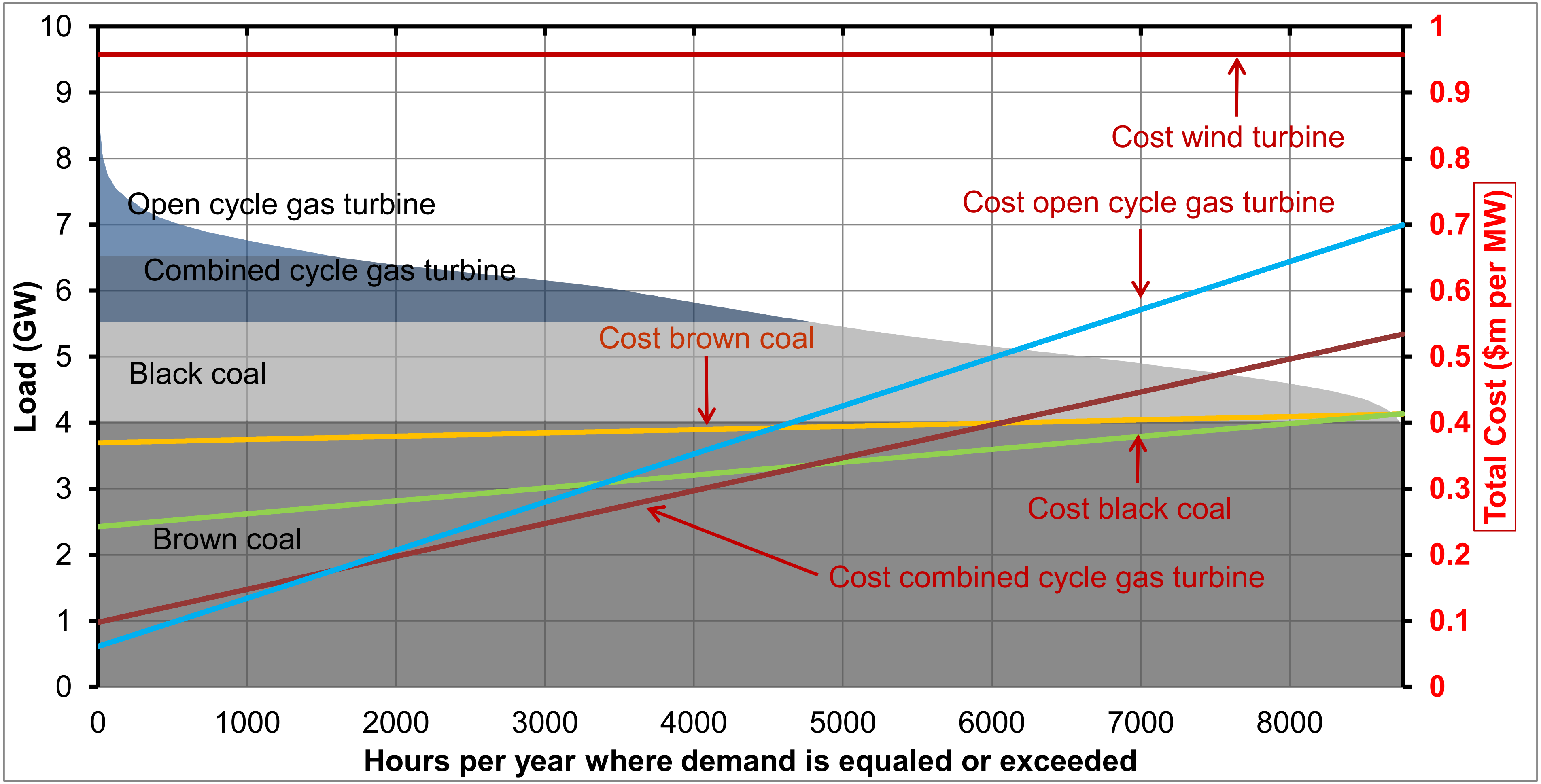
Converting the MCP to an NLP

- Takayama and Judge, net social revenue
  - At optimality, objective function zero
  - Complementary slackness conditions
    - Product always zero
  - sum of complementary slackness conditions
- Can derive NSR objective function for CGE (as MCP) and solve as NLP
  - Identical model, identical solution
  - Computational advantages and disadvantages



What theory does the model contain?

