National CGE Workshop 2016

Old Parliament House, Canberra
Monday August 8, 2016

Abstracts and Presentations

National CGE Workshop 2016

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8:00	Open for Registrations	
8:30	Welcome and introduction	
Keynote Speaker		
8:45	**Mark Cully**, Department of Industry, Innovation & Science	Modelling as *ex ante* policy evaluation
Session 1: Chair Rod Tyers		
9:30	**Rob Waschik**, Centre of Policy Studies, VU	Linking CGE and specialist models: Deriving the implications of highway policy using USAGE-Hwy
10:00	**Tim Murray**, Productivity Commission	Integrating a Partial Equilibrium model within a CGE framework (as a Mixed Complementarity Problem)
10:30	***Morning tea***	
Session 2: Chair Philip Adams		
11:00	**Cedric Hodges**, Deloitte Access Economics	Are we there yet? Adjustment paths in response to Tariff shocks: a CGE Analysis.
11:30	**Bruce Layman**, Economic Regulation Authority of Western Australia	CGE Modelling in Python: an application to electricity market trading-interval dispatch
12:00	**Peter Dixon**, Centre of Policy Studies, VU	DSGE modelling in GEMPACK
12:30	***Lunch***	
Session 3: Chair Guy Jakeman		
13:30	**Maureen Rimmer**, Centre of Policy Studies, VU	Immigration reform scenarios for U.S. agriculture
14:00	**Rod Tyers**, UWA	Contractions in Chinese fertility and savings: long run domestic and global implications
14:30	**Paul Gretton**, Crawford School, ANU	Modelling the potential impacts of economic reform in a partnership between Australia and China
15:00	***Afternoon tea***	
Session 4: Chair Paul Gretton		
15:30	**Xiao-guang Zhang**, Productivity Commission	Solving a partial equilibrium model in a CGE framework: the case of a BMS model
16:00	**Matt Clark**, Synergies Economic Consulting	Economic benefits from reforms to management of the East Coast Trawl Fishery
16:30	**Janine Dixon**, Centre of Policy Studies, VU	The implications of a cut to company tax in Australia
17:00	**Close**	

Workshop dinner: 6pm at Boffins Restaurant, University House, ANU
http://unihouse.anu.edu.au/boffins-restaurant/
This is an informal dinner at participants' own expense

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Abstracts

Linking CGE and specialist models: Deriving the implications of highway policy using USAGE-Hwy

Peter B. Dixon, Maureen T. Rimmer and Robert Waschik

Scientists/engineers create specialist partial-equilibrium models of energy, environment and transportation. We show how technical information from such models can be transferred into a CGE model. We illustrate the approach by describing the creation and application of USAGE-Hwy which combines USAGE, a CGE model of the U.S., with HERS, a specialist highway model. USAGE-Hwy, translates micro information from HERS on the effects of highway expenditure programs into implications for GDP, employment, and the trade-off between current and future living standards. Combination models such as USAGE-Hwy bring scientific/engineering analyses into the economic domain, facilitating the use of these analyses in policy discussions.

Integrating a Partial Equilibrium model within a CGE framework (as a Mixed Complementarity Problem)

Tim Murray

A number of different modelling frameworks have been used historically to address different policy questions. Partial equilibrium models have typically been used where engineering or industry-specific details are of particular importance; while CGE models have been used where economywide implications and inter-industry linkages are important. However, the two frameworks have a common mathematical and conceptual origin. Recent developments in approaches to designing and solving models presents an opportunity for incorporating typical PE characteristics (e.g. engineering characteristics) into detailed CGE models.

This presentation includes a proof of concept illustration integrating an energy model (which includes physical laws, as well as a nodal supply representation) within a CGE model (which includes typical CGE characteristics such as a number of industries, primary factors, taxes, as well as CET and CES relationships).

Are we there yet? Adjustment paths in response to Tariff shocks: a CGE Analysis.

Tony Wiskich and Cedric Hodges

This paper takes the mini USAGE model developed by Dixon and Rimmer (2005) and modifies it in order to better mimic the expected adjustment path following a tariff reduction. Results from the adjusted model are compared against the standard model. It is found that the standard model does a good job of capturing the expected long-run behaviour of the economy in response to this shock and, with a few relatively straight forward changes the standard model can retain the long-run outcomes and also have a more plausible adjustment path. These changes are documented in an appendix and are considered applicable to a wide range of models currently in use.

CGE Modelling in Python: an application to electricity market trading-interval dispatch

Bruce Layman

Python is an open-source, object-orientated interpreted programming language, while Pyomo is a Python optimisation modelling package that can be used to solve CGE models in the tradition of solving GTAP with GAMS software. This paper finds that while Python/Pyomo lacks the ease of use of GEMPACK for CGE modelling, its flexibility allows the implementation of assumptions different to standard CGE treatments. In particular it uses Python and Pyomo to construct: a simple stylised recursive-dynamic CGE model with forward-looking expectations in response to a known but staged policy change; and a simple stylised short-run comparative-static CGE model with an integrated electricity market trading-interval dispatch model. Its preliminary results indicate that forward-looking expectations lead to a more immediate investment response to a known staged policy change than comparative-static expectations, while the economic impact of increasing the supply of intermittent non-storable renewable energy production depends on how strongly this production correlates with electricity demand.

DSGE modelling in GEMPACK

Peter B. Dixon and Maureen T. Rimmer

This paper has two purposes. The first is to explain DSGE in a way that is comprehensible to CGE modellers with little experience in DSGE. The second is to show that DSGE models can be solved in GEMPACK. This is achieved by demonstrating a GEMPACK solution of the main illustrative model set out in Schmitt-Grohé and Uribe (2004). The GEMPACK approach offers the possibility of including DSGE features in full dimension CGE models.

Reference

Schmitt-Grohé, S. and M. Uribe (2004), "Solving dynamic general equilibrium models using a second-order approximation to the policy function", Journal of Economic Dynamics and Control, vol 28, pp. 755-775.

Immigration reform scenarios for U.S. agriculture

Peter B. Dixon and Maureen T. Rimmer

The general equilibrium method adopted here reveals several effects of agriculture-focused immigration policies that would not have emerged in partial equilibrium analysis applied to agriculture. Our general equilibrium model includes specifications of: inter-sectoral labor flows; the role of vacancies in determining occupational choices; and macroeconomic relationships. This enables us to show that agricultural guest-worker and legalization programs are likely to: have similar effects on the agricultural sector; cause a gradual welfare-enhancing transformation of the occupational mix of incumbent employment away from agriculture; have small (possibly negative) effects on farm income; and have positive effects on aggregate capital, employment and GDP.

Contractions in Chinese fertility and savings: long run domestic and global implications

Rod Tyers

Following three decades of rapid but unbalanced economic growth, China's reform and policy agenda are set to rebalance the economy toward consumption while maintaining a rate of GDP growth near seven per cent. Among the headwinds it faces is a demographic contraction that brings slower, and possibly negative, labour force growth and relatively rapid ageing. While the lower saving rates that result from consumption-oriented policies and rising aged dependency may contribute to a rebalancing of the economy, in the long run they will reduce both GDP growth and per capita income. Moreover, while an effective transition from the one-child policy to a two-child policy would help sustain growth and eventually mitigate the aged dependency problem, it would set real per capita income on a still lower path. These conundrums are examined using a global economic and demographic model, which embodies the main channels through which fertility and saving rates impact on economic performance. The results quantify the associated trade-offs and show that continuing demographic and saving contractions in China would alter the trajectory of the global economy as well.

Modelling the potential impacts of economic reform in a partnership between Australia and China

Paul Gretton

Effective economic reform agendas provide a means for promoting national economic growth, raising living standards and adapting to changes in trading conditions, new technologies and ways of working. Taking as a focus the Australia-China economic relationship, the GTAP model of the global economy is used to project the implications for Australia and China of preferential, unilateral and broader approaches to trade liberalisation, a broad agenda for reform across the services sector and financial market reform. The simulations show that reform strategies based on non-discriminatory trade liberalization and broadly-based concerted domestic reforms are likely to deliver substantive economic benefits and contribute to growth. Agendas that are restrictive, either through preferential deals between trading partners or through a narrow sectoral focus domestically are likely to constrain gains below levels that would otherwise be attainable.

Solving a partial equilibrium model in a CGE framework: the case of a BMS model

Xiao-Guang Zhang

This paper presents a new approach to decompose an integrated computable general equilibrium (CGE) model into a partial equilibrium (PE) model and a residual CGE model. This opens up the scope for richer analysis of policy relevant matters by expending the PE sub-model in selected circumstances.

Specifically, this paper outlines how to integrate a behavioural microsimulation (BMS) model within a CGE framework. It then shows how the household module can be separated from the CGE model and how the resulting PE sub-model and CGE model can be solved iteratively, so that the equilibrium is identical to that of the integrated model. The paper focuses on two challenges that arise when linking and solving two different models: how to find a convergent solution and how to ensure it is the true general equilibrium solution. This involves ensuring that databases and theory in both models are consistent and fit exactly with each other. Some cases may require the use of a slack variable to account for temporary inconsistencies between the two models.

This approach has the potential to extend the range and quality of the analysis of policy relevant issues. For example, using a microsimulation framework for the household sub-model, makes a richer analysis of the household sector transfer and tax system possible. Further work is required to investigate whether the general framework used for this specific partitioning of the structure of the model can be applied to structural partitions that relate to the other parts (eg the inter-industry part) of a CGE model.

Economic benefits from reforms to management of the East Coast Trawl Fishery

Matt Clark

The East Coast Trawl Fishery is Queensland's largest and most important commercial fishery. The fishery operates from the Gold Coast to Cape York and generates over $90 million in gross value of production per annum. The fishery is currently managed through the effort units which grant fishers a perpetual right to fish for a regulated amount of time each year. This regulatory regime has created significant incentives for inefficiencies and effectively means the industry is regulated by economic conditions rather than an effective catch constraint.

Modelling has been conducted in MMRF to demonstrate how economic benefits might accrue from reforms to the fishery.

The implications of a cut to company tax in Australia

Janine Dixon and Jason Nassios

We investigate the impact of a cut to the company tax rate using a miniature version of the Vic-Uni computable general equilibrium model of the Australian economy with additional detail on ownership of physical capital. Because of Australia's system of dividend imputation, a change to the company tax rate disproportionately affects the final post-tax rate of return for foreign investors. Therefore a cut to the company tax rate would transfer government revenue to foreigners, and add to pressure on government to reduce spending or to raise personal taxes.

We find that a cut to the company tax rate would attract more foreign investment to Australia, making workers more productive and increasing wages and output. However, there is a lag between new investment activity and capital growth, and a large share of future company profits will accrue to foreign investors. We also find that increased wages will reduce returns to domestically owned capital.

While the impact on national *production*, as measured by GDP, will be positive, this is not a suitable measure of national benefit. The right indicator of national benefit is the impact of a company tax rate cut on national *income* and we find that this will fall.

Linking CGE and specialist models: Deriving the implications of Highway Policy using USAGE-Hwy

8 August 2016

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Introduction:

- CGE models have been developed and used to address economic policy issues for many decades
- Reflect standard neoclassical utility maximization and cost-minimization problems, assuming CRS production in perfectly competitive markets
- But there is a large body of specialist theory and empirical information that can be brought to bear in a CGE framework
  - Energy/environment modelling
  - Water policy modelling
  - Transport policy modelling
- Objective of this paper is to show how information from a specialist highway model, the Highway Economic Requirements System (HERS), can be transferred into a CGE model, USAGE, to deliver policy results that are informed by both modelling techniques

Introduction:

- Plan for this talk:
  - Describe adjustments made to USAGE model to incorporate HERS data in creating USAGE-Hwy
  - Review information available from specialist highway model HERS provided by US Department of Transport, noting how it is integrated into the USAGE model
  - Report and explain results for USAGE-Hwy simulations of the macroeconomic effects of increased expenditure on highways and bridges (H&B) in the US

Creation of USAGE-Hwy:

		Absorption Matrix				
		1	2	3	4	5
		Producers	Investors	Households	Exports	Govt
	Size	← I →	← I →	← 1 →	← 1 →	← 1 →
Basic Flows	↑ $C{\times}S$ ↓	BAS1	BAS2	BAS3	BAS4	BAS5
Margins	↑ $C{\times}S{\times}N$ ↓	MAR1	MAR2	MAR3	MAR4	MAR5
Sales Taxes	↑ $C{\times}S$ ↓	TAX1	TAX2	TAX3	TAX4	TAX5
Labour	↑ M ↓	LABOCCIND				
Capital	↑ 1 ↓	CAPITAL				

C = Number of commodities (62 → 68)
I = Number of industries (59 → 65)
S = 2; domestic and imported
M = Number of occupations
N = Number of commodities used as margins

Size	Joint Production Matrix
	← I →
↑ C ↓	MAKE

Size	Import Duty
	← 1 →
↑ C ↓	TARIFF

Disaggregating "*Construction*":

- Decompose the single industry "*Construction*" into three distinct industries:
  - *Highways and bridges (H&B)*
  - *Street repairs*
  - *Other construction*
- 2005 I/O data show that expenditure on "*H&B*" accounted for 6.1% of total "*Construction*" sales
- Create a distinct "*H&B*" industry with the same input structure as "*Construction*"
- Sold all output of "*H&B*" to user "*Government*", with offsetting reduction in "*Government*" purchases of "*Construction*"
- Likewise, "*Street repairs*" accounted for 2.9% of total "*Construction*" sales

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Creating "*Household car repair*" industry:

- 2005 I/O data show that expenditure on "*Car repairs*" accounted for 22.5% of "*Household*" purchases of "*Miscellaneous services*"

- Create a distinct "*Household car repair*" industry with the same input structure as the "*Car repair*" industry in the detailed 2005 database

- Re-balance by
  1. reducing inputs into "*Miscellaneous services*" industry
  2. reducing sales of "*Miscellaneous services*" to "*Households*"
  3. Selling all output of the new "*Household car repair*" industry to a new "*Private road transport*" industry

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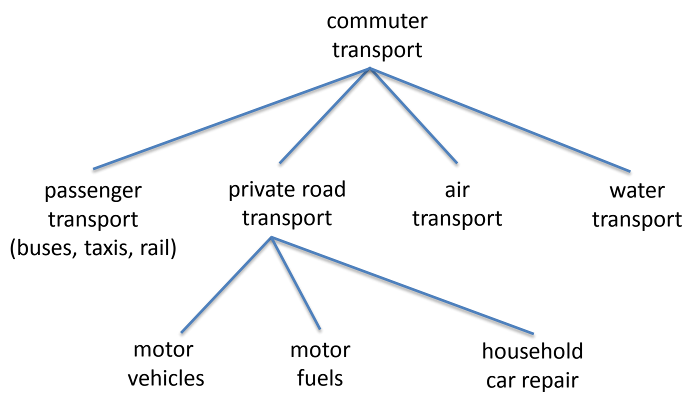
Private road, *Commuter* and *Vacation transport*:

- Create industry "*Private road transport*" (*PRT*) using inputs of "*Motor vehicles*", "*Motor fuels*" and "*Hhld car repair*"
- Distribution of "*PRT*" between "*CT*" and "*VT*" based on "*Motor fuel*" purchases by households and the vacation industry



Travel time:

- Estimate travel time by transport type, and introduce equations linking travel time to volume of travel/transport
- Introduce a phantom tax equal to the labor cost of travel time

	Value of travel time ($ per hour)	Time lost (m. of hours)	Fraction of time lost deduced from labor supply	Deduction from labor supply (m. person years)	Phantom tax on sales ($m)
	(1)	(2)	(3)	(4)=(2)*(3)/2000	(5) = (1)*(2)
Sales to VT					
AirInternal	5	974	0.1	0.0487	$4,870
PRT	5	13,448	0.1	0.6724	$67,241
PassengTrans	5	5,910	0.1	0.2955	$29,550
WaterInternal	0	0	0.0	0.0	0
Sales to CT					
AirInternal	15	16	0.25	0.002	$240
PRT	15	61,263	0.25	7.6579	$918,945
PassengTrans	15	8,704	0.25	1.0881	$130,568
WaterInternal	15	384	0.25	0.0479	$5,753

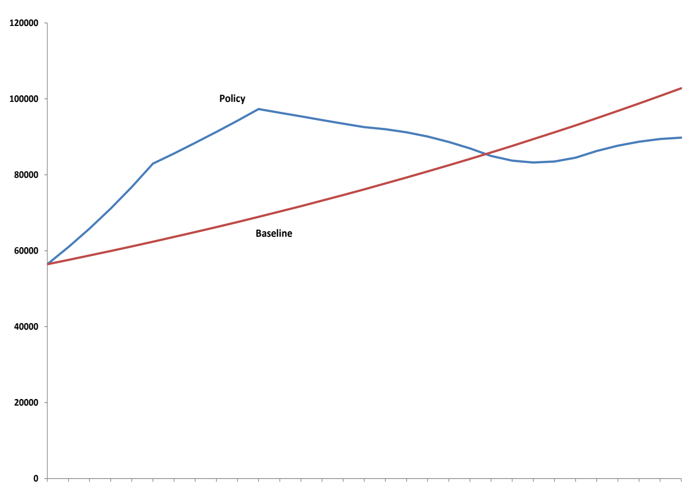
Results from HERS –> Inputs to USAGE:

- Volpe (National Transportation Systems Center) of the US Department of Transportation provided two sets of data derived from the Highway Economic Requirements System (HERS):
  - Baseline data representing business-as-usual
  - Policy data reflecting the effects of increased highway infrastructure expenditure
- Data cover the period 2010-2040
- Driven by changes in H&B infrastructure expenditure, and their effect on:

(i) maintenance cost savings	(iv) safety costs
(ii) vehicle operating costs	(v) fatalities
(iii) fuel use	(vi) time per vehicle mile travelled

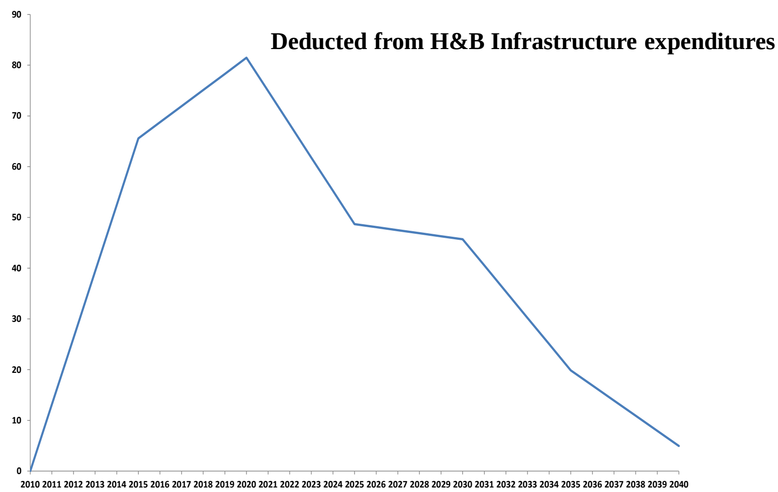
Results from HERS –> Inputs to USAGE:

Chart 2.1. Paths of Highway and bridge expenditure ($m 2010 prices)



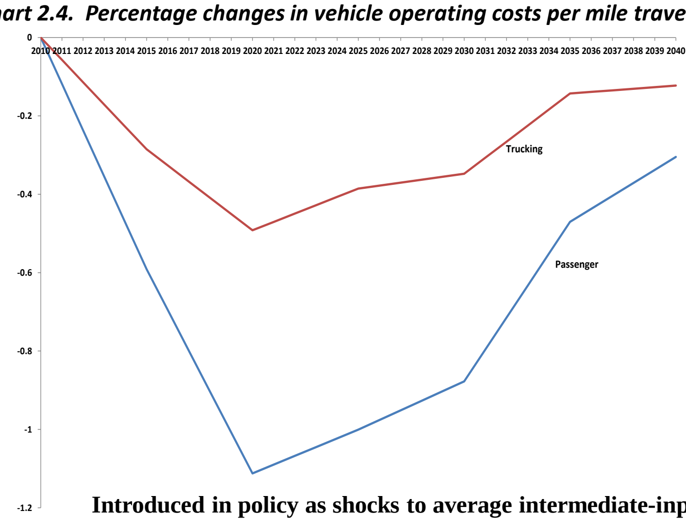
Results from HERS –> Inputs to USAGE:

Chart 2.3. Maintenance cost savings ($m 2010 prices, increased investment - baseline)



Results from HERS –> Inputs to USAGE:

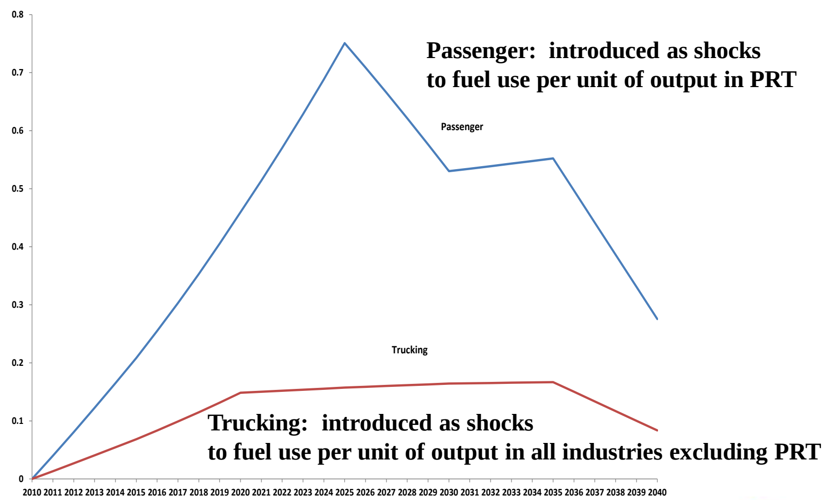
Chart 2.4. Percentage changes in vehicle operating costs per mile travelled



Introduced in policy as shocks to average intermediate-input-saving technical change in Private road transport and Trucking

Results from HERS –> Inputs to USAGE:

Chart 2.5. Percentage changes in fuel use per mile travelled



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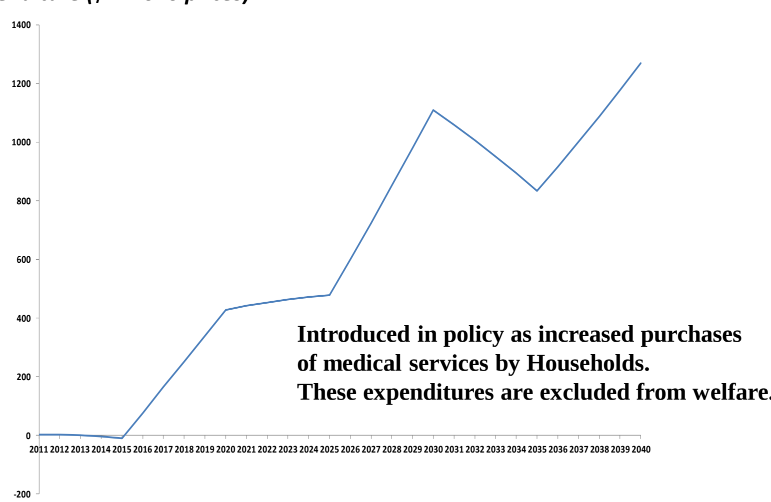
Results from HERS –> Inputs to USAGE:

Chart 2.6. Extra safety costs associated with increased highway investment expenditure ($m 2010 prices)



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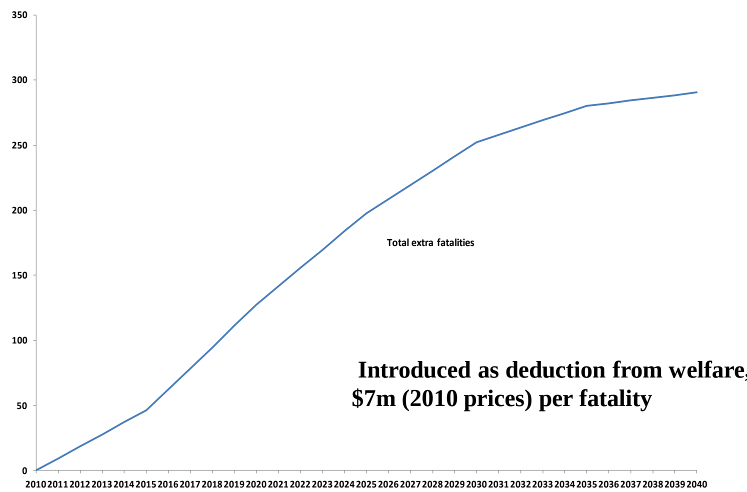
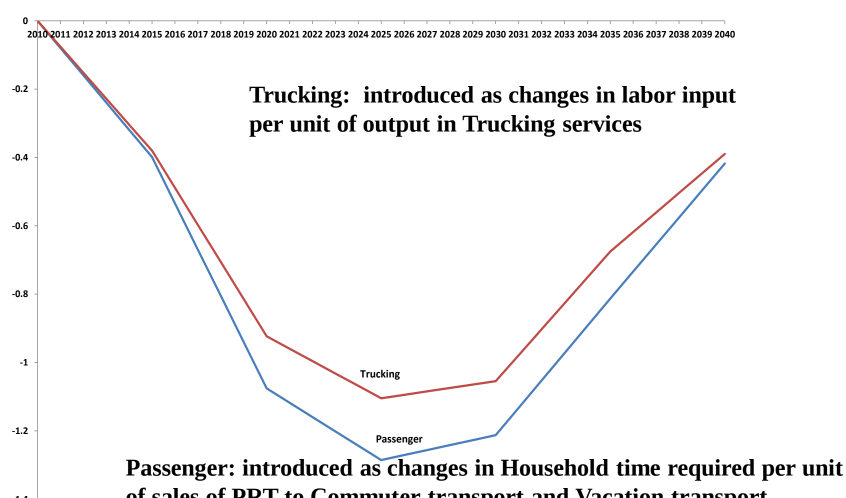
Results from HERS –> Inputs to USAGE:

Chart 2.8. Extra fatalities associated with increased highway investment expenditure



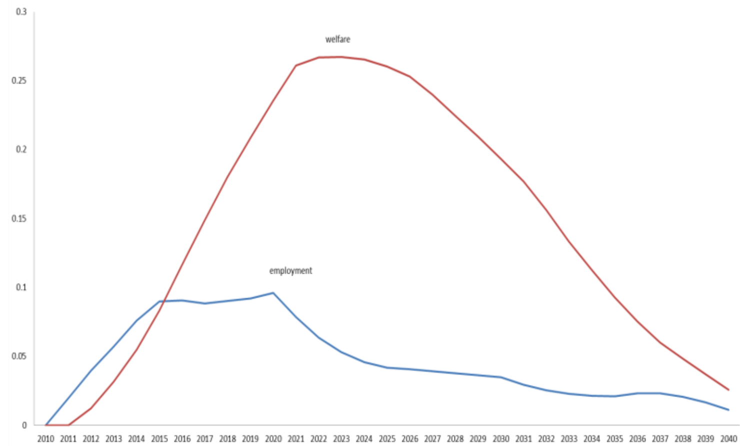
Results from HERS –> Inputs to USAGE:

Chart 2.9. % reductions in time per VMT associated with increased highway investment expenditure



Results of USAGE-Hwy Simulations:

- Increase in H&B infrastructure expenditures is welfare-improving – also leads to an increase in employment

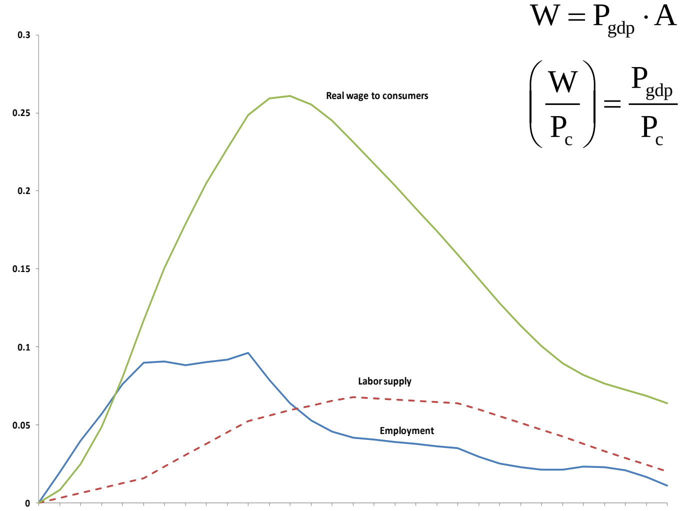


 P.17

Chart 3.3. Labor market variables (% deviations from baseline):

$$W = P_{gdp} \cdot A \cdot F_{\ell}(K/L)$$

$$\left(\frac{W}{P_c}\right) = \frac{P_{gdp}}{P_c} \cdot A \cdot F_{\ell}(K/L)$$



 P.18

Chart 3.3. Labor market variables (% deviations from baseline):

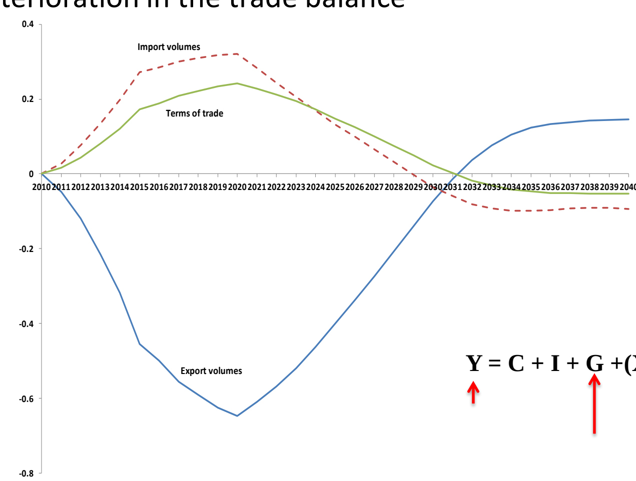
- A increases because of saving of time and intermediate inputs in PRT and Trucking
- Increased H&B is funded by an increase in government spending, leading to an appreciation as US prices rise
- P_{gdp}/P_c increases because the terms of trade improve (appreciation) and construction prices rise

$$W = P_{gdp} \cdot A \cdot F_\ell(K/L)$$

$$\left(\frac{W}{P_c}\right) = \frac{P_{gdp}}{P_c} \cdot A \cdot F_\ell(K/L)$$

Chart 3.4. Trade variables (% deviations from baseline)

- Improvement in terms of trade due to appreciation leads to a deterioration in the trade balance



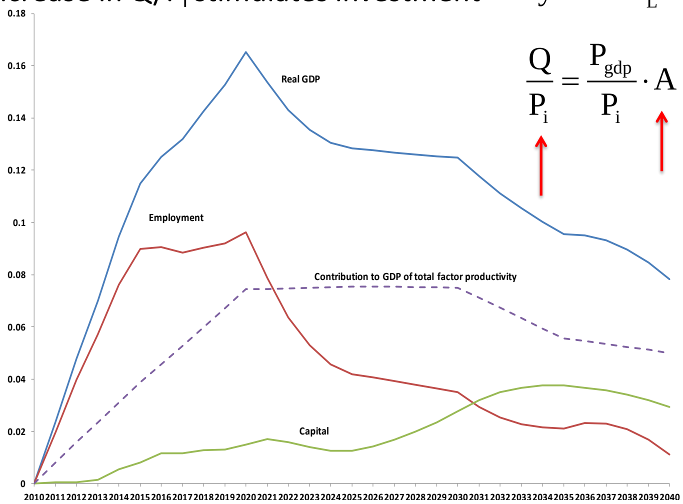
$$Y = C + I + G + (X - M)$$

Chart 3.5. GDP and factor inputs (% deviations from baseline):

- Q/P_i is related to real return to capital, so increase in Q/P_i stimulates investment

$$y = a + \overset{0.65}{S_L} \cdot \ell + \overset{0.35}{S_K} \cdot k$$

$$\frac{Q}{P_i} = \frac{P_{gdp}}{P_i} \cdot A \cdot F_k(K/L)$$



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Conclusions:

- Use information from a specialist highway model, the Highway Economic Requirements System (HERS)
- Increase in H&B infrastructure expenditures leads to:
  - Reductions in vehicle operating costs
  - Travel time savings
- Integrating these effects of H&B infrastructure expenditures into a CGE model like USAGE allows us to show how these effects translate into welfare and productivity improvements

- Also look at different methods of funding H&B expenditures, through:
  - Lump-sum tax financing
  - Petrol-tax financing

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Integrating a Partial Equilibrium model within a CGE framework

Tim Murray

August, 2016

Background and context

- The general approach was to develop the simplest model that could focus analysis on the both partial and general impacts
  - *Carbon and RET – energy*
    - … Sector is important
    - … General equilibrium is important
  - *use modelling to*
    - … illustrate the theory
    - … understand operation of policies

Background and context (cont’d)

- Developed a model including:
  - *Detailed energy sector, range of supply sources, power-supply network*
  - *Renewable energy target*
  - *General equilibrium too: industries, trade, factors, macro-closure*

Background and context (cont’d)

- A prerequisite for being able to develop such policy models was the capacity to apply
  - *inequality constraints in mathematical programming models*
  - *the associated the Karush-Kuhn-Tucker conditions underlying mathematical programming models with such constraints*
  - *endogenous prices and quantities as variables*

Background and context (cont'd)

- Carbon Caps and Renewable Energy Targets only have a positive price if they are binding
  - *a fundamental idea in economics*
- The question remained
  - *could the theory from spatial equilibrium models be incorporated into a CGE model*
- And the answer is? Yes

Outline

1. Brief review of the history of the development of modelling frameworks
2. Power System Economics
3. Traditional CGE
4. CGE model – add traditional CGE to power model
5. Outline of the policy simulations
   - *Renewable Energy Target (RET)*
6. Presentation of results
   - *principal focus on the electricity sector and RET policy*
7. Lessons from modelling

1. Brief review of the history

1952 Samuelson
- Spatial equilibrium
- Linear demand & supply functions
- Linear programming

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

1989-1992 Takayama & MacAulay
- Spatial equilibrium
- *Generalised to non linear programming*

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

1994 Mixed complementarity problem solvers
- Solve non-linear programming problem
- Solve problem with inequality constraints and no objective function
- Solvers improving daily
- Hard

1960 Johanson
- CGE model
- Square system of linear equations in change form and solution by matrix inversion

1975 Impact project (IAC)
- ORANI model
- CES, CET etc.
- Multi step solutions
  - remove linearisation error

Today
- Large applied
- Dynamics
- Linear
- Equalities, cont.

1. Brief review of the history (cont'd)

Mixed Complementarity problem

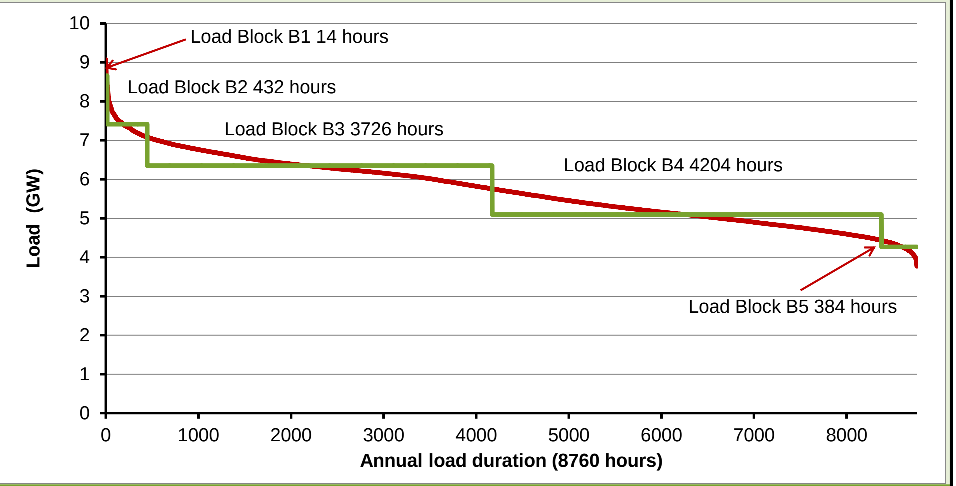
Non linear programming
Takayama & Judge models
primal-dual, prices and quantities endogenous and square system of constraints and variables

Problems with inequality constraints and no objective function
game theory models
CGE model with inequality constraints

Systems of non linear equations
traditional CGE models

Why are we interested?
Types of policies and technologies that can be simulated!
Flexibility to improve our understanding and insights into policy issues

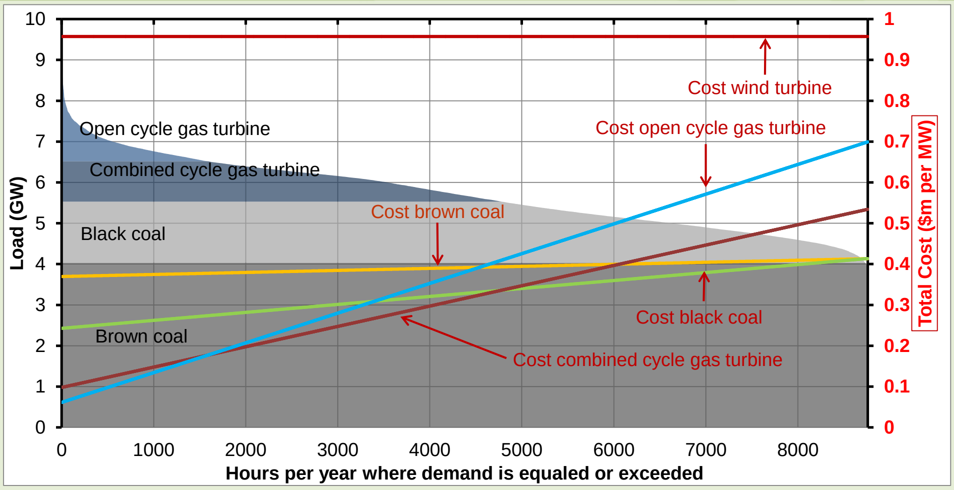
2. Power System Economics 101
System load duration curve



2. *Generation*

		Brown Coal	Black Coal	Gas Combined Cycle	Gas Open Cycle	Wind
Plant Availability	no.	0.97	0.97	0.99	0.99	0.25
Plant Size	MW	750.00	750.00	349.00	530.00	100.00
Fuel Cost	$/GJ	0.40	2.25	7.00	7.00	0.00
Capital Cost	$m/MW	4.39	2.88	1.09	0.73	2.56
Life of Plant	years	50.00	50.00	30.00	40.00	25.00
Thermal Efficiency		0.29	0.42	0.51	0.35	1.00
Carbon Emissions	tCO2e/MWh	1.13	0.74	0.35	0.52	0.00
Capital Cost Equivalent Annual Value	$m/MW	0.37	0.24	0.10	0.06	0.96
Operational Cost	$m/GW	0.0050	0.0195	0.0498	0.0728	0.0000

2. *Installed capacity and merit order*



Productivity Commission 11

2. **Power System Economics 101 (cont'd)** *Transmission power flow*

Node 2 ← 150 km → Node 1

Demand ← Generation

Phase angle at each node

θ_2=-0.349 $\theta_1 = 0$

Difference in phase angle at each node

$\theta_2 - \theta_1 = -0.349$ $\theta_1 - \theta_2 = 0.349$

$\boldsymbol{QP_{21} = 2396.04(-0.349) + 119.802(-0.349)^2}$ $\boldsymbol{QP_{12} = 2396.04(0.349) + 119.802(0.349)^2}$

Power flow` at each node

$QP_{21} = -821.72$ $QP_{12} = 850.81$

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

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

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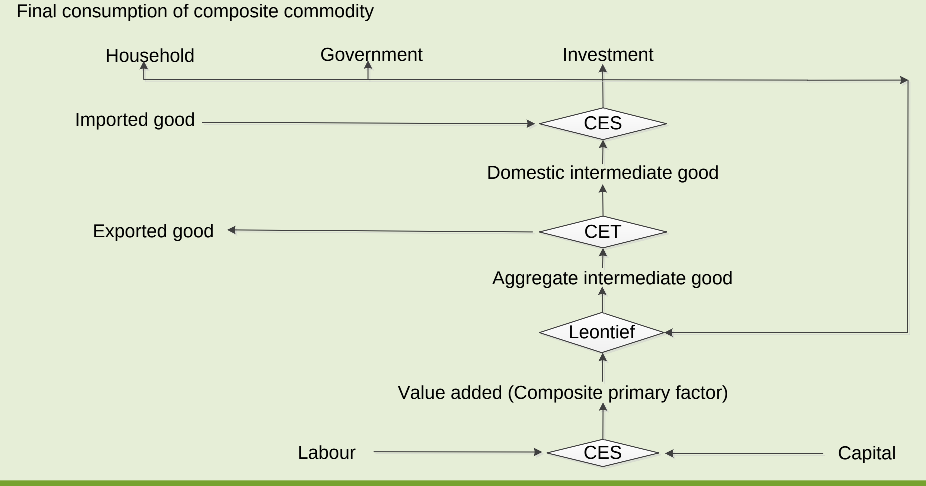
3. Traditional CGE 101
Input-Output core

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

3. *Stylised production (Gilbert, Tower)*



4. Model description

- Combines models
  - *core is a cut down version of electricity model by Salerian, Gregan, Jones published in the Journal of Policy Modelling (2000)*
  - *add to the core a modified version of a CGE model published by 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

4. (cont'd)

- 700 equations
- most constraints are inequalities
  - *very few equations*
- Under the MCP framework
  - *positive variables (≥0) have inequality constraints*
  - *free variables (positive or negative) have equality constraints*
    - … trade balance, phase angles, transmission power flow, accounting

4. (cont'd)

- 9 'CGE' goods
- 5 'Electricity' goods (load block)
- 3 primary factors (labour, capital, land) owned by households and foreigners
- Numeraire is nominal exchange rate
- Real government fixed
- Endogenous lump sum tax on households
- Basic long-run, forward-looking steady state through household savings

4. (cont'd)

- PE maximising consumer and producer surplus
- CGE with utility maximising households and cost minising firms
- Models combined through first order conditions
- Linking equations and variables
- Principles
  - *All defined in levels (but could do % change)*
  - *All solved in GAMS (but could be solved in alternative packages like GemPack).*

5. Outline of the policy simulations

- Basecase
- Introduction of Renewable Energy Target
  - *20 per cent of basecase generation (GWh)*
  - *price of renewable energy certificates*
  - *surcharge on end user electricity sales to pay for renewable energy from certificates*
  - *two markets for renewable generators*
    - … National Electricity Market (NEM)
    - … Renewable Energy Certificate market (RECs)

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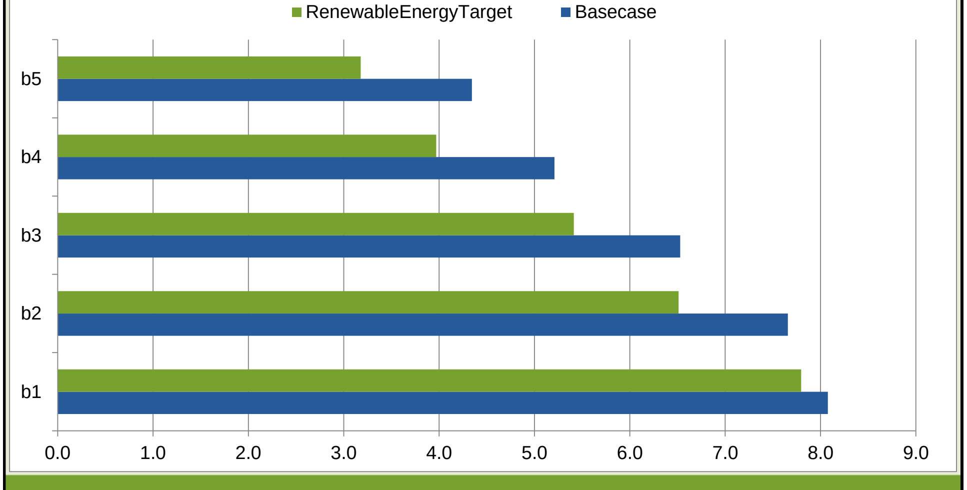
6. Results
Power system load in the NEM (GW)



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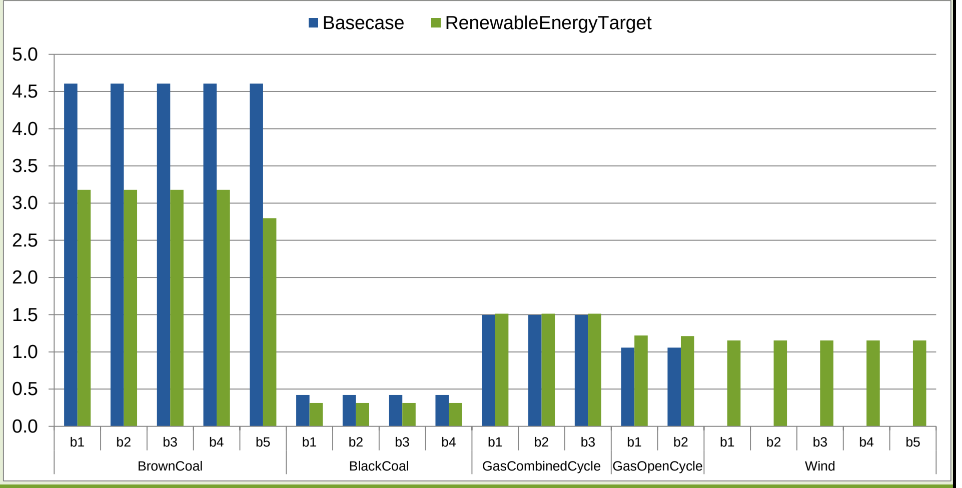
6. Power station generation by load block (GW)



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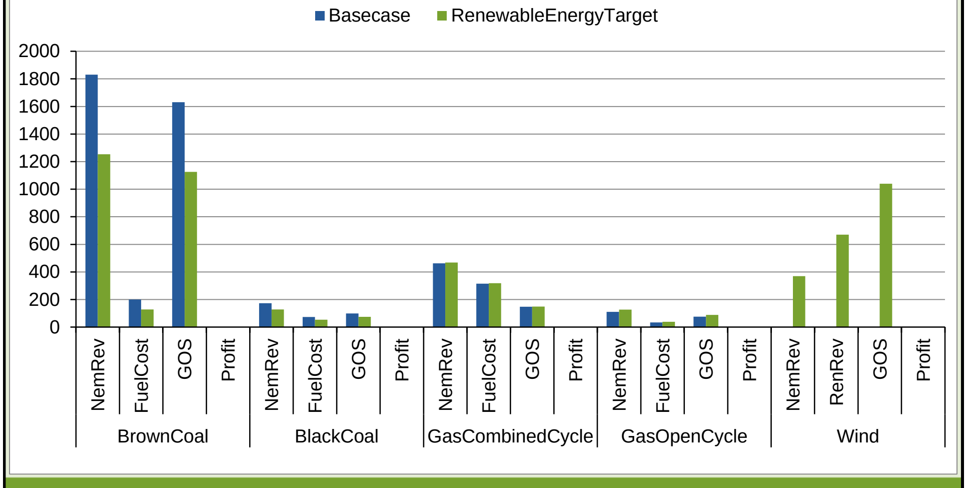
6. Power station revenue and costs ($m)



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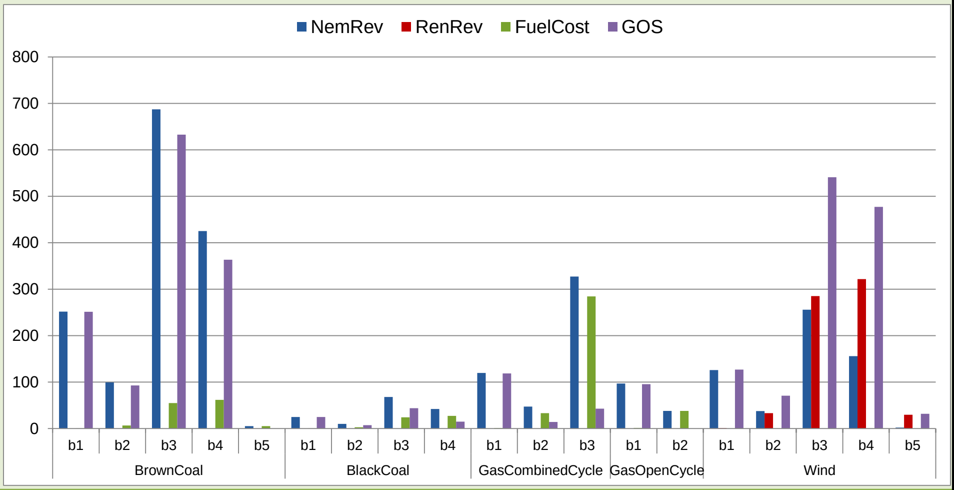
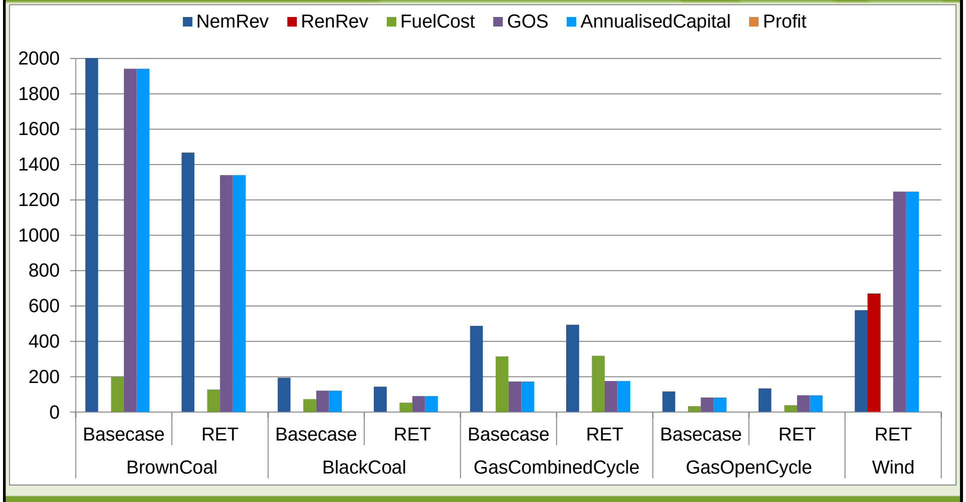
6. Power station revenue and costs by load block for RET simulation ($m)