Power economics in the partial model



Transmission losses and line relationships

Node 2	← 150 km →	Node 1
Demand	←	Generation

θ_2=-0.349 — Phase angle at each node — $\theta_1 = 0$

$\theta_2 - \theta_1 = -0.349$ — Difference in phase angle at each node — $\theta_1 - \theta_2 = 0.349$

$\boldsymbol{QP_{21} = 2396.04(-0.349) + 119.802(-0.349)^2}$

$\boldsymbol{QP_{12} = 2396.04(0.349) + 119.802(0.349)^2}$

$QP_{21} = -821.72$ — Power flow` at each node — $QP_{12} = 850.81$

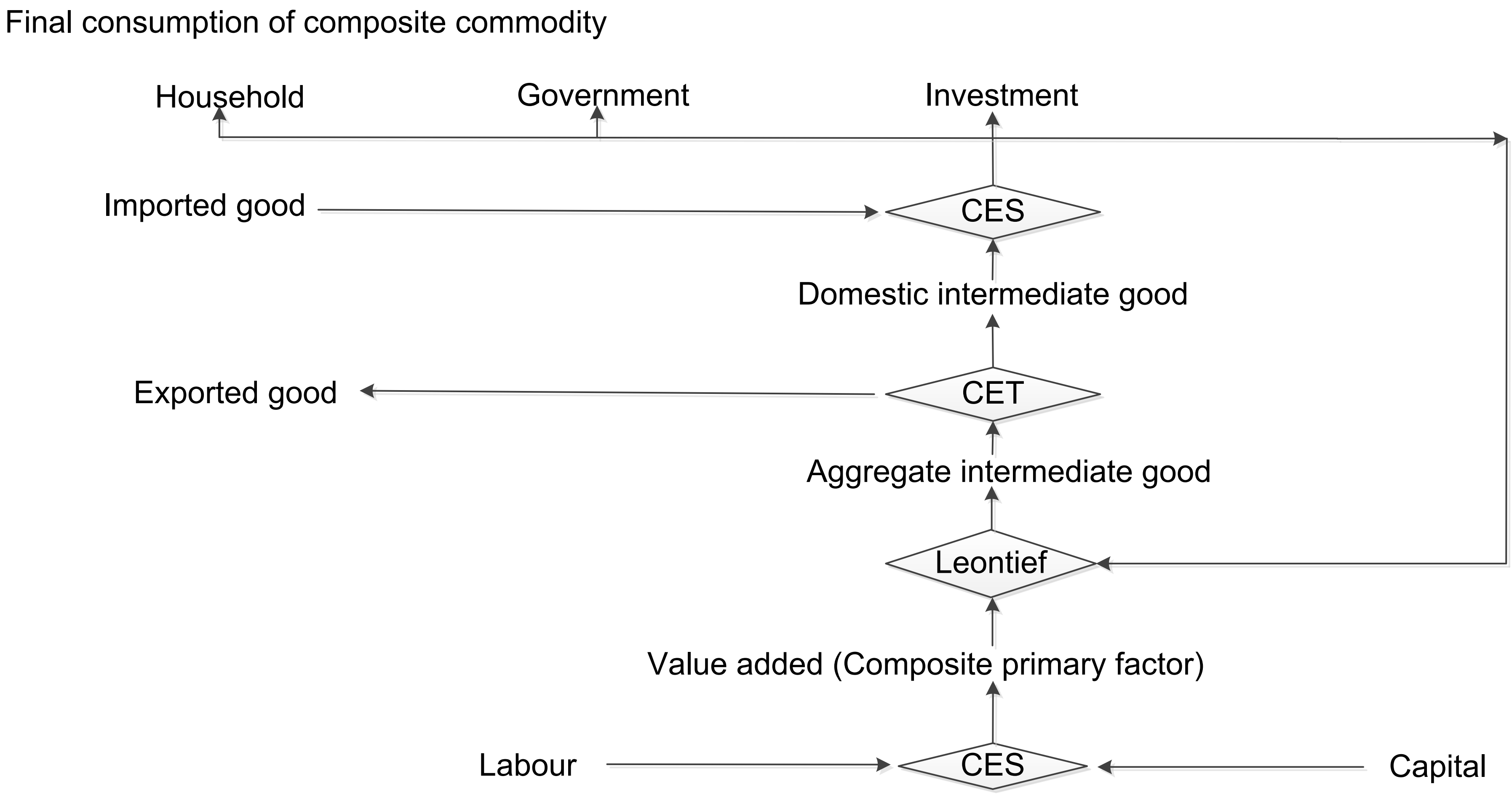
Power loss is $QP_{21} + QP_{12} = 28.94$