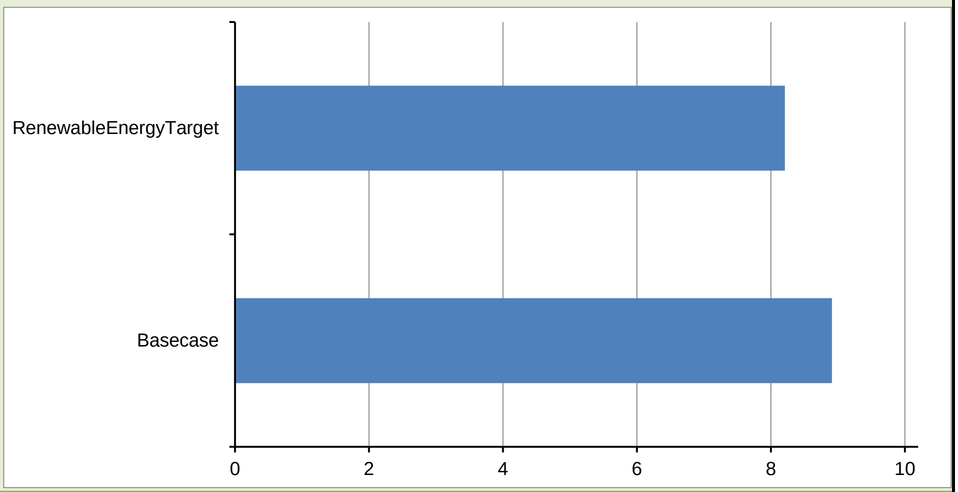
6. Power station revenue and costs for RET simulation ($m)



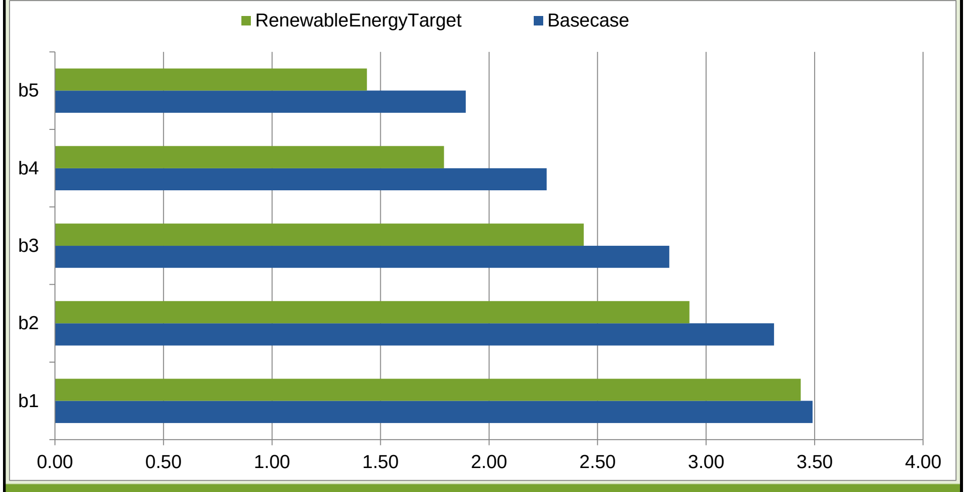
6. *Power flow for at each node by load block and simulation (MW)*

	Basecase	RenewableEnergy Target
n1	851	639
n2	-822	-812
n3		212
n1	850	473
n2	-781	-690
n3		238
n1	687	347
n2	-669	-577
n3	0	244
n1	548	202
n2	-537	-426
n3		232
n1	459	212
n2	-449	-342
n3		135

6. *Number of lines on the transmission link between generation and demand*



6. Average power loss for each line at each node by load block and simulation (%)



6. Nodal price at each end of the transmission link by load block and simulation ($ per MWh)

	Basecase	Basecase	Basecase	Renewable Energy Target	Renewable Energy Target	Renewable Energy Target
	n1	*n2*	*n3*	*n1*	*n2*	*n3*
b1	5648	7633		5649	8030	7775
b2	72	87		72	77	75
b3	58	62		58	61	59
b4	32	34		32	33	32
b5	8	9		5	5	5

6. Revenue, cost and profit for transmission line by simulation ($m)

	Basecase	RenewableEnergy Target
Revenue	196668	168133
Annualised capital cost	196668	168133
Profit	0	0

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6. End-user electricity prices by load block and simulation ($ 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

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6. *Price and quantity of fuel used for electricity generation ($ per GJ and PJ)*

			Basecase		Renewable Energy Target
Price	$ per GJ	Primary Energy Brown Coal	0.4000		0.3713
		Primary Energy Black Coal	2.2500		2.2254
		Primary Energy Natural Gas	7.0000		7.0082
Quantity	PJ	Primary Energy Brown Coal	501		344
		Primary Energy Black Coal	33		24
		Primary Energy Natural Gas	50		51

6. *Carbon emissions from power stations by simulation (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
Total	50.5		35.6

6. *Nominal and real wage*

	Basecase	RenewableEnergy Target
CPI	100.00	100.24
Nominal Wage	80.50	80.30
Real Wage	80.50	80.11

6. *Employment of labour in production of goods and services (core CGE)*

	Basecase	RenewableEnergy Target
Agriculture	41.63	41.59
Mining	24.23	24.16
Manufacture	190.24	189.84
ElecRetailDistn	1.23	1.21
GasRetailDistn	0.30	0.30
Services	1376.95	1376.70
BrownCoalProd	0.28	0.17
BlackCoalProd	8.66	8.61
GasProd	2.56	2.57

6. *Price of domestic production*

	Basecase	Renewable Energy Target
Agriculture	200.00	200.01
Mining	200.00	200.15
Manufacture	200.00	200.23
GasRetailDistn	200.00	200.14
Services	200.00	200.06
BlackCoalProd	2.25	2.25
GasProd	7.00	7.00

6. *Quantity of export goods*

	Basecase	Renewable Energy Target
Agriculture	19.70	19.69
Mining	32.65	32.53
Manufacture	56.86	56.53
GasRetailDistn	0.31	0.31
Services	140.06	139.86
BlackCoalProd	2543.38	2535.40
GasProd	135.82	135.57

6. *Quantity of composite final goods*

		Basecase		Renewable Energy Target
Agriculture		50.12		49.99
Mining		73.00		72.70
Manufacture		566.28		564.63
ElecRetailDistn		32.98		32.37
GasRetailDistn		3.13		3.12
Services		1628.24		1625.86
BrownCoalProd		500.96		343.92
BlackCoalProd		179.69		170.99
GasProd		329.79		330.26

6. *Macro results – GDP summary*

			Real change $m
Consumption			-652
Investment			10
Government			0
Exports			-149
Imports			-94

6. *Macro results – Welfare*

	Marginal Utility Income	Nominal Household Income	Household Utility	Nominal GDP	Real GDP
Change	-0.002	-323	-650	-295	-696

7. Lessons from modelling

- Fit for purpose
- Smallest possible
- Still, gets complicated quickly
- 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*
  - *this is illustrative of principles*

Are we there yet? Adjustment paths in response to Tariff shocks: a CGE Analysis

Tony Wiskich and **Cedric Hodges**

Outline

- Motivation
- The original model
- Adjustments
- The adjusted model
- Conclusion

Motivation

- What is the problem we are trying to solve?
- What have we done to address it?
- Why have we done it this way?

The Original Model

- We have used miniature version of the US AGE model (mini-USAGE) developed by Dixon and Rimmer (2005).
  - Same as big-USAGE in terms of theoretical structure but run with a more aggregated database.
  - 2 regions (US, RoW), 5 sectors (low/high protection, construction, services, government) and 2 factors (labour, capital).

The Original Model

- We shock the tariff rate on highly protected goods down by 5 percentage points (from 10% to 5%) permanently in the first year of 10 year simulation.
- This is offset by changes in the labour income tax rate (a standard closure).
- There are no other shocks.

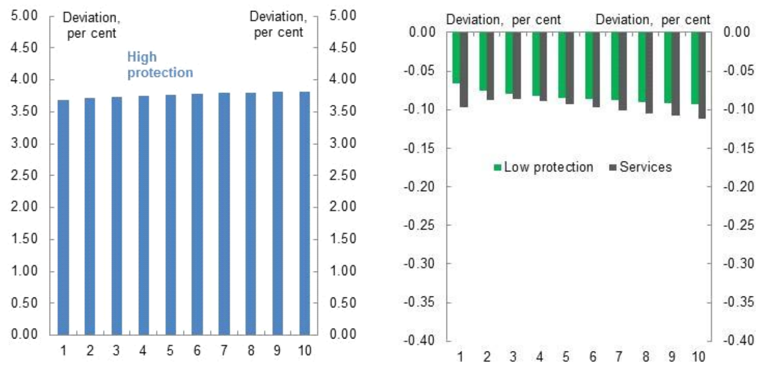
The Original Model

- Reducing tariffs should lead to more imports, especially of high protection goods.
- This should displace some domestic production, especially of high protection goods.
- The displaced production should free up domestic resources (labour and capital) which can be used in other sectors, so they should expand.
- In the short-run, as the economy is adjusting, there should be a fall in aggregate employment and output.
- But in the long-run the economy will be more productive (as tariffs are distorting) and thus output and perhaps employment may be larger.

The Original Model

- Some imports go up, some go down

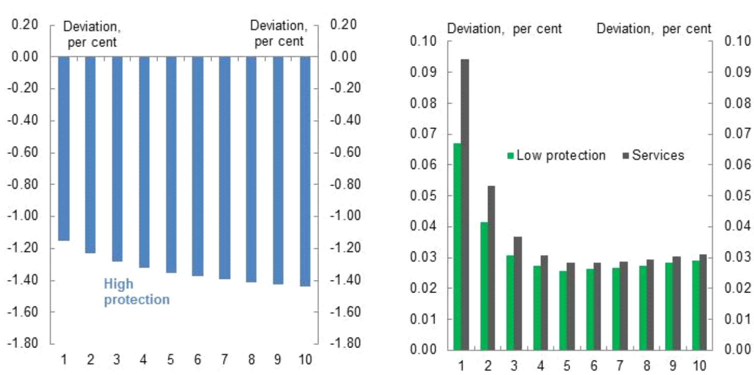
Figure 1: Change in imports



The Original Model

- This displaces some production

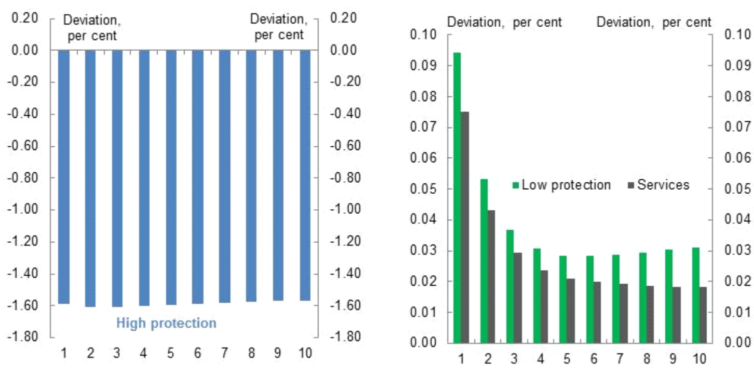
Figure 2: Change in output



The Original Model

- And some employment

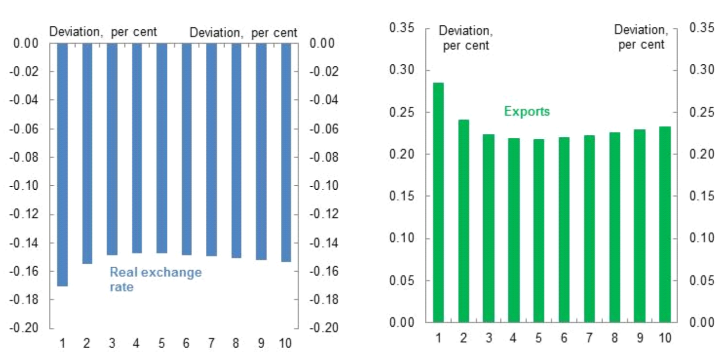
Figure 3: Change in employment



The Original Model

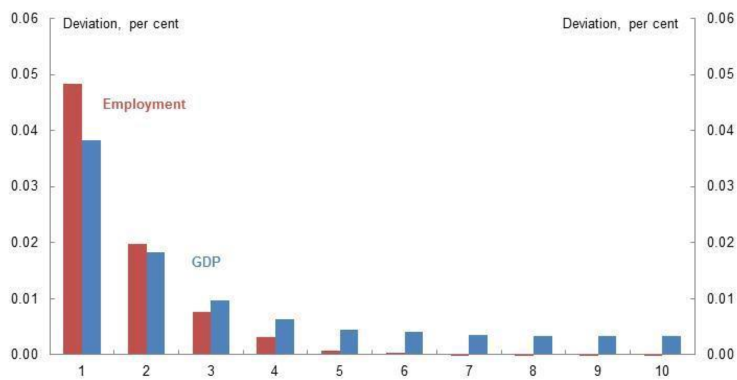
- Two issues

Figure 3: Change in real exchange rate and exports



What would you tell a policy maker?

- Cut tariffs, you'll lift GDP and employment straight away.



Issues

- The short-run response of both output and employment seems strange.
  - This could be driven by what's happening with the real exchange rate and exports.
  - It could also be driven by the speed of adjustment in factor markets.

Adjustments

- To address possible issues with the real exchange rate and exports, we tried:
  - Time varying export elasticities
  - Closing the current account with consumption
- To address possible issues with the adjustment in factor markets, we tried:
  - Introducing capacity utilisation
  - Introducing a Phillips curve
- We also tried doing all of the above at once.
  - None of it worked

Adjustments

- Real (green) vs. original (blue)

Adjustments

- Three more adjustments:
  - We introduce a price level variable, giving us a degree of freedom.
  - We use this degree of freedom to set the real exchange rate consistent with forward looking interest parity.
  - We introduce a central bank who follows a Taylor rule.

Original	Real	Nominal
No changes	Time varying export elasticities Current account consumption link Capacity utilisation Phillips curve	Time varying export elasticities Current account consumption link Capacity utilisation Phillips curve Price level variable Forward looking interest parity Taylor rule

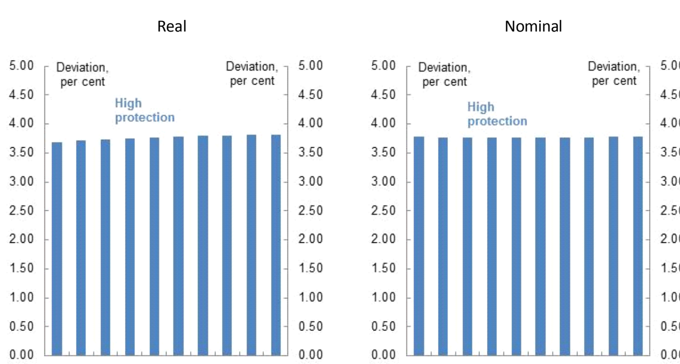
Adjustments

- Nominal (green) vs. real (blue)

The Adjusted Model

- Same

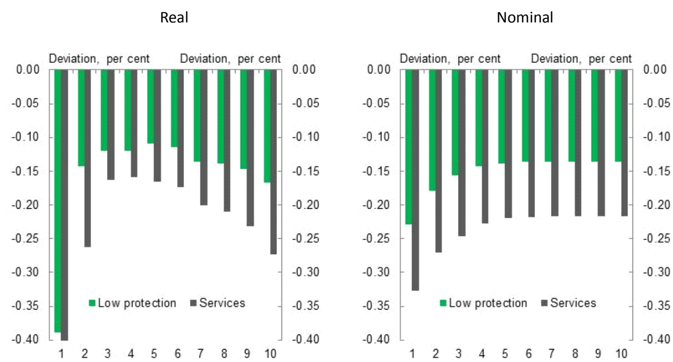
Figure 10: Change in imports – comparison



The Adjusted Model

- Different

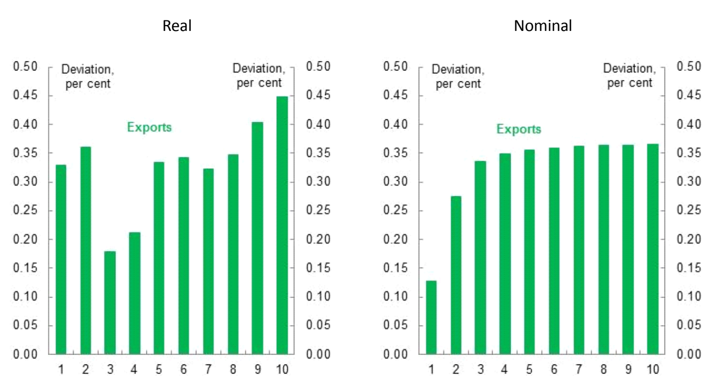
Figure 11: Change in imports – comparison



The Adjusted Model

- Very different

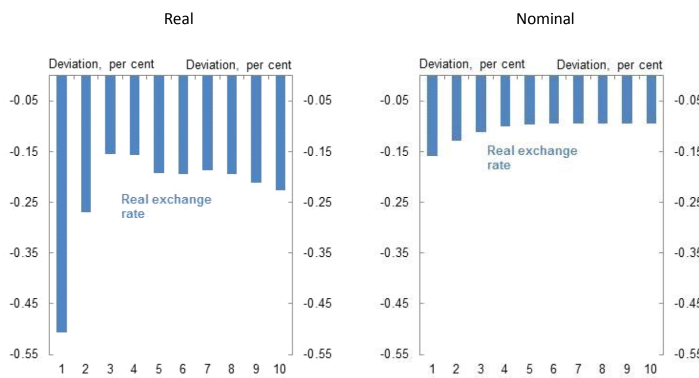
Figure 16: Change in exports – comparison



The Adjusted Model

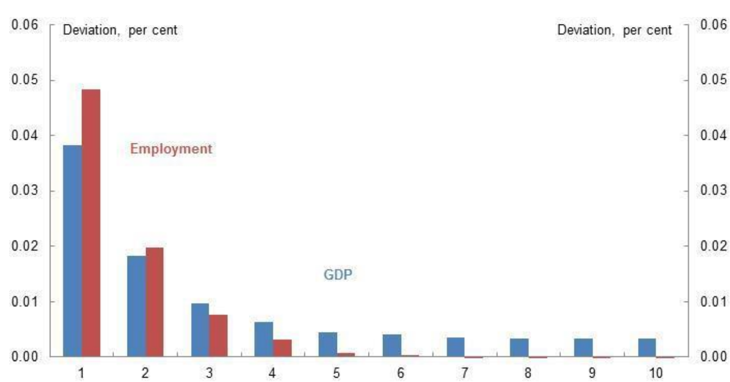
- Very different

Figure 15: Change in the real exchange rate – comparison



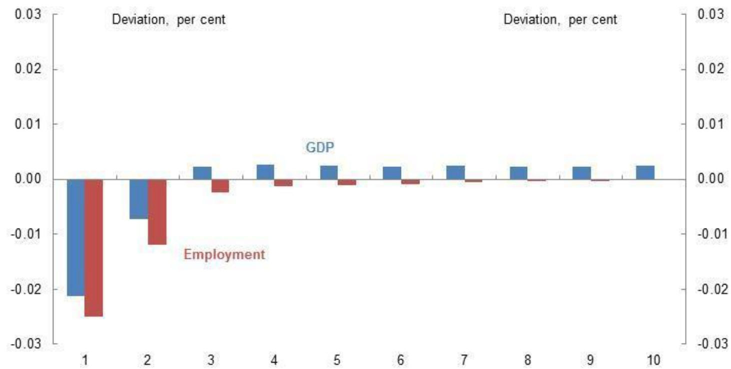
What would you tell a policy maker?

- A: cut tariffs, you'll lift GDP and employment straight away!



What would you tell a policy maker?

- Or… B: there are adjustment costs but in the long-run the economy will be larger.



Thank you.

Questions, comments, fan-mail, abuse to: cehodges@deloitte.com.au

Back pocket

Adjustments

- Time varying export elasticities

Adjustments

- Current account consumption link

Adjustments

- Capacity utilisation

Adjustments

- Phillips curve

Interest parity and Taylor rule

$$\frac{e_{�}}{e_{�-1)}} = \frac{1 + 0.5 * (R_{�} + R}{1 + R}$$

$�-1$ $��$

$R_{�}$ $(= 5 + \quad) + 0.5(L_{�} - L \ )$

1.5 $\pi_{�} - \pi$ $��$

$��$

Using Python/Pyomo to Undertake CGE Modelling: An Application to Forward-looking Expectations and Electricity Market Policy Changes

Bruce Layman

Chief Economist

Economic Regulation Authority of Western Australia*

Abstract

Python is an open-source, object-orientated interpreted programming language, while Pyomo is a Python optimisation modelling package that can be used to solve Computable General Equilibrium (CGE) models in the tradition of solving GTAP with GAMS software. This paper finds that while Python/Pyomo lacks the ease of use of GEMPACK for CGE modelling, its flexibility allows the implementation of assumptions different to standard CGE treatments. In particular it uses Python and Pyomo to construct: a simple stylised recursive-dynamic CGE model with forward-looking expectations in response to a known but staged policy change; and a simple stylised short-run comparative-static CGE model with an integrated electricity market trading-interval dispatch model. Its preliminary results indicate that forward-looking expectations lead to a more immediate investment response to a known staged policy change than comparative-static expectations, while the economic impact of increasing the supply of intermittent non-storable renewable energy production depends on how strongly this production correlates with electricity demand.

*The views presented herein are those of the author and should not be taken as reflecting the views of the Authority, individual members of the Authority, the Authority's Secretariat, or members of other organisations. The Author acknowledges the time and support from the Authority to undertake this paper.

Contents

Introduction

Since its introduction in 1984, GEMPACK (Horridge and Pearson, 2011) has facilitated some of Australia's most influential policy advice through the Centre of Policy Studies (CoPS) suite of models. It is also used in over 400 other locations in 60 countries. This is likely to continue in the future and for good reason.

GEMPACK allows modellers to solve large systems of simultaneous equations and, once some basic intuitive GEMPACK coding language is learned, it frees modellers to concentrate on the economics of a problem without worrying about computational issues or onerous data input and output considerations.

Additionally, the CoPS suite of models from ORANI (Horridge, 2014) to the Victoria University Regional Model (VURM, formerly MMRF, Peter, Horridge, Meagher, Naqvi and Parmenter, 1996) has allowed researcher to ask policy questions, perhaps with some slight modifications to the base model, without having to construct a Computable General Equilibrium (CGE) model and database from scratch. The author has used MMRF in particular to analyse a number of policy questions related to the Western Australian economy.

This study is conducted to undertake the somewhat eccentric task of CGE modelling outside of the CoPS/GEMPACK paradigm, although the basis for the modelling is firmly rooted in the CoPS linearised CGE tradition.

It is motivated by a desire to test the Python programming language and its Pyomo package, which can already be used across a range of uses, to another purpose. The attraction of a language with a wide range of uses is that, even if it is not the best for any single purpose, it potentially enables researchers to learn how to use only one language to undertake a range of tasks. This reduces the fixed cost of learning the background language for each task.

Another potential benefit from using Python for CGE modelling is that there is flexibility to go beyond the boundaries of GEMPACK's limits, although this increased flexibility comes with increased risk of model failure and data handling errors. Hence this study attempts to solve CGE models in ways that in the author's knowledge have not been used before.

This paper constructs simple stylised models to illustrate: a recursive dynamic model with forward looking expectations to deal with a policy change that is phased in over time; and a comparative-static model that is directly integrated with an electricity market dispatch model in the same Python file.

Both of these simulations are based on stylised or toy models with fictitious databases. This paper does not claim that the results hold beyond the models presented, either in terms of Python/Pyomo solving large scale CGE models or that the results presented have any practical policy implications. They do, however, suggest that further research in these areas could be useful.

This paper has been prepared by Bruce Layman, Chief Economist, in the Economic Regulation Authority (ERA) of Western Australia Secretariat. The views presented herein are those of the author and should not be taken as reflecting the views of the Authority, individual members of the Authority, the Authority's Secretariat, or members of other organisations.

Python/Pyomo

Python

Description

Python (Chan, 2014) is a general-purpose interpreted, interactive, object-oriented, and high-level programming language.[1] It has been used for many different software products and applications in the field of science and finance.[2]

Python is open source, meaning that it is free to use, even for commercial applications. It is managed by the Python Software Foundation[3]. However, there are commercial products leveraged off Python, while additional commercial software is sometimes required to run Python packages.

It is an object-orientated programming language, meaning that it focuses on the data or objects being analysed, rather than on the logic required to manipulate them as in procedural languages. Fortran, on which GEMPACK is based (Horridge and Pearson, 2011), is a procedural language.

It is an interpreted language, meaning its instructions are implemented directly rather than having to compile functions into machine-language instructions. This means that the program is slower to run, but allows the code to be more intuitive than for a compiled language. This is increasingly an advantage in a world where computer processing power is increasing and becoming cheaper every year.

Python is run on a text editor or inside an 'Integrated Development Environment' (IDE), which provides additional facilities for programmers. There are many popular Python IDEs. The calculations in this paper were constructed in the Anaconda[4] environment, which has many mathematical and scientific packages preinstalled.

Python may be run interactively in an IDE, or saved as a Python (.py) file, from which large blocks of code can be run.

Python has a large number of additional 'packages' that can be installed and called in a Python script. Such packages are sometimes difficult to install, but allow users to call intuitive functions to perform common and many less common tasks. Consequently, users do not need to be programmers with an extensive knowledge of Python programming concepts, but simply informed users of the packages that can be called to perform complex data manipulation tasks.

Python packages must be explicitly imported into Python scripts for which they are needed. For example, to call the 'pandas' package, which organises large datasets into dataframes (an organised spreadsheet-like table), the following Python script is run:

---

[1] Python for Unix/C Programmers Copyright 1993 Guido van Rossum 1 (1993), http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.38.2023 .

[2] A list of companies that use Python and products written with Python is available at: http://brochure.getpython.info/media/releases/psf-python-brochure-vol.-i-final-download.pdf/view .

[3] Information on the Python software Foundation can be found at: https://www.python.org/psf/ .

[4] Details of the Anaconda Environment can be found at: https://www.continuum.io/downloads .

```python
import pandas as pd
```

If the user requires a new dataframe using simple data directly inputted their keyboard, the following command could be used:

df = pd.DataFrame({'a': [1,2,3], 'b': [2,3,4]}).

The 'pd' is required to call the package, while 'DataFrame' is a function from within the package. This creates the following dataframe:

	a	b
0	1	2
1	2	3
2	3	4

The data are contained in columns 'a' and 'b', which the leftmost column of cells is the (yet unnamed) index.

In reality, base input data are more likely to be imported from spreadsheets, csv files or database products such as SQL. For example, it is straightforward for Python scripts to access information in a SQL database using the 'pymssql' package. This package executes SQL code written inside the Python script to access the SQL data.

As Python is open source, there are many discussion boards and websites dedicated to Python education and answering programmer questions. In all likelihood, if a user has a problem, some else has solved it and posted it online.

For example, the popular 'Stack Overflow' question and answer website for programmers[5] has over 600,000 questions directly tagged as 'Python', as well as many tens of thousands of questions each dedicated to individual Python topics.

Data Manipulation Example

As an example of data manipulation in Python, the following code retrieves 2015 Western Australian Wholesale Electricity Market (WEM) data of the Australian Energy Market Operator (AEMO) website, creates a dataframe containing only trading interval-by-trading interval system demand in Megawatts (MW)[6], and then charts this information.

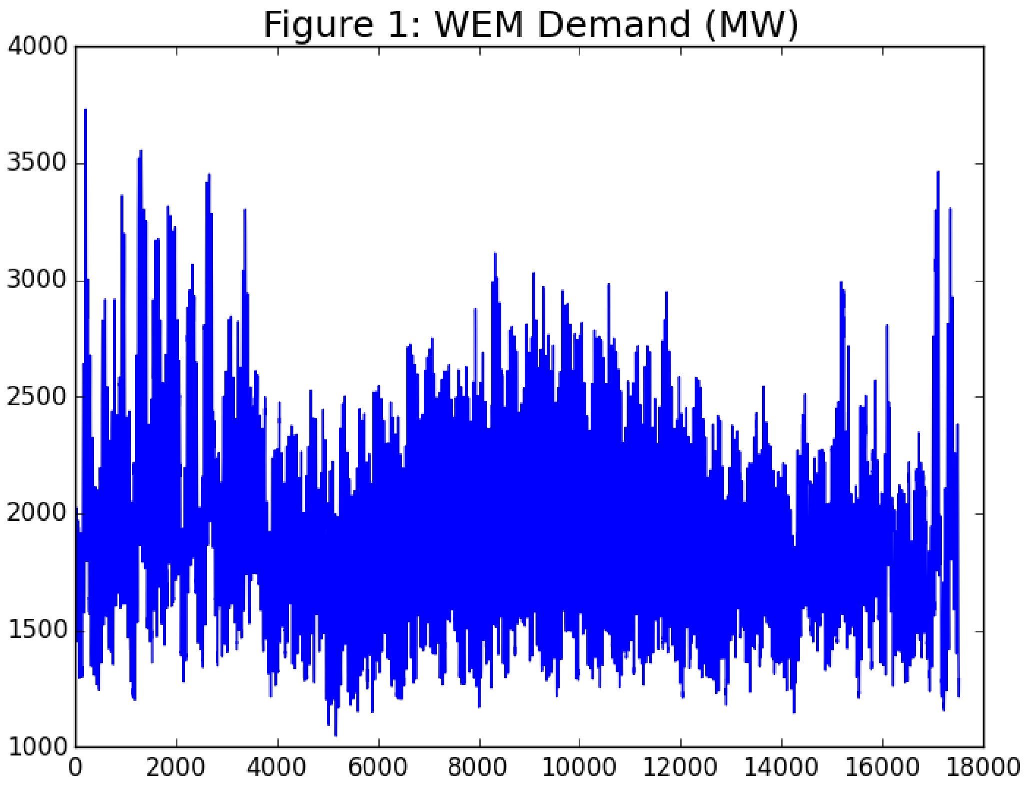
```
import pandas as pd

import matplotlib.pyplot as plt

url =http://data.wa.aemo.com.au/datafiles/balancing-summary/balancing-summary-2015.csv

table = pd.read_csv(url)

df1=pd.DataFrame(table)
```

[5] This can be found at: http://stackoverflow.com/ . The data are current as at 1 August 2016.

[6] Megawatts (MW) are units of power. Megawatt hours (MWh) are a measure of energy, or work multiplied by time.

```
df2=pd.DataFrame(df1['Scheduled Generation (MW)'])

df2.columns=['MW']

plt.plot(df2['MW'])

plt.title("Figure 1: WEM Demand (MW)", size=18)

plt.ylim(1000, 4000)
```

This generates Figure 1 below.



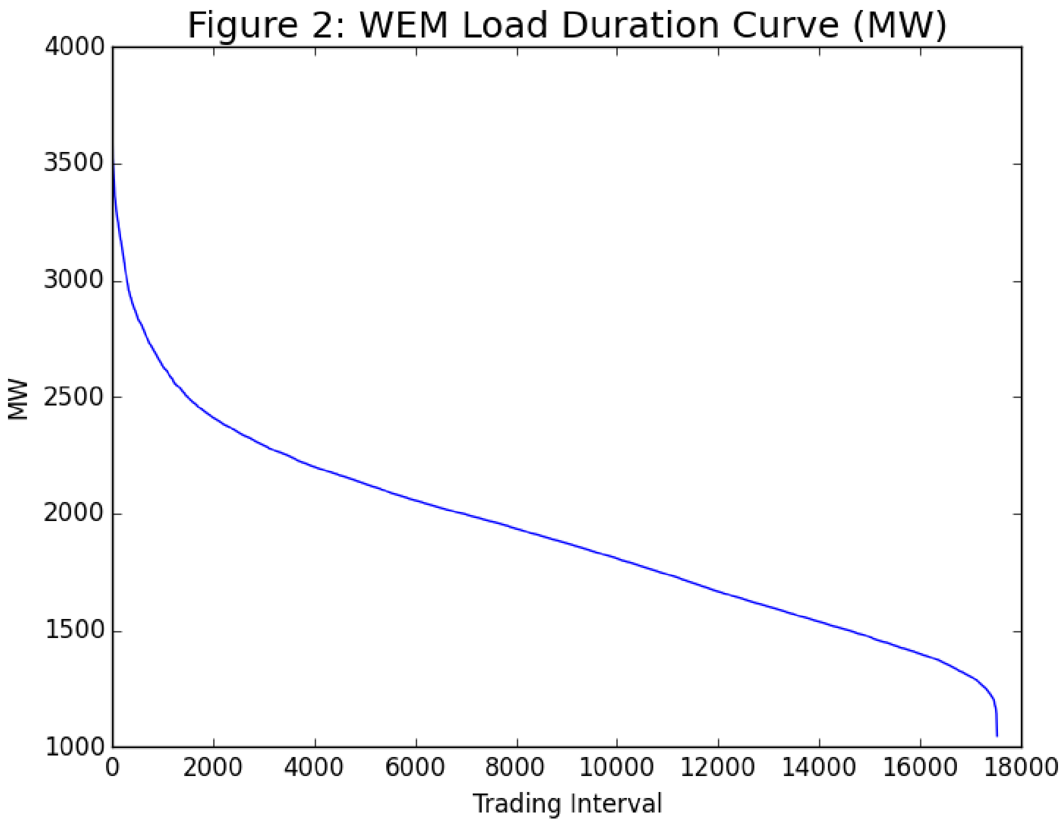
However, if the user were interested in the WEM's load duration curve, with demand ordered from the highest quantity to the lowest quality[7], they could create a new dataframe and re-order these data. Alternatively, if they wished to view the reordered data in a chart but leave the df2 dataframe untouched, and add a chart title and axes labels, the following plot command could be used:

```
plt.plot(df2.sort(['MW'], ascending=[False]))

plt.title("WEM Load Duration Curve (MW)", size=18)

plt.xlabel('Trading Interval', fontsize=12)
```

[7] Examining load duration curves are useful for power system or individual generator planning purposes.

plt.ylabel('MW', fontsize=12)

This code creates Figure 2 below.



Pyomo

Summary

Python Optimising Modelling Objects (Pyomo, Hart, Laird, Watson and Woodruff, 2012) is a Python package that 'supports the formulation and analysis of complex optimisation applications'. A simple optimisation problem is described in the next section.

While Python is an object-orientated language[8] and Fortran is a procedural language, in practice there is very little difference to a modeller in terms of how GEMPACK and Pyomo operate. The type of model used in the main simulations in this paper is an abstract model, which means that the code constructed can be used on different datasets.

Sets, parameters and variables have a similar meaning to the same terms in GEMPACK. Constraints are Pyomo optimisation functions that play a similar role as GEMPACK Equations. Constraints are further explained in the next section. Calculating initial

[8] In object-orientated programming terms, the Pyomo model type 'AbstractModel' is a Python class and a model constructed with that code is an instance of that class. Hence the term 'model= AbstractModel()' is included in the code near the beginning of the script, and all variables, the objective function and constraints are defined in terms of that instance. For example, in Pyomo a variable 'X" is defined as 'model.X'.

parameters, as is done with formulas in GEMPACK, is done with Parameter Initialisations in Pyomo.

As an example of Pyomo versus GEMPACK code, consider the standard equation for industry demand for labour taken from the Mini-USAGE model (Dixon and Rimmer, 2005). In GEMPACK the equation is:

```
Equation E_x1lab # Industry demands for labour # (All,i,IND)
x1lab(i) - a1lab(i) = x1prim(i) - SIGMA1PRIM(i) * [p1lab(i) - p1prim(i)];
```

In contrast, the Pyomo Constraint is as follows:

```
def E_x1lab (model,i):
return model.x1lab[i] == model.x1prim[i] -
model.SIGMA1PRIM[i]*(model.p1lab[i]-model.p1prim[i])
model. E_x1lab = Constraint(model.IND, rule= E_x1lab)
```

While there are differences in Syntax, the basic structure of the relationship is clear in both expressions.

Pyomo requires an optimisation solver program to run. The solver's required capabilities, such as linear versus no-linear programming or whether it supports mixed-integer programming or not, depends on the problem to be solved. Solvers range from free open source programs to very expensive commercial applications.

The models in this paper solve quickly using both the free CBC solver[9] and the commercial CPLEX[10] solver, but the models slow dramatically once additional complexity is included in the models. This is especially the case for the electricity dispatch model described later, which slows dramatically on both solvers once additional constraints are included.

Mathematical Optimisation Techniques

Linear Programming

Basics

Optimisation modelling seeks to solve for an 'objective function' relative to a set of constraints. For example, the models in this paper use a subset of optimisation modelling in Linear Programming (LP).

Briefly, LP is an optimisation procedure for linear objectives and constraints. Formally, for a vector of variables of interest x, vectors of parameters C and b and a matric of parameters A, an LP problem can be specified as:

[9] For more information on the CBC solver see: https://projects.coin-or.org/Cbc .

[10] For more information on the CPLEX solver see: https://www-01.ibm.com/software/commerce/optimization/cplex-optimizer/ .

Maximise $C^T x$

Subject to: $Ax <= b$

$x >= 0$

$C^T x$ is the objective function, while Ax <= b are the model constraints. The remaining terms sets the lower bound for the solution.

To illustrate the LP problem, consider a simple example for two variables x1 and x2, with the parameters set to their numerical values:

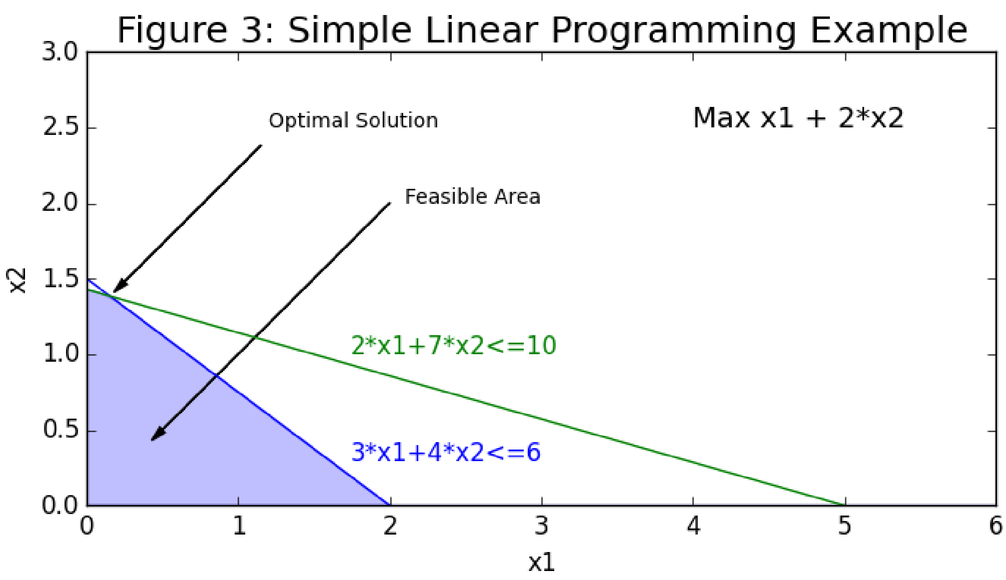
Maximize: model.x1 + 2*model.x2

Subject to: x1*3 + x2*4 <= 6

x1*2 + x2*7 <= 10

x1, x2=> 0[11]

This problem is shown graphically in Figure 3 below. The shaded area is the area below both constraint lines and, given both constraint inequalities are less-than-or-equal-to, is the area for which a solution is feasible. The optimal solution in this case is the intersection of the two curves in 0.15384615 for x1 and 1.3846154 for x2.



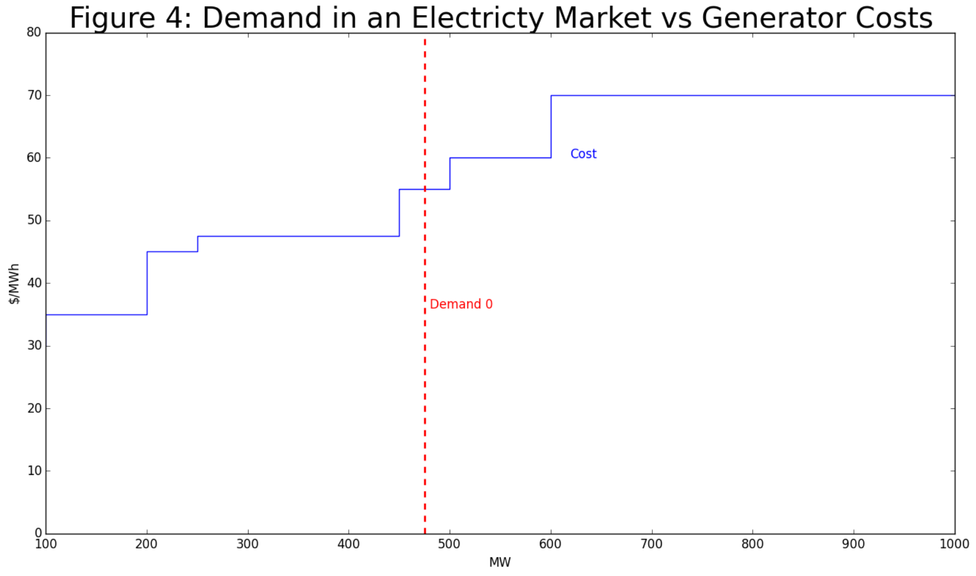
[11] The solution for this problem is 0.15384615 for C1 and 1.3846154 for C2.

Practical Linear Programming Example

For a more practical example of linear programming, such models are often used to solve electricity market dispatch problems for a central planner or a market with centralised dispatch. Dispatch quantities from each generator in each time interval (variables) are optimised to minimise the total generation cost for the period of interest (the objective), given a known set of generators with known marginal costs and fixed total demand (parameters). This is a short-run process that minimises variable costs.

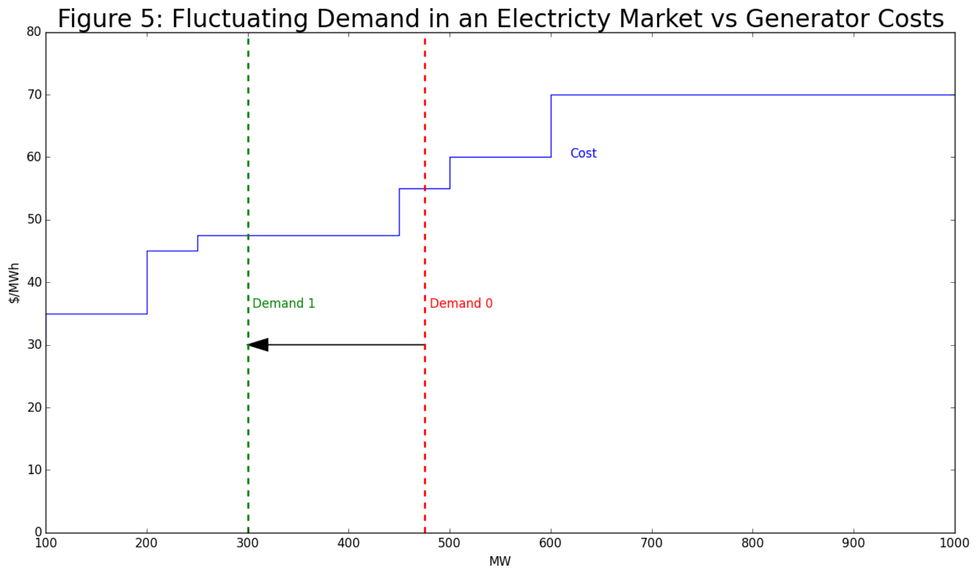
Figure 4 below shows the cost of electricity for a system as the power production increases. It is a step function, with the cheapest generator able to produce at $30/MWh until it reaches its maximum level of production of 100 MW, before the next cheapest generator produces at $35/MW for the next 100 MW, and so on.

If demand is initially 475 MW, the marginal generator's cost is $55/MWh. If the system were a market, this generator would set the market price. To the left of 475 MW, generator constraints are binding because generators cannot exceed their maximum levels of production. To the right of 475 MW however, higher cost generators are not needed and so the constraints are not binding.



The natural way to solve this type of problem of cost minimisation is by LP. The non-binding constraints are solvable because generators can produce less than or equal to their maximum production, rather than only at a set level of production.

While the example explained above is trivial, real-world electricity market problems are not. For example, if demand fell to 300 MW as in Figure 5 below, a different set of constraints become binding.



Additionally, successive trading interval cost minimisation problems are not independent because:

- Generators also have minimum production levels, meaning that plants might be shutdown even though notionally there is some demand for their output;
- Generators cost (often substantial amounts) of money to start up and shut down, meaning they may keep running even though the market price is less than their marginal cost, or may not start up if they are needed for only a few trading intervals;
- Technical requirements of each generator may mean that they have a minimum number of trading intervals that they must be run for and a minimum number of trading intervals for which they must be rested once shutdown. These are called minimum-up and minimum down times; and
- Plants have technically safe minimum changes in output over time, or ramp rates.

Finally, the short-run marginal cost of many traditional electricity generators actually slope downwards, as they become more efficient as they move from their minimum generation level to their maximum generation. Consequently, over small changes in demand, costs can go up when demand falls.

These factors mean that, rather than a succession of independent cost minimisation problems, electricity dispatch over a time period is one single problem. [12] The overall time period may be divided up into multiple time periods, but care needs to be taken that initial and terminal conditions for each sub-period do not lead to unrealistic results[13].

---

[12] This model can be solved by the Mixed-Integer Linear Programming (MILP) technique, which allows binary variables. This is explained later in the electricity dispatch model details.

[13] These can occur in situations where dispatch during trading intervals outside of the sub-sample affects dispatch inside the sub-sample. For example, it might make sense to shut-down a generator towards the end of a sub-sample if only the sub-sample was considered, but it might not make sense if this generator were required to be dispatched early in the next sub-sample.

CGE Modelling using LP Techniques

CGE modelling using optimisation techniques has been successfully conducted through the GAMS optimisation or the MPSGE GAMS subsystem software (Horridge and Pearson, 2011). GAMS has usually been used to solve nonlinear CGE problems such as those in various versions of GTAP (GTAP in GAMS, Rutherford, 2006)

The method used for GAMS is to set the objective function to zero and specify all the constraints as equalities rather than inequalities (Horridge and Pearson, 2011). This is in contrast to GEMPACK which solves an exactly identified set of linear equations.

As an example, consider the previous simple linear programming example. If the constraints are specified as equalities and the objective function is replaced with zero, the problem becomes:

Maximize: 0

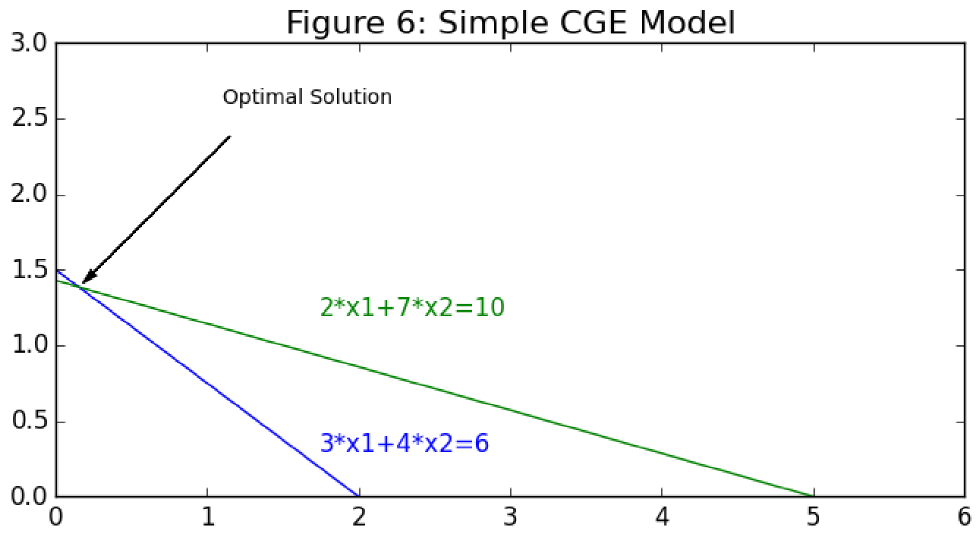
Subject to: x1*3 + x2*4 == 6

x1*2 + x2*7 == 10

x1, x2=> 0[14]

In this case the solution to the problem is exactly the same as the LP optimisation above. However, rather than this solution being the maximisation within a feasible region, in a CGE model is the only possible solution.

[14] The solution for this problem is 0.15384615 for C1 and 1.3846154 for C2.



The ability for Pyomo to solve system of equations that is not exactly identified can lead to difficulty in determining whether a CGE model has a valid closure. If the variable count is 1-2 variables over or under-identified, the model will still solve but will not give the 'correct' result. More than 1-2 variables from identification will lead to trivial solutions such as all price changes being equal to zero, and at some point the model will not solve.

Application 1: A Simple Dynamic CGE

Model description

To illustrate the concept of forward looking expectations in a CGE model, a simple stylised model is created. The model has the following characteristics:

- It has linearised economic relationships;
- It has one good and one industry;
- It has labour and capital inputs, but no intermediate demands;
- It has one single price for the good, which is the model numeraire. This is discussed further below;
- It has an instantaneous short-run labour market closure;
- It has linearised CES production technology for labour and capital inputs;

- It has no margins, taxes or government expenditure;
- It is a closed economy with no exports or imports. Income in each year is spent on either consumption or investment with no net debt created; and
- It has a standard recursive-dynamic modification, specifically modelled on mini-USAGE model (Dixon and Rimmer, 2005)

The model is calibrated so that it is in a long-term steady-state, with investment in each year exactly equal to depreciation in the database. This removes the need to do separate base and base-rerun simulations, as the alternative to the policy simulation results is zero.

Unlike a model with an export/import module with an associated exchange rate, a simple closed-economy model does not specifically require the creation of an exogenous model price numeraire. However, a numeraire is used in this model as it facilitates the model's steady state.

If the single price in this model is specified as an exogenous numeraire, the model's consumption function is not required as the model's commodity market clearing constraint is equivalent to a nominal income constraint. This reduces the number of equations by one, which accommodates the additional exogenous variable.