$$QP_{ij} = G_{ij}V_i^2 - G_{ij}V_iV_j cos(\theta_i - \theta_j) + Y_{ij}V_iV_j sin(\theta_i - \theta_j)$$
$$QP_{ij} = G_{ij}(V_i^2 - V_iV_j) - Y_{ij}V_iV_j(\theta_i - \theta_j) + \frac{1}{2}G_{ij}V_iV_j(\theta_i - \theta_j)^2$$
$$QP_{ij} = \beta_{ij}(\theta_i - \theta_j) + \gamma_{ij}(\theta_i - \theta_j)^2$$
$$QP_{ij} = 2396.04(\theta_i - \theta_j) + 119.802(\theta_i - \theta_j)^2$$

Linked in to the CGE core

	Production activities	*Final demands*	*Row Total*
Goods	Inter-industry flows	Final demands	
Primary factors	Value added		**Total income**
Column total		**Total expenditure**	

Stylised representation of the CGE



Combining the models

- Combines models
  - Energy: Salerian, Gregan, Jones (2000)
  - CGE: Gilbert, Tower (2013)
    - original model had equations (equalities)
    - rearranged to create inequality constraints
    - investment long-run steady state
    - foreign ownership share of capital
    - using an old database

Combining the models

- 9 ‘traditional’ goods
- 5 electricity goods (load blocks)
- 3 primary factors (labour, capital, land) owned by households and foreigners
- Numeraire is nominal exchange rate
- Real government fixed (balanced budget)
- Endogenous lump sum tax on households
- Basic long-run, forward-looking steady state through endogenous propensity to save

Outline of the hypothetical policy simulation

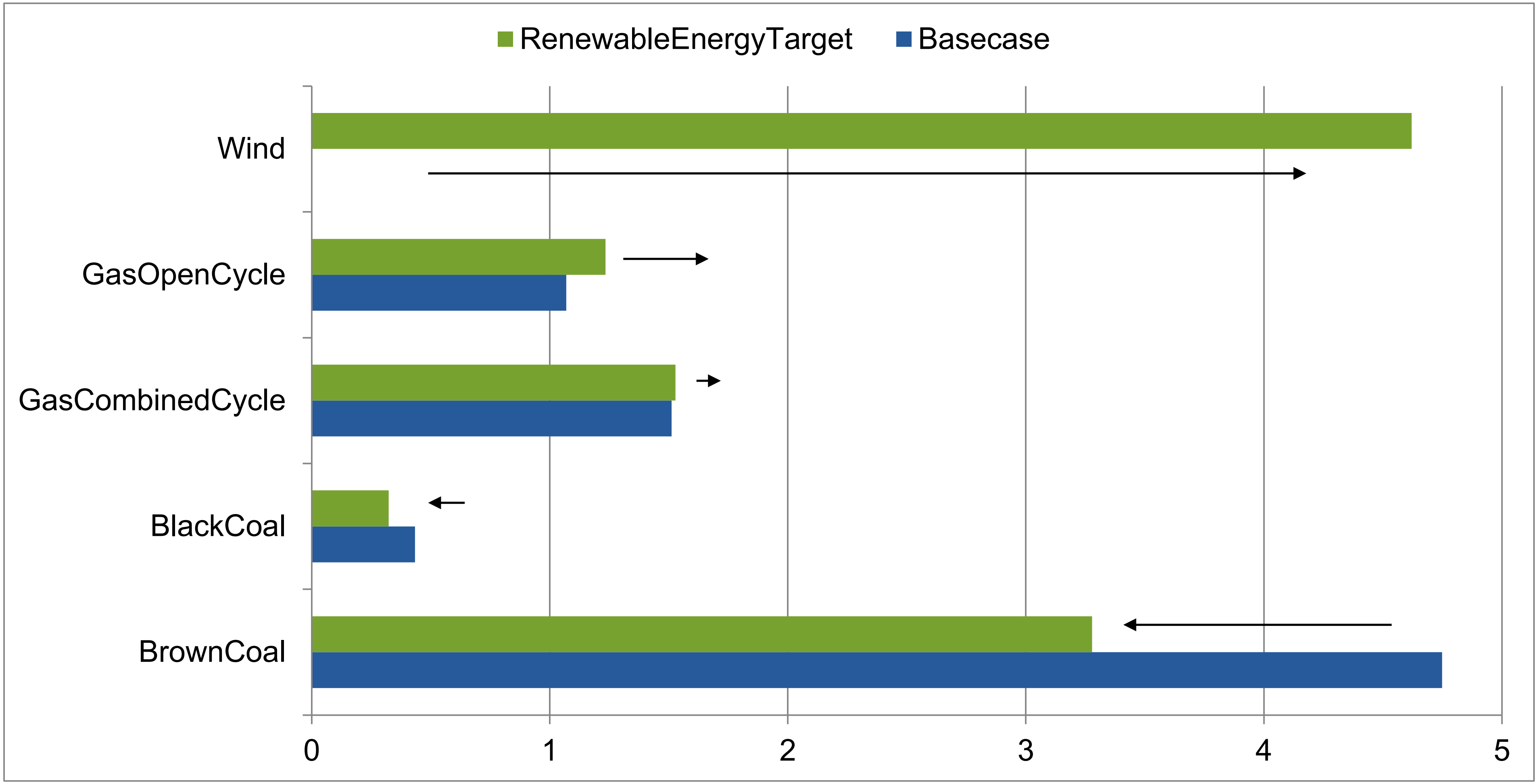
- Introduction of Renewable Energy Target
  - RET constraint
  - 20 per cent of basecase generation (wind)
  - price of renewable energy certificates
  - surcharge on end user electricity sales to pay for renewable energy from certificates
  - two markets
    - National Electricity Market (NEM)
    - Renewable Energy Certificate market (RECs)
    - The NEM and RET markets interact