Dynamic CGE Modelling and Expectations

Almost all dynamic modelling in the CoPs family of CGE modelling has been of the form of recursive-dynamic modelling, where a succession of comparative-static simulations are run with linking equations for stocks of capital and the database for each year is affected by the updated database from the previous year.

Dixon, Pearson, Picton and Rimmer (2003) note that recursive dynamic modelling has advantages over a fully specified dynamic modelling, where all years are solved simultaneously, as: the ability to solve larger and more detailed models with recursive-dynamic modelling; and higher transparency to the reader. With regard to the second point, even a percentage change model becomes non-linear under a simultaneous model, as the usual model coefficients become variables of the model rather than as input parameters.

Dixon et al (2003) note that the Monash Model static expectations formula is given by:

$$EROR(i,t)^1 = EROR\_SE(i,t)^1$$

Dixon and Rimmer (2005) show that in practical terms, the static expectations rate of return calculation is given by:

$$100 * del\_ror = \left[\left(\frac{1}{1+RINT}\right) * \left[\frac{V1CAP(i)}{VCAP(i)}\right] * (p1cap(i) - p2tot(i))\right]$$

Where:

EROR(i,t) is the rate of return used in the model for industry I in year t;

EROR_SE(i,t) is the static rate of return for industry I in year t. It is equal to 100*del_ror(i) in mini-USAGE;

del_ror is the linear change in the rate of return for industry I;

RINT is the real interest rate;

V1CAP(i) are the gross returns to capital for industry i

VCAP(i) is the value of the capital stock in industry I;

p1cap(i) is the price of capital for industry I; and

p2tot(i) is the price of investment goods to industry 1.

The interpretation of the static returns expectations relationship is that the rate of return considered by investors in year t is the rate of return for year t discounted by one year to reflect the fact that returns from investments in year t will not be received until year t+1.

However, almost all capital created in year t+1 will have a life beyond that year. For example, if the same gross return was received in year t+2 as in t and t+1, it would need to be discounted by the real interest rate twice. Additionally, depreciation from year t+2 onwards would mean that the return would be on successively lower capital unless offsetting capital expenditure was made[15].

Dixon et al. (2003) proposed a method to incorporate rational expectations into recursive dynamic models by iteratively ensuring that expected rate of return in each industry in year t is equal to the actual rate of return in year t+1, plus the residual value of the new capital at the end of year t+1.

Dixon et al. (2003) replace static expectations with one-year forward looking expectations, which they define as 'rational expectations'.

$$EROR(j,t)^2 = ROR\_ACT(j,t)^2$$

In this equation ROR_ACT is the actual return plus residual value of the capital in year t+1.

$$ROR\_ACT(j,t) \quad = -1 + \left[\frac{1}{1+INT}\right] * \left[\frac{Q(j,t+1)}{PI(j,t)}\right] + \left[\frac{1-D(j)}{1+INT}\right] * \left[\frac{PI(j,t+1)}{PI(j,t)}\right]$$

Firstly, the model is run under static expectations. Then the rate of return in year t is replaced by ROR_ACT(i,t) (the actual return in year t+1) and the model runs again. If investment in year t changes relative to the initial comparative-static simulation, ROR_ACT(i,t) will also change. As such it is required to loop the model until:

$$EROR(j,t)^N = ROR\_ACT(j,t)^N$$

The Dixon et al. (2003) method assumes that the residual value of new capital at the end of year t+1 is reflects only the change in the price of investment between year t and year t+1. Hence the investment is reversible at the end of period t+1. This might be a reasonable expectation for many or most industries, but it might not be appropriate for a specific class of policy shocks where the change is phased in over time and there is reasonable certainty of the path of the change.

Consider an import tariff change or the imposition of a carbon tax that a government announces is to be phased in over time. For example, a government might think that the social cost of carbon is \$100/t CO2, but that immediate imposition of such a tax would cause

[15] The rate of return flows directly through to capital growth, not investment.

major costs on the economy. It therefore decides to start the tax at $20/t in year one, rising by $5/t per annum until it reaches $100/t in year 16.

Under static expectations, investors will make decisions about their capital stock in year t+1 onwards based on a carbon tax of $20/t, while under the Dixon et al method rational expectations method, they will consider $25/t plus residual value at the end of year t+1.

Both of these methods are likely to understate the impact on investment decisions on (say) a coal-fired power station with an effective life of at least 30 years. Assuming a tax of $20-$25/t in an investment calculation is clearly too low for the life of the asset, while returns from year t+2 onwards are likely to be less than the cost-based residual asset value at the end of year t+1. This could have major implications for the pattern of investment in a CGE model policy shock.

Additionally, economic cost of such action on carbon will depend critically on a race between the investment impact of the increase in the carbon tax and the improvements in the cost and practicality of low-carbon technologies. CGE models are likely to underestimate the economic cost of a phased-in carbon tax if their investment responses lag those likely to occur.

This paper uses a similar method to Dixon et al (2003) to calculate the rate of return on an investment from year t until the terminal year of the analysis. This formulation is designed to be comparable to static expectations, except that it allows for deviations in the present value of returns from year t+1 to the terminal year. There is only one industry in the model, so the formula is:

$$\mathrm{ROR\_ACT(t)} = \left[\left(\frac{1}{1+RINT}\right) * \frac{V1CAP(t)}{VCAP(t)} * \frac{\left[\sum_{u=t+1}^{T}\left(Q(u)\right)^{u}\right]}{(T-(t+1))}\right]$$

The variables in this equation are the same as above. For example, if the static expectations rate of return increases from 5% in year t+1 to 6% in year t+2, EROR_ACT(t) would be 5.5% discounted back from year t+1 to year t.

Neither the Dixon el al. (2003) method nor the method suggested in this paper is true rational expectations in terms of maximising consumption over time. Investment is based on an annual approximation the response of investment to changes in rates of returns. True rational expectations require moving to a single solution nonlinear model.

Additionally, the formula is greatly simplified by the adoption of only a single price in the model which is treated as an exogenous numeraire. This means that the formula does not have to account for changing investment prices.

Finally, the formula does not at this stage include a residual asset value for capital remaining at the end of the terminal year of the simulation. This could be improved in any future iterations of this method. Otherwise, the model could simply be run for a number of years after the period of interest ends, so that the present value of capital created during the period of interest is mostly depreciated.

The process to iterate expected and actual returns is as follows:

1. The model is run with static expectations, where EROR(t) = EROR_SE(t)

2. The actual rate of return for each year t to the terminal year is calculated as above (EROR_ACT(t)^{0}).

3. A vector of coefficients, DIFF, is created. This is the difference between the imposed expected rate of return in the model, versus the actual return once the model is run with investment based on these expectations.

4. A variable, tolerance, is created. This is the modeller accepted maximum error

5. The model is looped using the Python ‘while’ function as follows.

While DIFF(t) > tolerance(t):

Run model with EROR(t) = $EROR\_ACT(t)^1$

Calculate $EROR\_ACT(t)^2$

DIFF = abs($EROR\_ACT(t)^1$ - $EROR\_ACT(t)^2$)

$EROR\_ACT(t)^1$ = $EROR\_ACT(t)^2$

If the absolute value of DIFF(t) is less than the tolerance, then the process ends. If the absolute value of DIFF(t) is greater than or equal to the tolerance, the model replaces $EROR\_ACT(t)^1$ with $EROR\_ACT(t)^2$ and starts the process again.

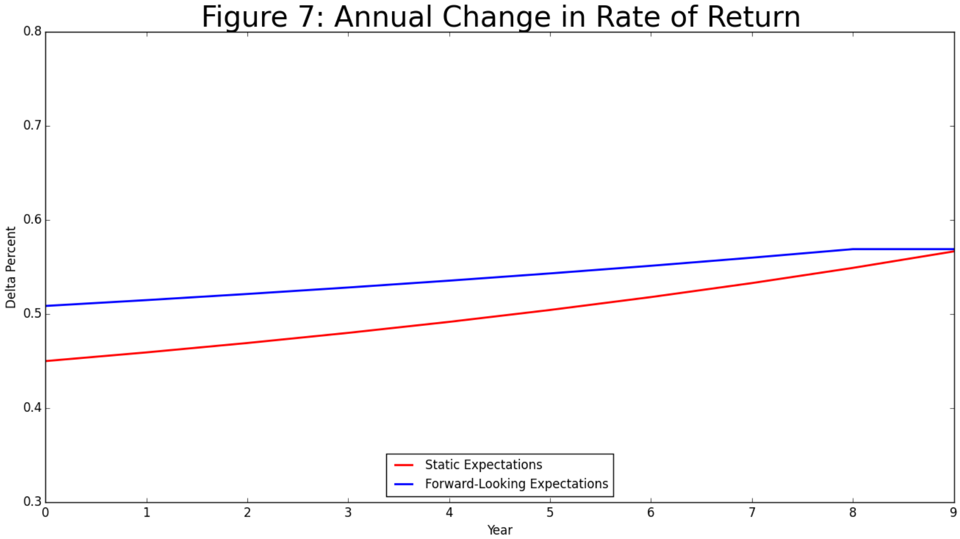
For the small model examined convergence is achieved relatively quickly (less 5 seconds) for a relatively small number of iterations (2-3 loops), negating the need for a partial adjustment mechanism to avoid result cycling (as described in Dixon et al., 2003). This paper does not examine whether this result holds for larger models.

Policy Shock and Results

A 2.5% per annum labour saving technology is applied to the model in the form of a shock to an exogenous variable in the model’s labour demand equations.

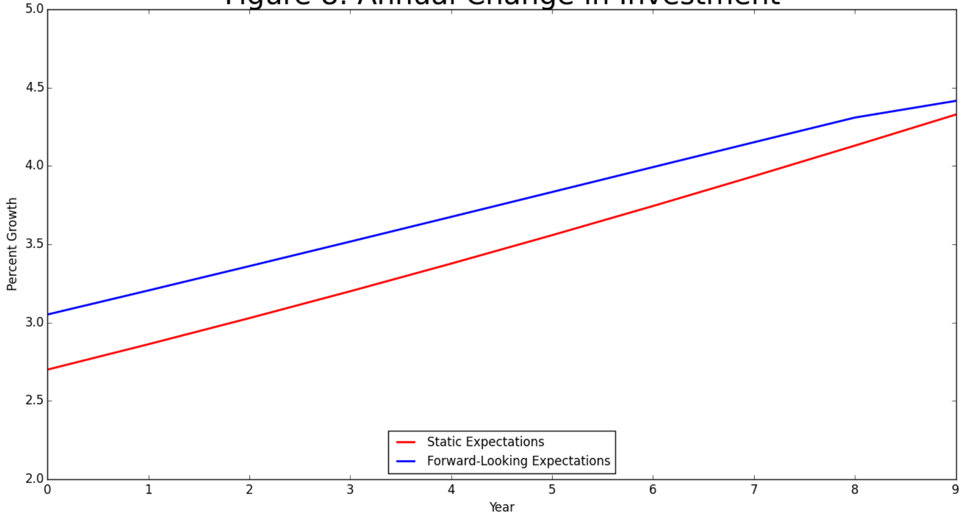
As expected, the expected rate of return in the comparative-static simulation climbs gradually over time as the effect of the annual shocks compounds through the database. The forward-looking returns, however, are much larger at the start of the period as investors foresee the impact of the change on their returns from investment now in future years. This is shown in Figure 7 below.

Figure 7: Annual Change in Rate of Return



Consistent with higher changes in rates of return in the early years of the model run, changes in investment starts much higher in the forward-looking expectation simulation that the comparative-static simulation and stays higher for the entire period. This is partially because investment early in the period causes the capital stock to grow rapidly, requiring greater investment to offset depreciation later. Investment for both simulations is shown in Figure 8 below.

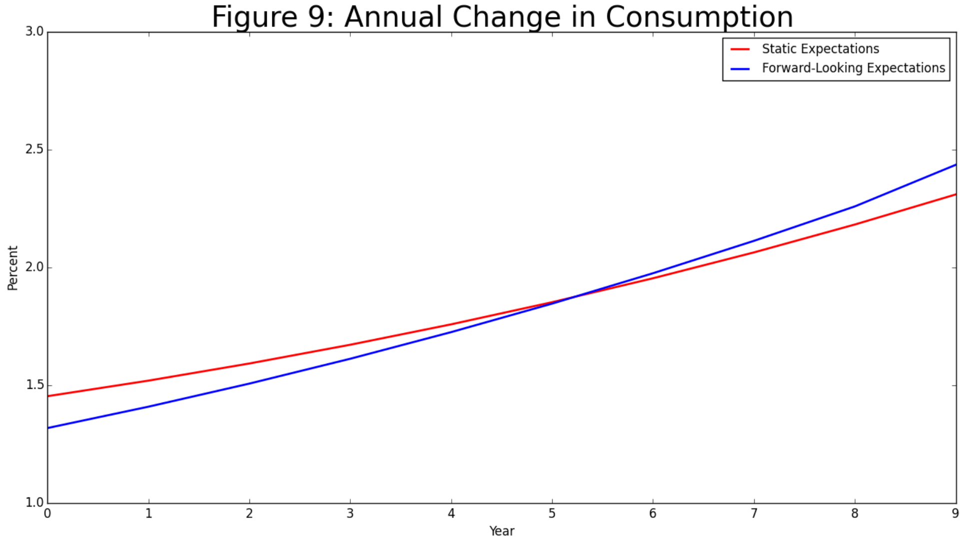
Figure 8: Annual Change in Investment



The capital stock in year 9 rises very slightly under the forward looking expectations scenario, from $1,016.1 million to $1,017.4 million or 0.13% higher. The growth in capital from the steady state capital stock of $1,000 million was 7.94% higher under forward looking expectations than under static expectations.

Figure 9 shows that real consumption in the forward-looking expectations simulation falls dramatically as the economy devotes more resources to investment rather than consumption in a closed system. In the later years of the forward-looking expectations simulation, consumption rises dramatically as the larger capital stock generates incomes and rates of return fall.

Figure 9: Annual Change in Consumption



As noted above, the model does not optimise consumption over time, so the results are dependent upon how well the approximation of the dynamic investment response accurately represents the actual response in the economy. This is not an ideal situation, but solving to optimise consumption would entail solving a complex large non-linear model for all years considered simultaneously.

Application 2: An Integrated CGE Model and a Detailed Electricity Generation Model

Background

The concept of combining the advantages of CGE models and electricity dispatch/market models is not new. For example in 2011 the MMRF CGE model and ROAM Consulting/SKA MMA electricity-sector models[16] were combined for Treasury's modelling of the Carbon Pollution Reduction Scheme (Treasury, 2011).

This process is described in Adams, Parmenter and Verikios (2016), where MMRF was combined with Frontier Economics' WHIRLYGIG model (Frontier Economics, 2009). The modelling process was:

- MMRF Provides information on fuel prices and other electricity-sector costs and on electricity demand;
- Given these assumptions, WHIRLYGIG generates detailed cost estimates for various generation types, which are then fed back into MMRF; and
- Information is passed back and forth between the models in a series of iterations until the retail price of electricity has stabilised in both models.

Adams et al. (2016) do not specify whether WHIRLYGIG is run with electricity demand specified in actual trading interval order (as in Figure 1 above) or as a load duration curve (Figure 2 above).

They note that using electricity market models has the advantage of increasing the technical detail, better simulate changes in generation capacity and increase in the policy detail that can be analysed.

Given the level of detail in each model, it makes sense to utilise the pre-existing detail in established model which has been built up over a many years, rather than start again with an integrated model.

Nevertheless, with improvements in computer processing power and the importance of the policy, this might not be the case indefinitely. This paper undertakes the first steps towards an integrated model, by linking still separate models communicating in a similar way to Adams et al. (2016), but combined in the same software file and with the looping process automated.

[16] And other industry specific models.

The Models

CGE Model

The CGE model used in this simulation is a very simple. It is a linearised comparative-static model set to a short-run closure, with capital in each industry fixed and wages set to an economy-wide fixed level.

It is a three industry, three good model. The industries are electricity generation, resources (which supplies fuel to electricity generation) and services. The database for the model is simulated but the electricity sector is approximately scaled to that in the electricity dispatch model below. All industries are then scaled to the equivalent to the equivalent industries in the Australian Input-Output Table Direct Requirements Coefficients (Australian Bureau of Statistics, 2016).

The model has Leontief technology at the top level for intermediate inputs and primary factors. There is linearised CES substitution between primary factors. The model is a closed economy with no investment in which all outputs are consumed.

The model contains both a nominal income constraint and a commodity market clearing constraint, so has no general price numeraire as discussed above. The only fixed price is the economy-wide wage.

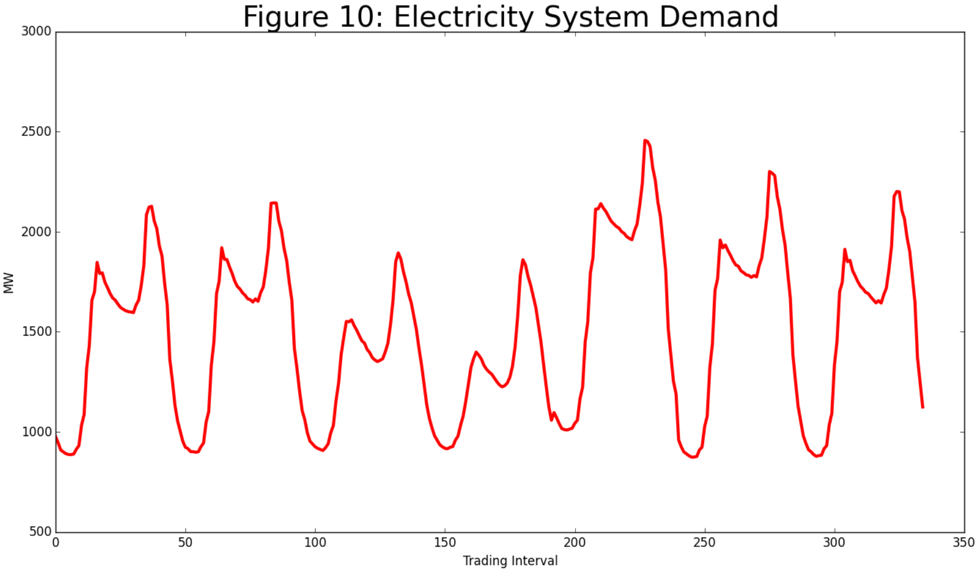
Electricity Markey Model

The electricity dispatch model used in this simulation is a straightforward standard but simplified model of electricity generator dispatch (modelled on a simplified version of Morales-Espańa, Latorre and Ramos, 2013). It is a Mixed-Integer Linear Program (MILP) in levels, which allows for binary variables to impose minimum generation constraints. In this model:

- There are 335 trading intervals, or approximately one week's worth of half hour trading intervals. Cost is minimised for a fixed level of varying demand across the entire 335 intervals;

- Demand varies between 876 MW (or 438 MWh per trading interval) and 2,456 MW per trading interval, and varies by trading interval according to daily fluctuations in winter demand in the Western Australian Wholesale Electricity Market (WEM). This is shown in Figure 10 below;

Figure 10: Electricity System Demand



- It is energy-only dispatch, with no specific allowance for capital costs, as occurs in the National Electricity Market (NEM);

- There is a fixed capacity of generators of 3,150 MW. Generators have constant marginal costs of production between minimum and maximum generation levels;

- A generator can be shut down, but if it is to be dispatched it must be at no less than its minimum generation level. For example, a generator with minimum generation of 100 MW and maximum generation of 200 MW can be dispatched at 0 MW, or anywhere between 100-200 MW;

- The generation sector comprises of :

    - Three baseload generators totalling 1,200 MW, with low marginal cost of production, but high start-up and shut-down costs;

    - Two mid merit plants totally 350 MW, with moderate startup and shutdown costs and higher marginal costs than the baseload units;

    - Six peaking plants, with very low startup and shutdown costs; and

    - One Generator with very flexible production levels, but very high ($1000/MWh) costs, this is to reflect that the system might run out of capacity for some trading intervals. This can be thought of as approximating a situation where generators offer higher than their marginal costs in the NEM during periods of high demand and limited supply/ Thist has not been fed back to the electricity industry in the CGE model as super-normal profits at this stage.

The model is highly simplified to accommodate fast solution times. For example, no generator ramp-rates or minimum up or down-times are contained in the model at this stage. Including generator ramp rates was trialled but this dramatically increased model run times.

Link between Models and the Policy Shock

The integration between the two models assumes that the 335 trading intervals equates to one year in the CGE model. In reality, there are 17,520 trading intervals during a non-leap year.

The electricity model is treated as a cost calculator in the CGE model, rather than as a market in its own right. It effectively calculates the fuel cost (or price of the resource industry commodity) for the CGE electricity industry.

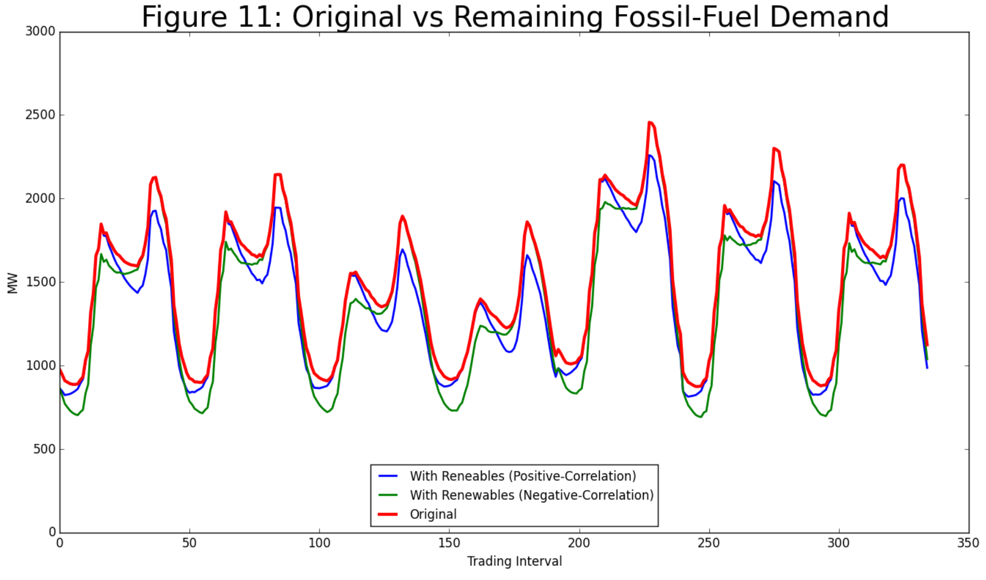
The process is best explained by outlining the policy shock in this paper. The shock is in the form of a 200 MW renewable generator entering the system. It is a short-run simulation, so the model does not consider the investment cost of the new generator. Rather, it just appears in the electricity industry capital stock and is automatically valued at its rental value.

Electricity production for the renewable intermittent generator is simulated with production rising and falling according to a Sine Curve;

- Two scenarios are examined for renewable production. The first has production from the new generator correlating with demand, reducing the system's demand peaks and not affecting offpeak production.
- The second correlates negatively with demand, leaving the system peaks unaffected but the offpeak troughs lower than beforehand; and
- The renewable generator is said to have 'dispatch priority', where it is dispatched whenever the wind is blowing. This is consistent with arrangements in electricity markets around the world[17].

Demand for the initial fossil-fuel industries after the renewable generator has dispatched under both scenarios is shown in Figure 11 below.

Figure 11: Original vs Remaining Fossil-Fuel Demand



[17] Can turn off if price too low.

The renewable generator's marginal cost is zero[18] when it is running, but its production is intermittent depending on the availability of the resource, with no energy storage possible. This might be because the wind does not blow or the sun does not shine all of the time.

The steps to implement this shock into the two models are numerous and outlined below.

- Calculate the original average price of electricity in the electricity industry/commodity by running the electricity market model separately. This is **AP0**.

- Run the CGE model with an increase in capital of 6.3% (200 MW divided by 3,150 MW) in the electricity industry;

- Calculate the change in the quantity of capital in the electricity generation industry and the change in fuel input price (from the resources industry) to the electricity generation industry.

- Loop the two models as follows:

  While C_DIFF>tol_C or Q_DIFF>tol_Q (see below for definitions):

    Calculate remaining demand for traditional generators by subtracting renewable production from the original production. This reduction in traditional electricity demand is then increased by the increase in production from the CGE model in **QELEC_CGE^{1}**.

    The marginal cost for each generator is increased by the increase in the price of resources industry output used by the electricity industry from the initial CGE run. This is **PRES_CGE^{1}**.

    The electricity dispatch model is run with demand and generator costs affected by Z_CGE and A_CGE. The model calculates an average price for electricity for the remaining demand. This is then adjusted for the zero marginal cost energy from the renewable source to find **AP** and **dp**=(AP-AP0)/AP0.

    The value for dp is fed into the CGE model as an exogenous value for the cost of intermediate inputs purchased by the electricity industry and the CGE model is run again. Updated value for PRES_CGE^{2} and QELEC_CGE^{2} are calculated.

    C_DIFF and **Q_DIFF** are calculated as the difference between the original values for PRES_CGE and QELEC_CGE and the updated values.

    Specify tolerances for each of C_DIFF (**tol_C**) and Q_DIFF (**tol_Q**) that are acceptable to the modeller for convergence.

    If the either difference is larger than its respective tolerance, the updated values of Z_CGE and A_CGE are fed back into the electricity model and so on.