What do the model results look like?

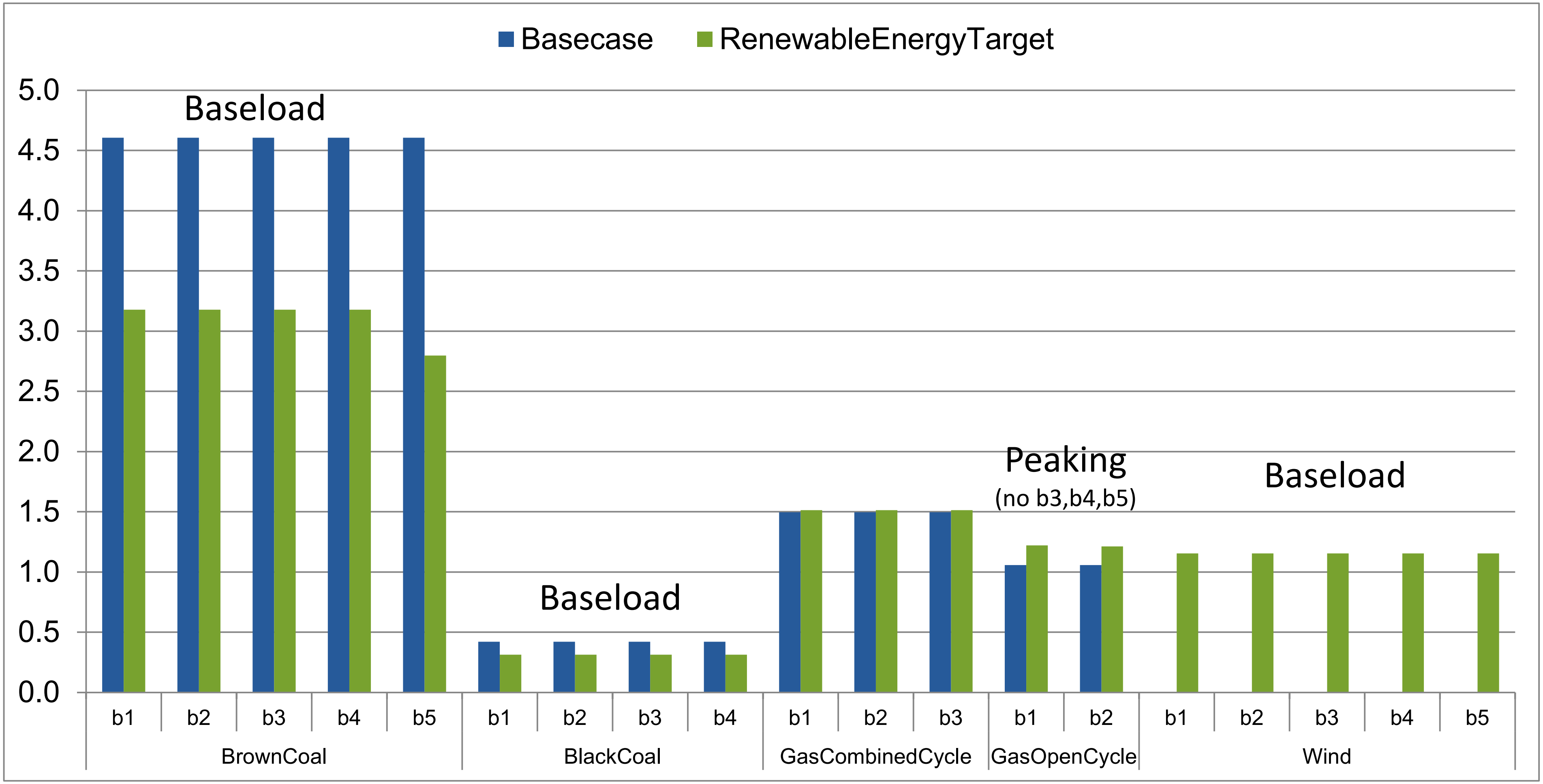
Carbon emissions from power stations (Mt CO2e)

	Basecase	RenewableEnergy Target
Brown Coal	45.4	31.2
Black Coal	2.6	2.0
Gas Combined Cycle	2.2	2.2
Gas Open Cycle	0.2	0.3
Wind	NA	0.0
Total	50.5	35.6

Installed capacity of generation (GW)



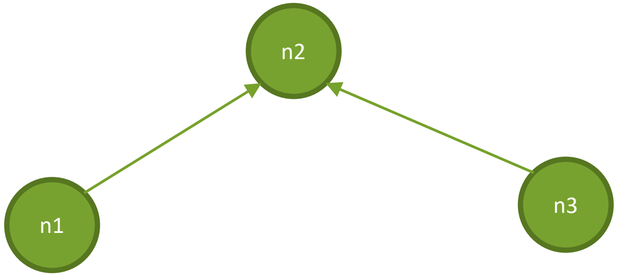
Power station generation by load block (GW)



Power flow across transmission links (MW)

	Basecase	Basecase	Basecase	Renewable Energy Target	Renewable Energy Target	Renewable Energy Target
	n1	→ *n2*	*n3*	*n1*	→ *n2*	← *n3*
b1	8076	-7799		6577	-7529	1220
b2	7658	-7408		5491	-6323	1020
b3	6528	-6346		4398	-5283	1015
b4	5210	-5094		2983	-3899	987
b5	4344	-4263		2249	-3133	929

- positive = origin
- negative = destination
- sum = total transmission losses



End user prices by load block ($ per MWh)

		Basecase	RenewableEnergy Target
b1	Electricity Market Price	7633	8030
b1	Renewable Energy Surcharge		15
b1	Total	7633	8044
b2	Electricity Market Price	87	77
b2	Renewable Energy Surcharge		15
b2	Total	87	92
b3	Electricity Market Price	62	61
b3	Renewable Energy Surcharge		15
b3	Total	62	76
b4	Electricity Market Price	34	33
b4	Renewable Energy Surcharge		15
b4	Total	34	48
b5	Electricity Market Price	8	5
b5	Renewable Energy Surcharge		15
b5	Total	8	19
All	Price of renewable energy certificates	na	66

Employment and labour in production

	Basecase	RenewableEnergy Target
Agriculture	41.63	41.59
Mining	24.23	24.16
Manufacturing	190.24	189.84
Electricity Retail Distn	1.23	1.21
Gas Retail Distn	0.30	0.30
Services	1376.95	1376.70
Brown Coal Mining	0.28	0.17
Black Coal Mining	8.66	8.61
Gas Extraction	2.56	2.57
Generation and transmission	3.93	4.85

Macro results – GDP summary ($m)

	Basecase	Renewable Energy Target	Deviation
C	124309	123657	-652
I	65218	65228	10
G	43280	43280	0
X	56589	56440	-149
M	37026	36932	-94
Household income	176483	175739	-743

Lessons from the modelling

- Fit for purpose
- Smallest possible
- Capture the interaction between policy variables of interest to the policy analyst
- Models are an aid to policy analyst
  - not a means of providing the 'right' answer
- Connections between theory/model formulation
- Paper will be available in future

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Questions?

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