- The adjustment process in this loop is specified as a full adjustment process, where the exogenous inputs are imposed at less than the change from the alternative

[18] The vast majority of costs in currently-know renewable technologies are fixed capital costs.

model. For the shock implemented in this paper there is no value recycling where values do not converge, or explosive cycling where the values move away from convergence.

The speed of convergence depends on the power of computer and type of solver involved, but is usually less than 20 seconds for around 3-5 loops for convergence. This compares to Adams et al. (2016), which notes a typical count of three loops before MMRF and WHIRLYGIG results converge.

Results

The results of the from the stand-alone CGE simulation, the CGE model with positively correlated renewable energy and CGE scenario with negatively correlated renewable energy are shown in Table 1. The levels of various electricity prices from each scenario are also shown.

The simulation has added capital for no investment cost, which is an old consultant's trick to curry favour with governments to support their client's projects, so is expected show some aggregate economic benefit. The initial CGE simulation shows that this is the case.

Table 1: CGE/Electricity Market Model Results from the Addition of a 200 MW Renewable Generator (% Change unless otherwise stated)

	Original (no electricity model) CGE Results	CGE Results with Electricity Model Positive Correlation	CGE Results with Electricity Model Negative Correlation
Production of Electricity Industry	1.85	02.41	1.60
Aggregate Prices	-0.027	-3.72	1.50
Aggregate Consumption	1.84	5.43	2.00
Price of Electricity	-0.597	-27.70	8.95
Price of Electricity Fuel Input	4.99	-31.80	17.90
Average Marginal Fuel Cost of Fossil Fuel Generation	na	$56.92/MWh	$102.34/MWh
Average Marginal Fuel Cost of All Generation	na	$54.42/MWh	$97.11/MWh

Note: the original Electricity Price from the initial electricity market simulation (AP0) was $81/MWh[19]

However, when the electricity model is integrated to the CGE model, several things happen:

- In the stand-alone electricity model, electricity prices fall faster than the CGE model predicts in the for the positive correlation scenario, but rise very slightly in the negative correlation scenario;
    - This is because the additional supply during low demand periods in the negative correlation scenario forces base load generators into costly start-ups and shut-downs and to run more expensive mid-merit generators during offpeak periods[20];
- In both scenarios, the rise in economic activity in the intial CGE simulation causes the prices of the resources industry, which supplies the electricity industry's main commodity input, to rise;
- This increase in input prices feeds through to increasing electricity prices, which loops through the model back to increasing fuel input prices;
- The final electricity prices in both scenarios are higher than where the stand alone CGE model and stand-alone electricity model originally predicted, although the price in the positive correlation simulation is much lower than the original or base price; and
- The price of electricity in the negative correlation simulation is almost twice that in the positive correlation scenario.

These results, while very preliminary, show that the shape of the renewable production curve relative to the system demand curve is critical to calculating the economic impact of adding such technologies to an electricity system. The currently topical 'duck curve' in California (California Independent System Operator, 2016) shows the difficulty a system might experience if too much electricity is produced at low demand time.

For a model of this type to be truly useful it needs a theory of investment, capital growth and capital retirement in the electricity industry that integrates into both the CGE and electricity models. Additionally, commercially viable electricity storage may be available in the future, which will need to be incorporated into the electricity model.

Discussion

The examples presented in this paper are specific to the precise models, databases and policy shocks presented. This paper does not examine whether the results are applicable to more general and realistic models and the number areas for development before they could be considered useful models is virtually endless.

Nevertheless, for the specific cases considered, this paper shows that:

---

[19] The prices in the stand-alone electricity market model, with original demand minus renewable supply, were $49.84/MWh and $82.74/MWh.

[20] This does not include additional ancillary services costs (e.g. additional load following costs) that renewable impose on the system.

- Small-scale comparative-static and recursive-dynamic CGE models can be built in the Python Pyomo package;

- Static expectations may lead to a smaller investment shock than is warranted in response to a known but phased-in policy shock;

- Construction of an integrated CGE model and electricity model is possible; and

- The economic impact of new non-storable renewable energy generation entering the energy sector depends critically on how production from this new industry correlates with electricity demand.

Given the development of substantial development of GEMPACK over many years it is unlikely that the first bullet point is little more than a novelty. Additionally, while not certain, modification of the Dixon et al. (2003) algorithm to look forward past year t+1 would probably be able to be accommodated with GEMPACK and its associated dynamic modelling software.

Undertaking an integrated CGE and electricity model would be a substantial undertaking and no claim is made regarding whether this is a worthwhile exercise. However, exact specification of the stationary energy sector is important to policy questions that are likely to become more important over the next decade. It is not clear whether this could be accommodated directly into GEMPACK.

Practical implementation of the concepts examined in this paper would require substantial computing power. However, computing power continues to improve enormously. For example, computers are much more powerful in 2016 than then when Dixon el al. (2003) noted that solving a fully dynamic model was computationally intensive.[21]

Additionally, the pioneering CGE modellers in Australia were not deterred by daunting computing tasks. The original ORANI model was run on the external CSIRO's CYBER 76 computing system, with charges of $50 (in 1977 prices) to run the model (Sutton, 1977). In the early 1980s ORANI was still solved on the CSIRO mainframe computer where modellers would submit data cards and wait overnight for the model to run (Horridge, Meeraus, Pearson and Rutherford, 2013). They did so, presumably, because they thought the results were vital enough to wait for. The question is still whether the results are worth the wait.

[21] The difficulty of interpreting non-linear equations still remains.

References

Adams, P.D., B.R. Parmenter and G. Verikios (2016), An Emissions Trading Scheme for Australia: National and Regional Impacts, Centre of Policy Studies Working Paper G-243 Melbourne.

Australian Bureau of Statistics (2016), Australian Input-Output Tables 2013-14, Canberra, Table 9, Direct Requirement Coefficients (Indirect Allocation of Imports).

California Independent System Operator (2016), *What the Duck Curve Tells Us About Managing a Green Grid, Fast Facts*, Folsom, https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf .

Chan, J. (2014), *Learn Python in One Day and Learn it Well*, LCF Publishing, Kindle Edition.

Dixon, P.B., K.R. Pearson, M.R. Picton and M.T. Rimmer (2003), Rational Expectations for Large Models: a Practical Algorithm and a Policy Application, Centre of Policy Studies Working Paper ip-81, Melbourne.

Dixon, P.B and M.T Rimmer (2005), *Mini-USAGE: reducing Barriers to Entry in CGE Modelling*, Paper prepared for the 8th Annual Conference on Global Economic Analysis, Lűbeck, Germany, June 9-11 2005.

Frontier Economics (2009), Modelling *Methodology and Assumptions: A Report for IPART*, Melbourne.

Hart, W.E., C. Laird, J. Watson and D.L. Woodruff (2012), *Pyomo - Optimisation Modelling in Python*, Springer, New York, Kindle Edition.

Horridge, M. (2014), *ORANI_G: A Generic Single-Country Computable General Equilibrium Model*, Centre of Policy Studies and Impact Project, Victoria University, Australia.

Horridge, M. and K.R. Pearson (2011), *Solution Software for CGE Modelling*, Centre of Policy Studies Working Paper G-214, Melbourne.

Horridge, M and Pearson, K and Meeraus, A and Rutherford, T (2013), “Solution Software for Computable General Equilibrium Modeling”. In: *Handbook of Computable General Equilibrium Modelling*. Dixon, PB and Jorgenson, D, eds. Elsevier, Amsterdam, 1331 - 1381. ISBN 9780444595560

Independent Market Operator (2012), *Wholesale Electricity Market Design Summary*, http://www.aemo.com.au/Electricity/-/media/F12B82DEB2484DD0848FD5C277DB5CA8.ashx , accessed 7 August 2016.

Morales-España, G., J.M. Latorre and A. Ramos, (2013), “Tight and Compact MILP Formulation of Start-Up and Shut-Down Ramping in Unit Commitment”, *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 1288-1296, May 2013.

Peter, M.W., M. Horridge, G.A.Meagher, F. Naqvi and B.R. Parmenter (1996), *The Theoretical Structure of MONASH-MRF*, Centre of Policy Studies Working Paper Number OP-85, Melbourne.

Rutherford, T.F. (2006), *GTAP6 in GAMS*, http://www.mpsge.org/gtap6/ .

Sutton, J. (1977), Computing Manual for the ORANI Model - First Edition, Centre of Policy Studies Computing Paper C1-01, Melbourne.

Treasury (2011), *Strong Growth, Low Pollution: Modelling a Carbon Price*, Commonwealth of Australia, Canberra, http://carbonpricemodelling.treasury.gov.au/content/report.asp .

CoPS

Combining CGE and DSGE through GEMPACK

by
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Presentation by Peter B. Dixon
National CGE Conference
Canberra
August 8, 2016

1

CoPS

CGE and DSGE: strengths and weaknesses

CGE strength	- structural detail
CGE weakness	- rudimentary macro, backward-looking expectations, decision making under certainty
DSGE strength	- agents at year t form forward-looking expectations taking account of the current situation and their estimates of probability distributions for future variables
DSGE weakness	- rudimentary structural detail
Aim:	Create an integrated CGE/DSGE model for Australia to be run in GEMPACK Make GEMPACK a user friendly platform for DSGE modelling

2

Example of a DSGE model

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The household sector makes decisions at time t with a view

to maximizing $E_t\left[\sum_{\tau=t}^{\infty}\frac{\beta^{\tau-t}C_\tau^{1-\gamma}}{1-\gamma}\right]$ **(B1)**

subject to $K_{\tau+1}-K_\tau(1-\delta)-K_\tau^\alpha A_\tau+C_\tau=0$, τ= t, t+1, …, ∞ **(B2)**

where

$A_{\tau+1}=e^{\sigma\varepsilon_{\tau+1}}*A_0$ τ= t, t+1, …, ∞ **(B3)**

K_t is pre-determined and known at time t, A_t is also known but ε_τ for τ>t is not known. Consequently the household must make decisions at time t without knowing future values of A.

The first-order condition for the consumer maximization problem is

$E_t\left[\beta C_{t+1}^{-\gamma}\left((1-\delta)+\alpha K_{t+1}^{\alpha-1}A_{t+1}\right)-C_t^{-\gamma}\right]=0$, **(B4)**

3

Format of a DSGE model

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$E_t\left[F\left(Y_{t+1},Y_t,X_{t+1},X_t\right)\right]=0$ **(1)**

$X_{t+1}=e^{\sigma Z\varepsilon_{t+1}}*\hbar\left(X_t,Y_t\right)$ **(2)**

E_t denotes expectation held at time t

X_t vector of n_x pre-determined and exogenous variables (e.g. capital and technology)
Y_t vector of n_y endogenous variables (e.g. consumption)
F vector of n_y functions
$\hbar$ vector of n_x functions

At time t, X_t, ε_t and σ are known. To solve the model we need a "Policy rule" of the form

$Y_t=G\left(X_t,\sigma\right)$

4

Finding the policy rule. Imagine that we know it. Then use it to eliminate Y_t, Y_{t+1} and X_{t+1}

CoPS

Policy rule: $\boxed{Y_t = G\left(X_t, \sigma\right)}$

Starting at (2) we have

$$X_{t+1} = e^{\sigma Z \varepsilon_{t+1}} * \hbar\left(X_t, Y_t\right)$$

$$X_{t+1} = e^{\sigma Z \varepsilon_{t+1}} * \hbar\left(X_t, G(X_t, \sigma)\right)$$

$$\boxed{X_{t+1} = e^{\sigma Z \varepsilon_{t+1}} * H(X_t, \sigma) \qquad (3)}$$

where $H(X_t, \sigma) = \hbar\left(X_t, G(X_t, \sigma)\right)$ **(4)**

Also note that $Y_{t+1} = G\left(X_{t+1}, \sigma\right)$ **(5)**

So that

$$\boxed{Y_{t+1} = G\left(e^{\sigma Z \varepsilon_{t+1}} * H(X_t, \sigma), \sigma\right) \qquad (6)}$$

5

Now substitute from the policy rule and (3) into (1) to eliminate Y_t, Y_{t+1} & X_{t+1}

CoPS

$$E_t\left[F\left(\boxed{Y_{t+1}} ; \boxed{Y_t} ; \boxed{X_{t+1}} ; X_t\right)\right] = 0$$

$$E_t\left[F\left(G(e^{\sigma Z \varepsilon_{t+1}} * H\left(X_t, \sigma\right), \sigma) ; G(X_t, \sigma) ; e^{\sigma Z \varepsilon_{t+1}} * H\left(X_t, \sigma\right) ; X_t\right)\right] = 0$$

Shorthand notation: $J(X_t, \sigma) = 0$

6

Since $J(X_t,\sigma) = 0$ for all values of X_t and σ, the derivatives of any order of J with respect to X_t and σ must be zero

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This allows us to evaluate derivatives of the policy function G without knowing the levels form of G.

For GEMPACK users this is a familiar idea. We have a model of the form

$$M(V_1, V_2) = 0$$

where V_1 and V_2 are vectors of endogenous and exogenous variables.

We would like to express V_1 as a function of V_2: $V_1 = N(V_2)$

We know the form of M but it is impossible to find an explicit form of N. However, we can evaluate derivatives of the unknown function N by totally differentiating M, leading to the familiar

$$v_1 = -A_1^{-1} * A_2 * v_2$$

where A_1 and A_2 are matrices of first-order derivatives of M evaluated at an initial solution, $-A_1^{-1} * A_2$ is the matrix of first order derivatives (or elasticitites) of N with respect to V_2 and $v_1$and v_2 are percentage deviations of V_1 and V_2 away from the initial solution

7

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$$\begin{array}{cccc} Y_{t+1} & Y_t & X_{t+1} & X_t \end{array}$$

$$J^i(X_t,\sigma) = E_t\left[F^i\left(G(e^{\sigma Z\varepsilon_{t+1}} * H\left(X_t,\sigma\right),\sigma);G(X_t,\sigma);e^{\sigma Z\varepsilon_{t+1}} * H\left(X_t,\sigma\right);X_t\right)\right] = 0$$

$$i = 1, 2, ..., n_y$$

$$\left(J_X^i\right)_m = 0, \quad m = 1, 2, \ldots, n_x \qquad (7)$$

$$\left(J_X^i\right)_m \equiv E\left[\sum_{\alpha,\beta}\left(F_{y1}^i\right)_\alpha\left(G_{x1}^\alpha\right)_\beta * e^{\sigma Z^\beta \varepsilon} * \left(H_x^\beta\right)_m + \quad \ldots \quad + \left(F_x^i\right)_m\right] = 0$$

8

Derivatives of J are zero

CoPS

$$\left(\mathbf{J}_X^i\right)_m \equiv \mathbf{E}\left[\begin{array}{l}\sum_{\alpha,\beta}\left(\mathbf{F}_{y1}^i\right)_\alpha\left(\mathbf{G}_{x1}^\alpha\right)_\beta * \mathbf{e}^{\sigma Z^\beta \varepsilon} * \left(\mathbf{H}_x^\beta\right)_m \\ \qquad + \sum_\alpha\left(\mathbf{F}_y^i\right)_\alpha\left(\mathbf{G}_x^\alpha\right)_m + \sum_\alpha\left(\mathbf{F}_{x1}^i\right)_\alpha * \mathbf{e}^{\sigma Z^\beta \varepsilon} * \left(\mathbf{H}_x^\alpha\right)_m + \left(\mathbf{F}_x^i\right)_m\end{array}\right] = 0 \tag{8}$$

$$\mathbf{J}_\sigma^i \equiv \mathbf{E}\left[\begin{array}{l}\sum_{\alpha,\beta}\left(\mathbf{F}_{y1}^i\right)_\alpha\left(\mathbf{G}_{x1}^\alpha\right)_\beta\left\{\mathbf{e}^{\sigma Z^\alpha \varepsilon}\left(\mathbf{H}_\sigma^\beta + \mathbf{Z}^\beta \varepsilon \mathbf{H}^\beta\right)\right\} \\ \qquad + \sum_\alpha\left(\mathbf{F}_{y1}^i\right)_\alpha \mathbf{G}_\sigma^\alpha + \sum_\alpha\left(\mathbf{F}_y^i\right)_\alpha \mathbf{G}_\sigma^\alpha + \sum_\alpha\left(\mathbf{F}_{x1}^i\right)_\alpha \mathbf{e}^{\sigma Z^\alpha \varepsilon}\left(\mathbf{H}_\sigma^\alpha + \mathbf{Z}^\alpha \varepsilon \mathbf{H}^\alpha\right)\end{array}\right] = 0 \tag{9}$$

$$\left(\mathbf{H}_x^\alpha\right)_k = \left(\hbar_x^\alpha\right)_k + \sum_\beta\left(\hbar_y^\alpha\right)_\beta\left(\mathbf{G}_x^\beta\right)_k \tag{10}$$

$$\mathbf{H}_\sigma^\alpha = \sum_\beta\left(\hbar_y^\alpha\right)_\beta \mathbf{G}_\sigma^\beta \tag{11}$$

9

Set σ at zero and X,Y at steady state: reveals $\bar{\mathbf{G}}_x$ and $\bar{\mathbf{G}}_\sigma$

CoPS

$$\begin{array}{l}\sum_{\alpha,\beta}\left(\bar{\mathbf{F}}_{y1}^i\right)_\alpha\left(\bar{\mathbf{G}}_x^\alpha\right)_\beta\left[\left(\bar{\hbar}_x^\beta\right)_m + \sum_\gamma\left(\bar{\hbar}_y^\beta\right)_\gamma\left(\bar{\mathbf{G}}_x^\gamma\right)_m\right] + \sum_\alpha\left(\bar{\mathbf{F}}_y^i\right)_\alpha\left(\bar{\mathbf{G}}_x^\alpha\right)_m \\ \qquad + \sum_\alpha\left(\bar{\mathbf{F}}_{x1}^i\right)_\alpha\left[\left(\bar{\hbar}_x^\alpha\right)_m + \sum_\beta\left(\bar{\hbar}_y^\alpha\right)_\beta\left(\bar{\mathbf{G}}_x^\beta\right)_m\right] + \left(\bar{\mathbf{F}}_x^i\right)_m = 0 \text{ for all i and m}\end{array} \tag{18}$$

$$\begin{array}{l}\sum_{\alpha,\beta}\left(\bar{\mathbf{F}}_{y1}^i\right)_\alpha\left(\bar{\mathbf{G}}_x^\alpha\right)_\beta \sum_\gamma\left(\bar{\hbar}_y^\beta\right)_\gamma \bar{\mathbf{G}}_\sigma^\gamma + \sum_\alpha\left(\bar{\mathbf{F}}_{y1}^i\right)_\alpha \bar{\mathbf{G}}_\sigma^\alpha + \sum_\alpha\left(\bar{\mathbf{F}}_y^i\right)_\alpha \bar{\mathbf{G}}_\sigma^\alpha \\ \qquad + \sum_\alpha\left(\bar{\mathbf{F}}_{x1}^i\right)_\alpha \sum_\beta\left(\bar{\hbar}_y^\alpha\right)_\beta \bar{\mathbf{G}}_\sigma^\beta = 0 \quad \text{for all i.}\end{array} \tag{19}$$

10

How to solve for $\bar{G}_x$ in GEMPACK

CoPS

Obtain steady-state solution, $\bar{X}, \bar{Y}$

Evaluate derivatives of F and $\hbar$ at the steady-state solution. GEMPACK can do this for us.

Write linearized form of (18): $\left(d\bar{G}_x\right) = d\_slack$

Conduct simulation in which d_slack moves exogenously to zero.

```
Equation E_d_slack
(All,i,NY)(All,m,NX) d_slack(i,m) = - SLACK_B(i,m)*del_unity;

Equation E_d_g_x
(All,i,NY)(All,m,NX) d_SLACK(i,m) =
Sum(j,NY, Sum(k,NX, F_Y1(i,j)*[H_X(k,m)*d_G_X(j,k) +Sum(l,NY, H_Y(k,l)*G_X(j,k)*d_G_X(l,m))
        +Sum(l,NY, H_Y(k,l)*G_X(l,m)*d_G_X(j,k))] ))

+ Sum(j,NY, F_Y(i,j)*d_G_X(j,m))
+ Sum(j,NX, F_X1(i,j)*[  +Sum(l,NY, H_Y(j,l)*d_G_X(l,m))])
;
```

11

How to solve for $\bar{G}_{xx}$ and $\bar{G}_{\sigma\sigma}$

CoPS

Derive $J_{xx}, J_{x\sigma}, J_{\sigma\sigma}$

Set σ at zero and X and Y at steady-state values.

This gives a linear system in which the variables are $\bar{G}_{xx}$ and $\bar{G}_{\sigma\sigma}$

and the coefficients are first-order derivatives of F and G
and second order derivatives of F all evaluated at $\sigma = 0$,
and X, Y at their steady-state values

The first-order derivatives have already been evaluated.
The second-order derivatives of F can be found from the update statements.

12

Introducing the policy rule to GEMPACK

CoPS

Policy rule: $\mathbf{Y_t = G(X_t)}$

Second-order Taylor approximation

$$\mathbf{Y_t = \bar{Y} + \left(\bar{G}_x\right) * (X_t - \bar{X}) + \frac{1}{2} * (X_t - \bar{X})' * \bar{G}_{xx} * (X_t - \bar{X}) + \frac{1}{2} * \sigma * \bar{G}_{\sigma\sigma} * \sigma} \quad \mathbf{(22)}$$

Representation in GEMPACK

$$\mathbf{d\_Y = \left(\bar{G}_x\right) * (d\_X) + (X - \bar{X})' * \bar{G}_{xx} * (d\_X) + \sigma * \bar{G}_{\sigma\sigma} * d\_\sigma} \quad \mathbf{(23)}$$

13

Solving a 1-sector DSGE model in GEMPACK

CoPS

$$\mathbf{K_{\tau+1} - K_\tau(1-\delta) - K_\tau^\alpha A_\tau + C_\tau = 0, \quad \tau = t, t+1, \ldots, \infty \quad (B2)}$$

$$\mathbf{A_{\tau+1} = e^{\sigma\varepsilon_{\tau+1}} * A_0 \quad \tau = t, t+1, \ldots, \infty \quad (B3)}$$

$$\mathbf{E_\tau\left[\beta C_{\tau+1}^{-\gamma}\left((1-\delta) + \alpha K_{\tau+1}^{\alpha-1} A_{\tau+1}\right) - C_\tau^{-\gamma}\right] = 0, \quad \tau = t, t+1, \ldots, \infty \quad (B4)}$$

Parameter values: δ **= 0.08;** γ **= 0.999;** β **= 0.96;** α **= 0.36;** A_0 **=1**

Set σ **= 0, find** $\left(\bar{C}, \bar{A}, \bar{K}\right)$

$$\bar{A} = A_0 = 1$$

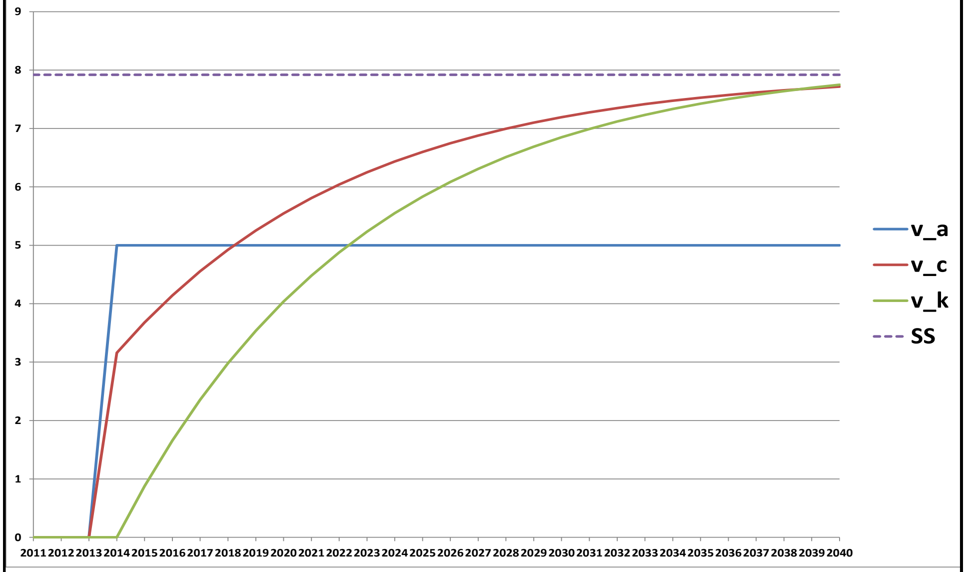
$$\beta\bar{C}^{-\gamma}\left((1-\delta) + \alpha\bar{K}^{\alpha-1}\bar{A}\right) - \bar{C}^{-\gamma} = 0 \text{ implies } \bar{K} = 5.447$$

$$\bar{K} - \bar{K}(1-\delta) - \bar{K}^\alpha\bar{A} + \bar{C} = 0 \text{ implies } \bar{C} = 1.405$$

14

Unanticipated 5% improvement in technology in 2014, with σ = 0

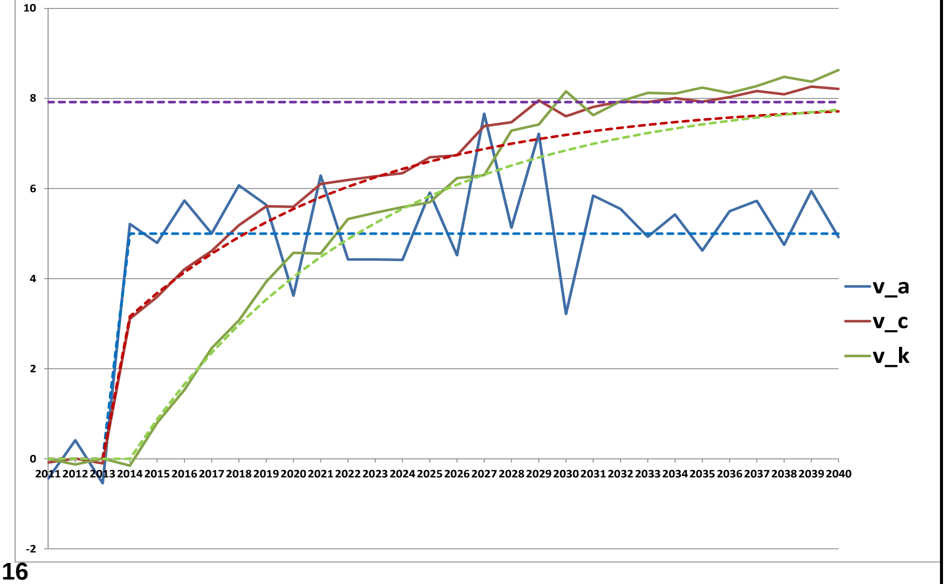
CoPS



15

Unanticipated 5% improvement in technology in 2014, with σ = 0.01

CoPS



16

CoPS

Immigration reform scenarios for U.S. agriculture

by

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Presentation by Maureen T. Rimmer
National CGE Conference
Canberra
August 8, 2016

1

Immigration policy and Agriculture

CoPS

6 to 8 million people work illegally in the U.S.

Components of recent policy proposals (e.g. H.R. 1773, S. 744 and H.R. 2278) include

(1) Tighter border security
(2) Tighter control of employers
(3) Guest worker programs for agriculture
(4) Legalization of illegals currently working in U.S. agriculture with provisos that legalized workers stay in agriculture for specified periods of time

Why special treatment of agriculture?

Half of hired workers in agriculture are illegal, implying that about 20% of labour input to agriculture is illegal, compared with about 2.5% for the U.S. as a whole.
If (1) and (2) are implemented, then it is thought that (3) and (4) may be necessary to maintain the supply of labour to agriculture, preventing a sharp increase in wage costs to U.S. farmers and an associated decline in their incomes.

2

Previous work on immigration

CoPS

Our previous studies for the U.S. Departments of Homeland Security, Commerce and Agriculture and the Cato Institute have dealt with general policies of tighter border security, control of employers, legalization and guest worker programs. See:

Dixon, P.B. and Maureen T. Rimmer (2009), "Restriction or Legalization? Measuring the economic benefits of immigration reform", Trade Policy Analysis paper no. 40, Cato Institute, Washington DC, August, pp. 22.

Dixon, P.B. and Maureen T. Rimmer (2010), "U.S. imports of low-skilled labor: restrict or liberalize?", chapter 5, pp. 103-51 in John Gilbert (editor) *New Developments in Computable General Equilibrium Analysis of Trade Policy*, Volume 7 of H. Beladi and K. Choi (series editors) *Frontiers of Economics and Globalization*, Emerald Publishing, UK.

Dixon, P.B., Martin Johnson and Maureen T. Rimmer (2011), "Economy-wide effects of reducing illegal immigrants in U.S. employment" *Contemporary Economic Policy*, Vol. 29(1), January, pp. 14-30.

Zahniser, S. T. Hertz, P.B. Dixon and M.T. Rimmer (2012), "Immigration policy and its possible effects on U.S. agriculture and the market for hired farm labor: a simulation analysis", *American Journal of Agricultural Economics*, Vol. 94(2), January, pp. 477-82.

Dixon, P.B., M.T. Rimmer and B.W. Roberts (2014), "Restricting employment of low-paid immigrants: a general equilibrium assessment of the social welfare implications for legal U.S. wage-earners" C*ontemporary Economic Policy*, Vol. 32(3), pp. 639-52.

Current work using the USAGE model

CoPS

This study was undertaken for the U.S. Department of Agriculture and is concerned specifically with the effects on agriculture and the rest of the economy of guest-worker programs to supplement the supply of low-skilled workers to agriculture and legalization programs designed to retain currently illegal workers in agriculture.

In our analysis we use a large-scale CGE model, USAGE, which includes:

- **69 industries, 16 in agriculture**
- **200 labour force categories, 50 occupations by 2 birth places and 2 legal statuses**
- **Dynamic relationships governing capital accumulation, domestic and foreign debt accumulation, and changes in the occupational composition of employment through the creation of vacancies and the occupational choices of labour-market participants, particularly new entrants**

Exposition via a Minimal model

CoPS

In this presentation we convey the essential features of USAGE and its results on immigration policies for agriculture by building and applying a model that embraces the minimal ingredients necessary to explain the effects of supplementing supply of labour to agriculture via foreign workers.

The Minimal model has:

- 2 sectors (agriculture/non-agriculture)
- labour supply consisting of: a fixed number of incumbent hired workers who can move between agriculture and non-agriculture in response to changes in relative wage rates; a fixed number of farmers who work in agriculture only; and an exogenous quantity of foreign labour assigned to agriculture
- measures of welfare for farmers and more generally for incumbents

For expositional purposes, an advantage of the Minimal model is that the variables, coefficients, parameters and equations can be listed in relatively small tables.

We set up the database for the Minimal model so that the cost-structure and relative size of the agricultural sector is realistic

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Database for Minimal Model: Values of flows in base year

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	Industry 1 (ag)	Industry 2 (non-ag)	Consumption
Commodity 1 (ag)	0	0	2.00
Commodity 2 (non-ag)	0	0	98.00
Competitive farmer labour	0.53	0	
Hired incumbent labour	0.28	93.10	
Foreign labour	0.19	0	
Fixed factor	1.00	4.90	
Cost (output)	2.00	98.00	

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Percentage effects of a 50% increase in the supply of foreign labour to agriculture: results from the Minimal model

CoPS

	Simulation:	1	2	3	4
	Elasticity of substitution in consumption, σ_c	1.000	1.000	*1.1725*	1.000
	Farmer competitive labour share	1	1	1	*0.81*
	Initial Ag/NonAg wage ratio	0.5	*1*	0.5	0.5
	Results:				
1	GDP	0.137	0.093	0.136	0.140
2	Aggregate employment, wagebill weights	0.146	0.099	0.145	0.149
3	Aggregate employment, persons	0.200	0.101	0.200	0.200
4	Employment, Agric	*5.078*	*5.058*	*5.169*	*5.274*
5	Employment, Non-Agric	*0.095*	*0.048*	*0.093*	*0.102*
6	Incumbent welfare	0.066	0.021	0.064	0.071
7	Direct effect	*0.020*	*0.020*	*0.019*	*0.021*
8	Occupation-mix effect	*0.044*	*0.000*	*0.043*	*0.048*
9	Farm income	-0.336	-0.379	0.000	0.087
10	Agricultural output	2.462	2.452	2.505	2.291
11	Agricultural prices	-2.269	-2.304	-1.975	-2.103
12	Real wages, Agric	-8.248	-8.258	-8.075	-8.901
13	Real wages, NonAgric	0.035	0.042	0.029	0.031

7

Percentage effects of a 50% increase in the supply of foreign labour to agriculture: results from the Minimal model

CoPS

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8

Percentage effects of a 50% increase in the supply of foreign labour to agriculture: column 2, no initial wage difference

CoPS

	Simulation:	1	2	3	4
	Elasticity of substitution in consumption, σ_c	1.000	1.000	*1.1725*	1.000
	Farmer competitive labour share	1	1	1	*0.81*
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Farm income

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Farm income is:

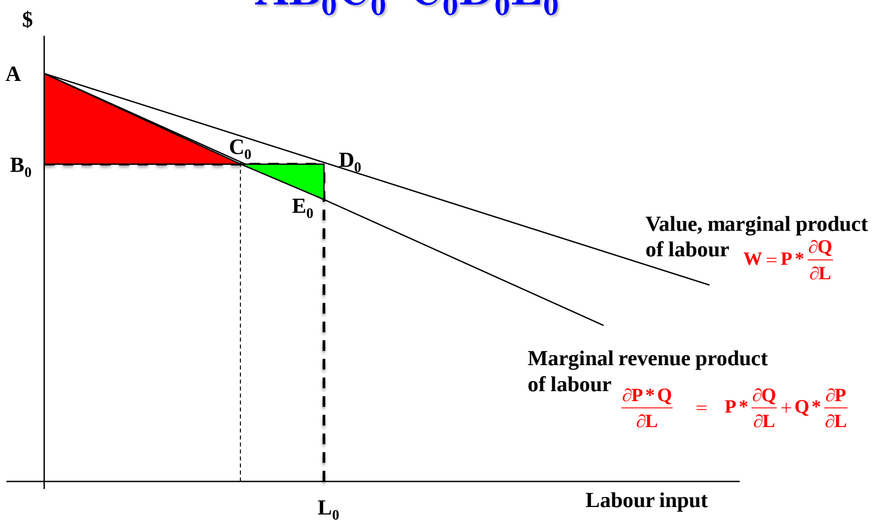
farm profits (returns to land and capital)

returns to farmer labour

10

Farm Profits: $AB_0C_0 - C_0D_0E_0$

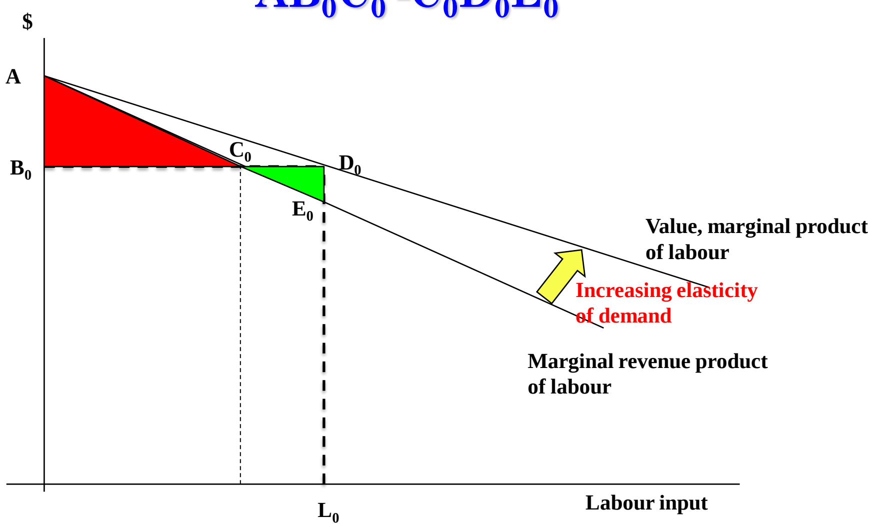
CoPS



11

Farm Profits: $AB_0C_0 - C_0D_0E_0$

CoPS



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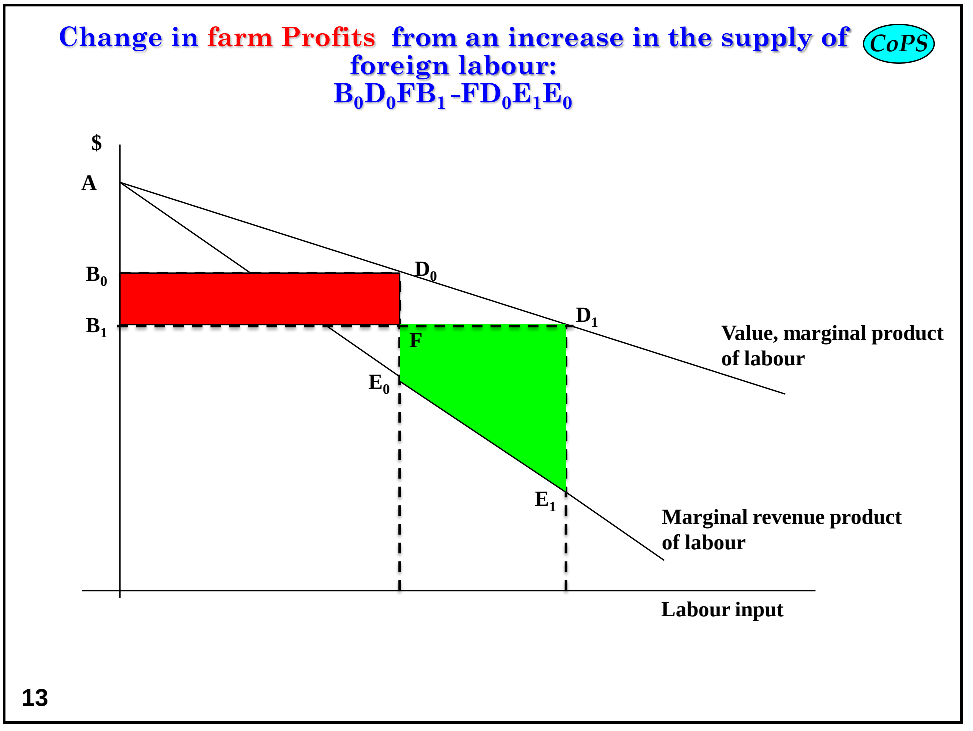
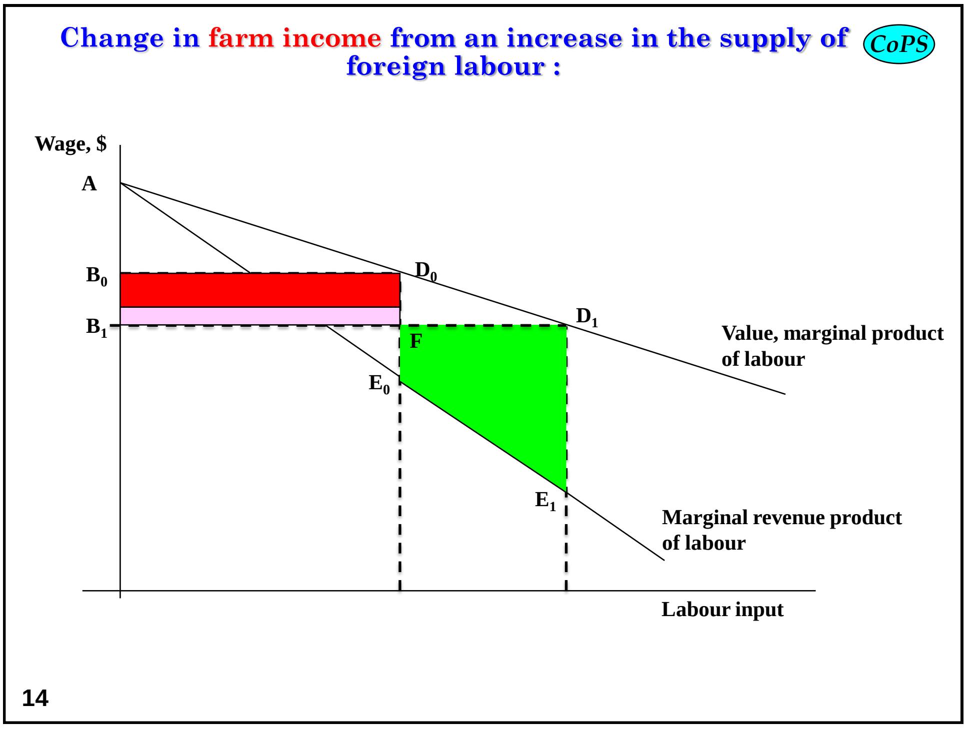

Change in farm Profits from an increase in the supply of foreign labour:
$B_0D_0FB_1 - FD_0E_1E_0$
CoPS
$
A
B_0
D_0
B_1
D_1
F
E_0
E_1
Value, marginal product of labour
Marginal revenue product of labour
Labour input
13


Change in farm income from an increase in the supply of foreign labour :
CoPS
Wage, $
A
B_0
D_0
B_1
D_1
F
E_0
E_1
Value, marginal product of labour
Marginal revenue product of labour
Labour input
14

Percentage effects of a 50% increase in the supply of foreign labour to agriculture: column 3, higher elasticity of demand for Agricultural products

CoPS

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Percentage effects of a 50% increase in the supply of foreign labour to agriculture: column 4, lower share of farmer labour competes with hired labour

CoPS

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Concluding Remarks

CoPS

Policy makers want realistic detail. Consequently we build large detailed models.

These models often reveal policy-relevant insights that we wouldn't have thought of *a priori*, e.g. the occupation-mix effect and the potential negative relationship between immigration policies designed to support agriculture and farm income.

Academics display little patience in understanding detailed models and are sceptical of their results.

How can we bring big model insights to the attention of academics?

We are trying to do so through construction of Minimal easily absorbed models.

We should emphasize however that the big model comes first. Results from the big model suggest what must be encapsulated in the Minimal model.

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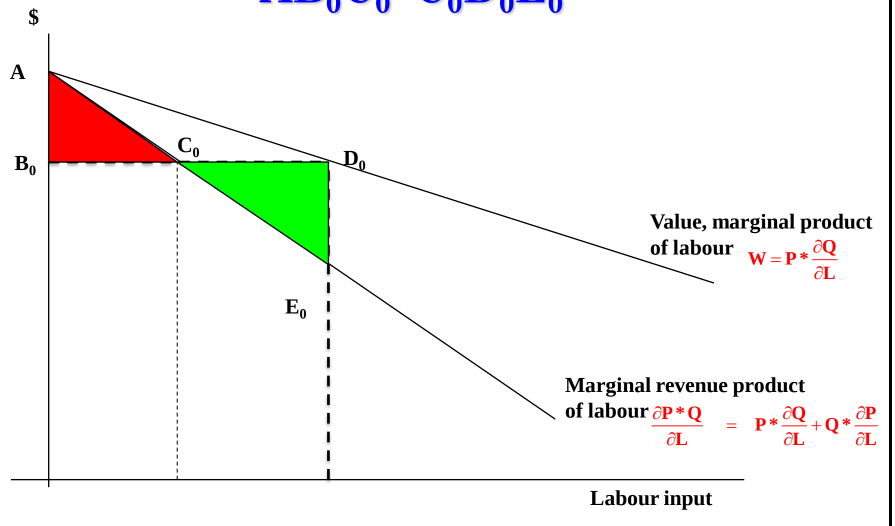
Farm Profits: AB_0C_0 -$C_0D_0E_0$

CoPS



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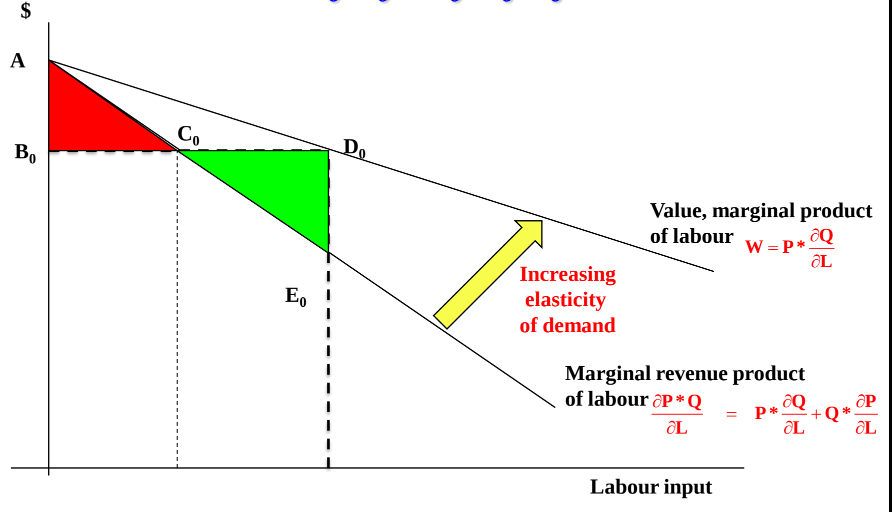
Farm Profits: $AB_0C_0 - C_0D_0E_0$

CoPS



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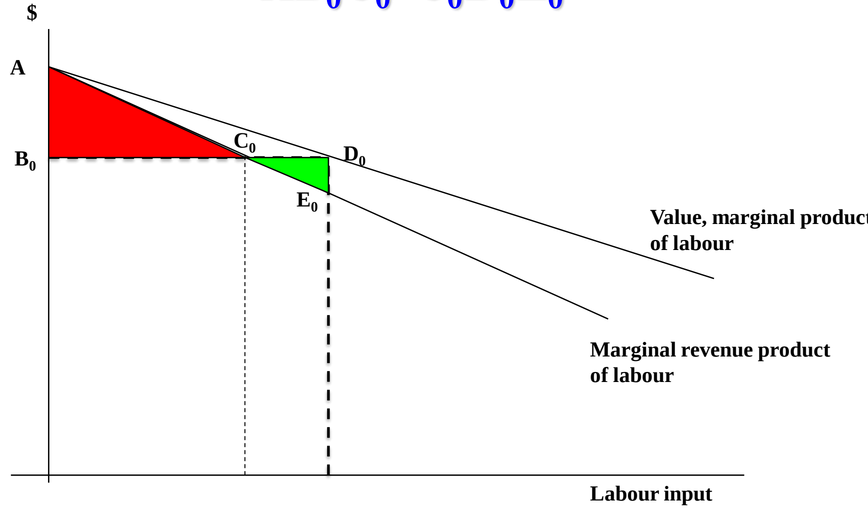
Farm Profits: $AB_0C_0 - C_0D_0E_0$

CoPS



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Two controversial effects: occupational mix and reduction in farm income

CoPS

Occupation-mix effect:

Doesn't mean that a significant number of incumbent individuals switch occupations. In USAGE the change in the composition of incumbent employment takes place mainly via changes in the composition of vacancies and the consequent effects on the occupational choice of new entrants.

Depends on wage difference between agriculture and non-agriculture.

In column 2 we assume that there is no initial wage difference

The occupation-mix effect disappears, causing comparable reductions in incumbent welfare and GDP. All other effects are minor and the reduction in farm income remains in place.

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Two controversial effects: occupational mix and reduction in farm income

CoPS

Reduction in farm income:

Farm income is returns to farmer labour and returns to land and capital (profits). Cheaper hired labour may increase returns to land and capital but reduces returns to farmer labour. The farmer labour effect can dominate.

Farm income result depends on elasticity of demand for agricultural products, column 3 (low elasticity of demand causes the industry to hire more labour than is profit maximizing for the industry even though each farmer is profit maximizing)

and on

**degree to which farmer labour competes with hired labour, column 4
(The wage of the part of farmer labour that is substitutable with land and directly competitive with hired labour decreases with the wage of hired labour.)
Makes little difference to anything except farm income.**

Conclusion: Farm income could move positively or negatively with an increase in supply of foreign labour – either way the effects are likely to be quite small.

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Contractions in Chinese fertility and saving: Long run domestic and global implications

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Australian Centre on China in the World, ANU

Rod Tyers
UWA Business School and ANU

Yixiao Zhou
School of Economics and Finance
Curtin University

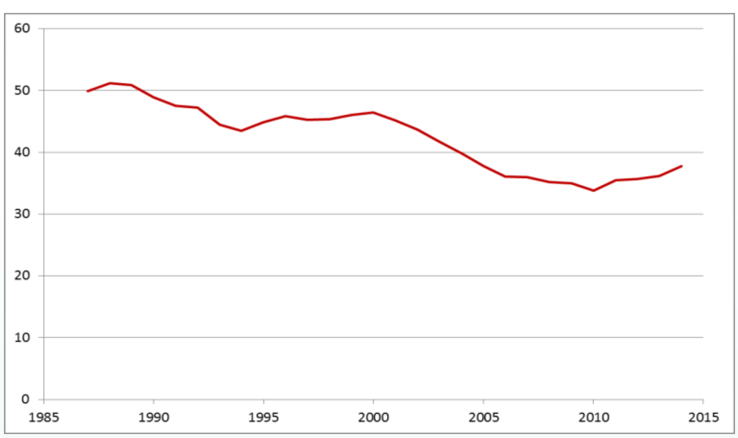
Outline

- From three decades of rapid but unbalanced growth to 'rebalancing'
- From one child to two?
- Conundrums facing Chinese leaders
- Modelling demographic change and the global economy
- Implications for China
- Implications for the world and Australia

From rapid, unbalanced growth to rebalancing and the 'new normal'

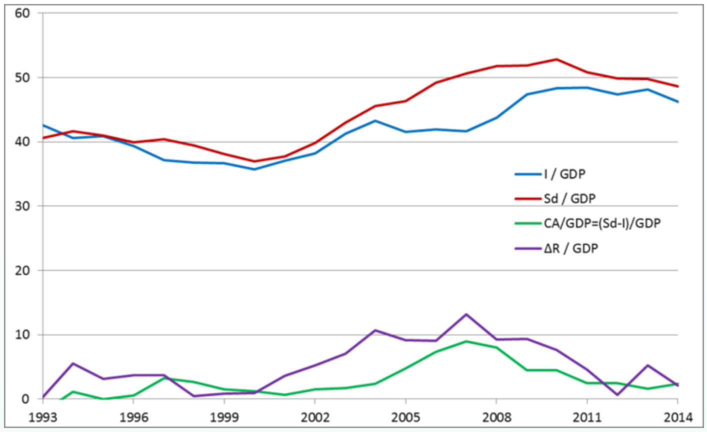
- Three decades of rapid but unbalanced growth (1978-2008)
- Declining consumption share of GDP, high saving rates
  - Both household and corporate
- Imbalances cause tension in domestic and global economies
  - Exchange rate "manipulation" and "savings glut" - fueled global financial crisis
- 'Rebalancing' starts in 2004, ramped up under Xi Jinping (Third Plenum)
  - Likely to encourage continuing declines in total saving rates
- Premier Li Keqiang's 'new normal' rate of growth at 'around 7%'
  - New target of 6.5-7% for 2016
  - Debate over accuracy and sustainability

Consumption as a share of GDP



Sources: National Bureau of Statistics yearbook 2009-2014; IMF IFS data base

Savings, Investment and the CA Surplus
(% GDP)



Sources: National Bureau of Statistics yearbook 2009-2014; IMF IFS data base

From One Child to Two?

- Decline in fertility PRIOR to one-child policy in 1980
- Rapidly declining youth dependency since 1980
- Demographic dividend: rise in working- to non-working age population ratio to 2010
  Accounts for up to ¼ of China's per capita GDP growth in first three decades of reform
- Concerns about ageing population - 'getting old before getting rich'
- Tightening of labour markets and rising wages since mid 2000s
- One-child policy to two-child policy from Jan 1, 2016
  'Low-fertility trap' – low uptake?
- New policy intended to:
  Boost GDP growth by 0.5 per cent per year through to 2050
  Reduce aged proportion of population by 2 percentage points by 2050
  But (not surprisingly) quiet on the per capita income costs

Linking demographic change and economic performance

- Standard Solow-Swan growth model

  Realistically incorporates diminishing factor returns

  Unrealistically assumes a closed economy and constant labour participation and an ageless population

  Slower population growth yields a slower-growing labour force, which reduces GDP growth, but higher capital per worker raises per capita income

- Adding demographic structure alters growth

  Demographic dividend: age distribution affected by fertility, mortality & migration

  Lower fertility initially reduces total dependency, which boosts per capita income further.

- Fertility rate and age distribution changes also alter:

  The product composition and quantity of final consumption

  The average saving rate (life-cycle hypothesis)

  - Ageing likely to reduce saving rate via this channel but low fertility raises household saving rate initially

  Sex-ratio at birth and hence gender imbalance (said to raise China's saving rate)

7

Conundrums

1. Rebalancing requires lower saving rates

   Lower saving rates slow capital accumulation and more new capital is foreign owned, income from which is repatriated abroad, so income growth is slowed

2. Two-child policy will boost GDP growth and consumption but demographic dividend would be reversed

   High fertility comes at a further per capita income cost to the average Chinese citizen

We explore these consequences using a dynamic global economic model with full demographic behaviour

Modelling demographic change and economic growth

Dynamic model of global economics and demographics to 2050

- 18 regions, of which China is one
- 16 households in each region are age-gender-skill groups with populations driven by endogenous births, deaths, survival and migration flows
- Labour force participation is modelled explicitly so that dependency ratios are based on *employed* populations
- Industries: agriculture, light manufacturing, heavy manufacturing, energy, metals, minerals, services
- Factors: skilled labour, unskilled labour, capital, land, natural resources
- Endogenous growth: capital accumulation, demographic change, skill upgrading
- Exogenous growth: technical change by factor and industry, common to all scenarios
- Open capital accounts with investment abroad via a global trust
- Consumption & saving group-specific, responsive to real per capita disposable income and real private rates of return on saving
- Real exchange rates driven by differentiated products and little-traded services

9

Simulations to 2050

Baseline

'High GDP growth' scenario

The 2CP is successful, moving fertility to sustainable population

Saving rates decline only moderately with ageing

Low saving only

'Dual policy success' scenario

The 2CP is successful, moving fertility to sustainable population

The rebalancing push sees saving rates decline to advanced region levels by 2050

Low fertility only

Fertility continues to decline, roughly in the manner of the UN low growth case

Saving rates decline only moderately with ageing

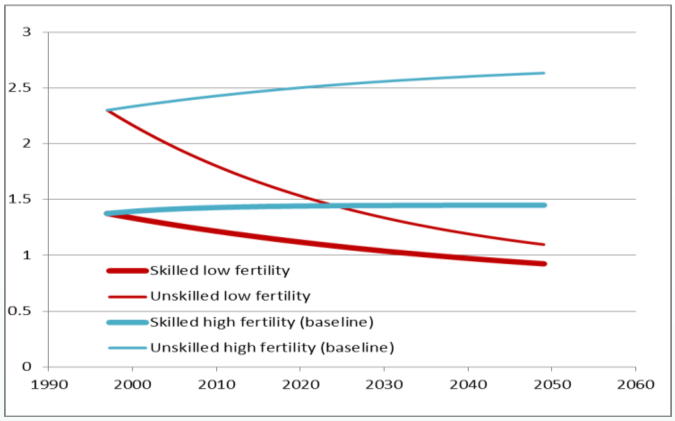
Low saving and low fertility

'Double contraction' scenario

Fertility continues to decline, roughly in the manner of the UN low growth case

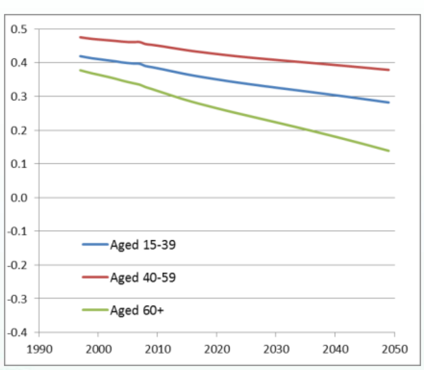
The rebalancing push sees saving rates decline to advanced region levels by 2050

Total fertility rates, skilled and unskilled

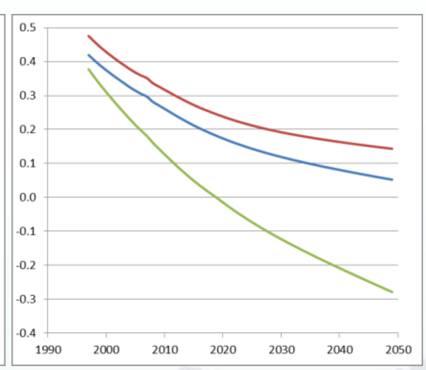


Age-specific saving rates from personal disposable income

Relatively slow decline (high savings)



Relatively rapid decline (low savings)



Adjusted to incorporate saving by corporations

Summary of Results

Chinese demographic contraction

- The aggregate Chinese effects of the demographic contraction are to

  Raise 2050 real low-skill wages and real per capita income by more than a fifth
  Raise saving slightly in the short run
  Accelerate skill transformation
  Reduce youth dependency but raise aged dependency by slightly more
  Slow real GDP growth by less than 0.5% per year

- 2CP, if it is effective, would offset these
- Global effects are modestly negative, except for India and "other South Asia", which would gain

Summary of Results

Chinese double contraction

- Further effects due to the demographic and saving contraction include

  GDP growth is slowed by more than a 1%/year
  Reversal of CA surplus into considerable deficit
  The rest of the world would lose more, except only for India

Bottom lines

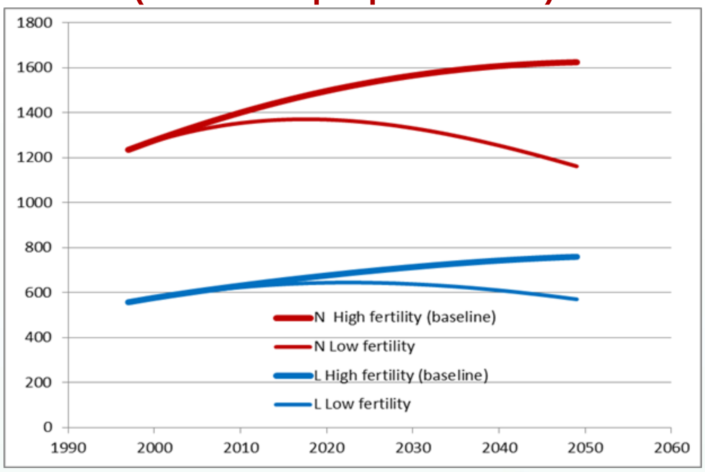
Too much saving contraction leaves few beneficiaries

Sources of GDP growth *other than population expansion and raw capital accumulation* are keys

- Increasing productivity
- Skill transformation
- Increasing labour force participation rates (retirement ages, *hukou* reform)

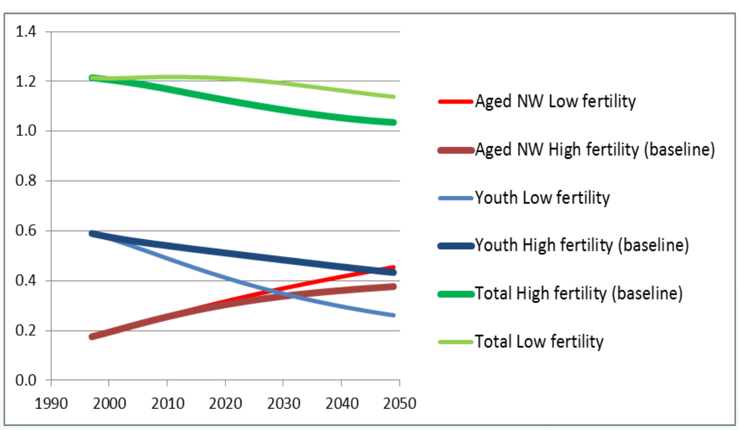
China's population and labour force

(millions of people/workers)



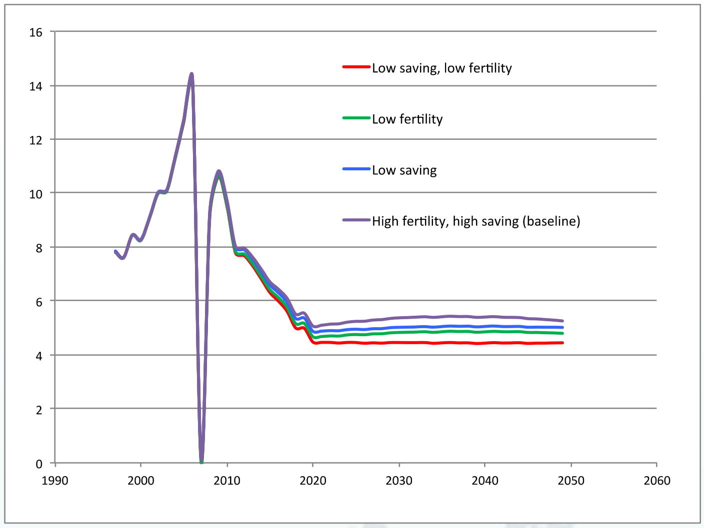
- 'High fertility' implies population sustainability.
- Low fertility: labour force above 1997 levels through to 2050

Dependency rates (non-working per worker)



Note: adjusted for labour force participation, so measuring non-working over working.

China's projected real GDP growth

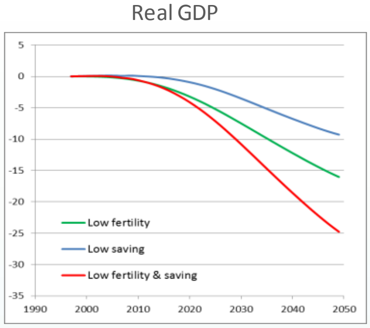


Slower range of long run growth rates than the 'new normal'.
Raises real per capita income 9-fold relative to US but still only 1/5.

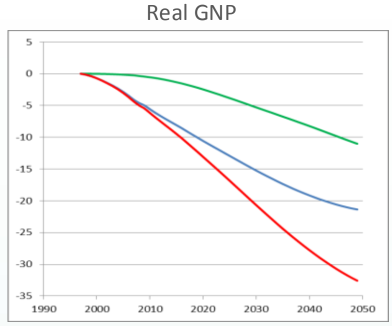
Real GDP and GNP

(% difference from baseline)

Real GDP



Real GNP

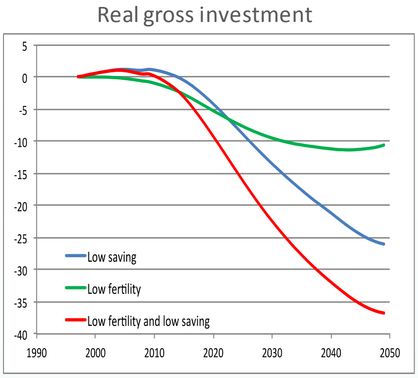


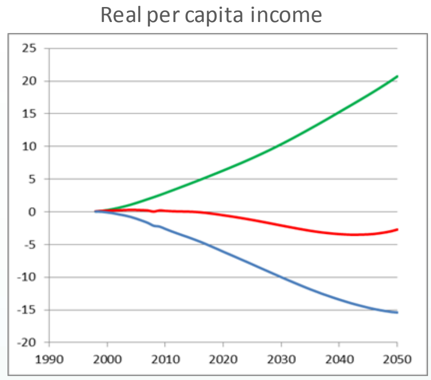
Small changes growth rates result in large changes in 2050 levels
Low fertility and low saving see China's real GDP lower by 25% in 2050

GNP decline greater for low saving scenario because greater foreign investment means more repatriation of capital income abroad

Real investment and per capita income

(% difference from baseline)



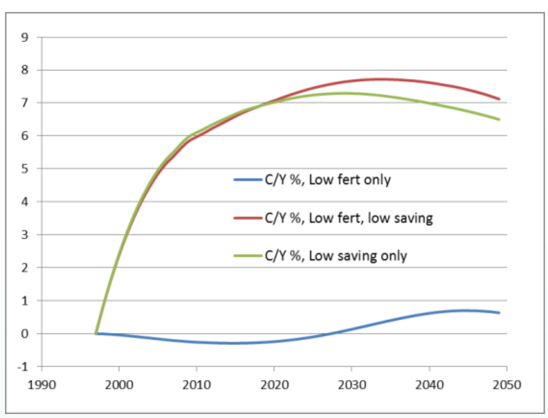


Low fertility *reduces* labour supply and expected investment returns, investment and real GDP but yields *higher* real wages and *per capita* income

Low saving reduces total and home owned capital accumulation rates: so real per capita income *and* GDP growth are *both lower*.

Consumption as a share of GDP

(% difference from baseline)



Low savings increases it but not permanently (via lower per capita income – consumption growth turns negative by 2035)

Low fertility: shifts expenditure away from children, towards retirees (who still save) so lower consumption, despite higher per capita income.

Global impacts

The effects of Chinese contractions are adverse on average

Mechanisms

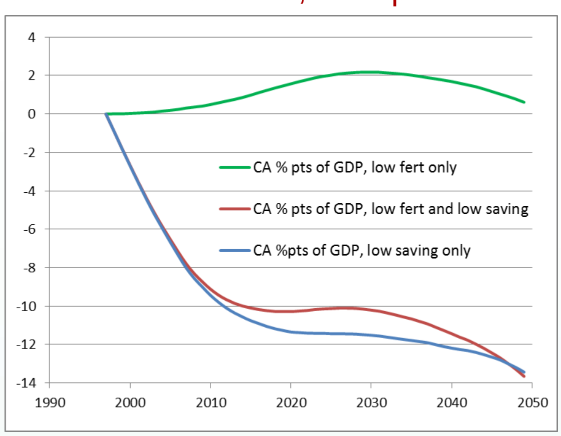
- Low Chinese saving shifts it to CA deficit and tightens global financial markets
- Slower growth reduces trade volumes in all Chinese industries
- In other regions, both contractions depreciate the real effective exchange rate and shift the terms of trade adversely

Bottom line

- World GDP (excluding China), % difference by 2050
  - Low fertility only -1%
  - Low saving only -6%
  - Double contraction -7%

China's current account

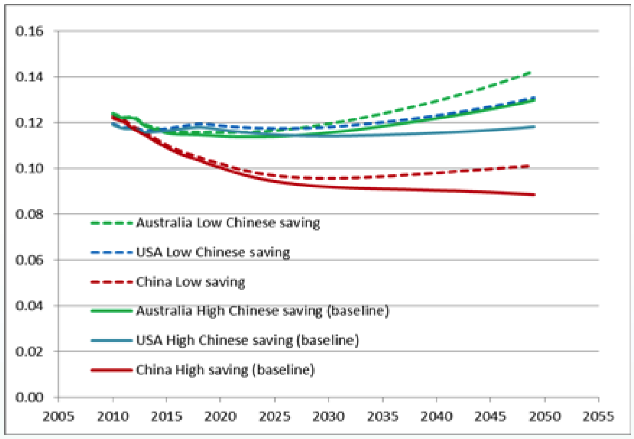
(difference from baseline, in % points of GDP)



Saving rates as low as in this scenario reverse China's CA surplus

Low fertility raises saving in the early decades

Gross rates of return in US, China, Australia

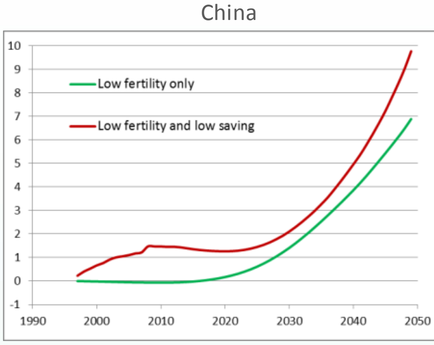


Tighter global financial markets, higher costs of capital: contracting global investment

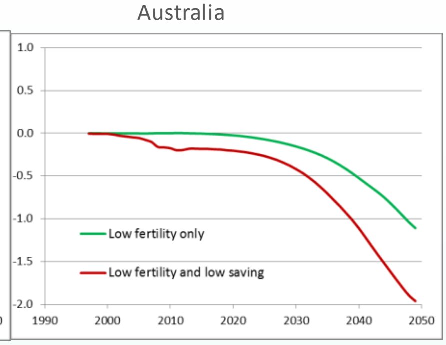
China's and Australia's real effective exchange rates

(% departures from baseline)

China



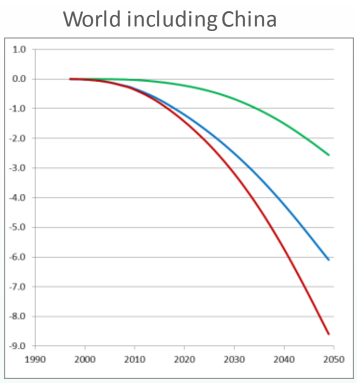
Australia

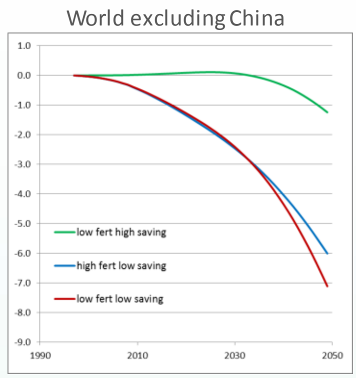


China: contracting factor endowments appreciate real exchange rate

Australia: contracting Chinese demand reduces global demand for exports, lowers relative prices, real exchange rate depreciates

Change in global real GDP
(% relative to baseline)





Eventual net losses globally, even without including China

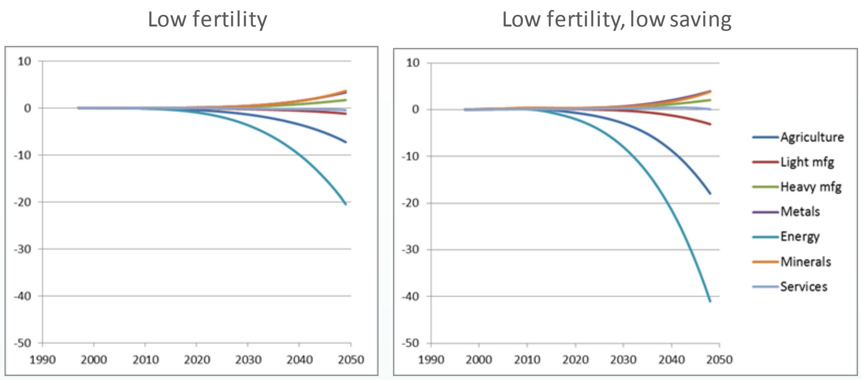
Product market impacts

Small impacts on products that dominate world trade – manufactures

Large impacts for natural resource based industries (agriculture, energy and minerals)

- Due to slower Chinese capital and income growth
- Worst with the Chinese saving contraction
- International trading prices of energy and agricultural products substantially lower

World trading price impacts

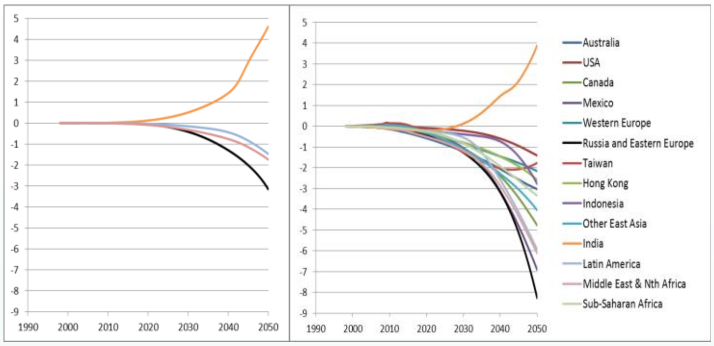


Regional impacts

- Impacts on individual regions depend on
  - Own sources of comparative advantage
  - Terms of trade and real exchange rate changes stemming from Chinese contractions
- Australia and India provide two extreme examples:
  - Australia: terms of trade changes mixed, gains from Chinese imports of minerals, losses from declining energy demand. Savings contraction contributes 2.9 of 3.0% reduction in real per capita income to 2050.
  - India: own high fertility and pending demographic dividend delivers gains from slower Chinese manufacturing exports. Real per capita income boosted by 4.6% from Chinese fertility decline alone. Limited impact of savings.
- Biggest loser is Russia from collapse in Chinese energy imports and world energy trading prices.

Change in real per capita income
(% relative to baseline)

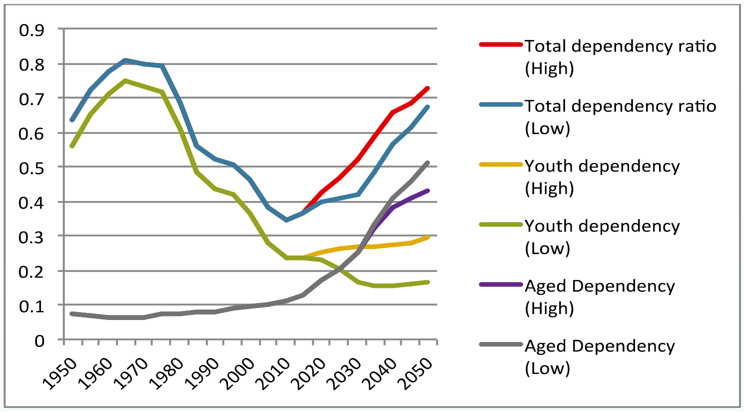
Low fertility | Low fertility, low savings



India stands out
Australia doesn't!

Addenda

UN age-group based dependency ratios 1950-2050

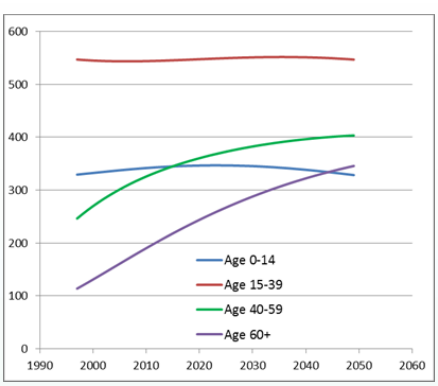


Sources: United Nations (2015) Population projections

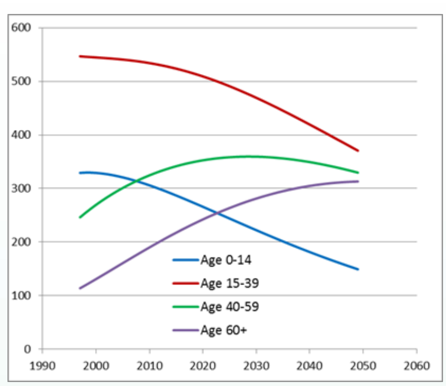
- Bottom of total dependency in 2010, rising sharply thereafter.
- Fertility change as of 2015 has delayed and small impact on aged dependency

China's age distribution
(millions of people)

High fertility baseline

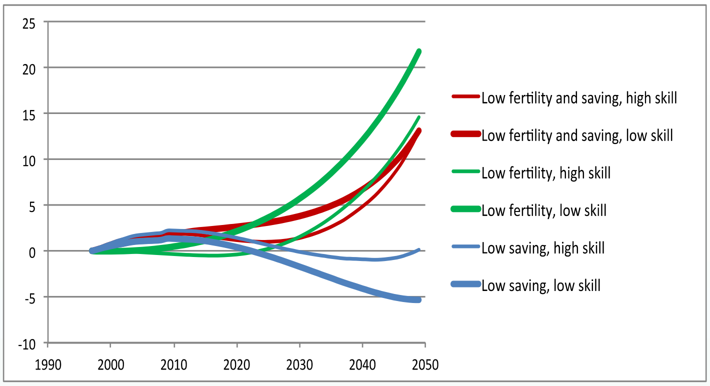


Low fertility



Real wages

(% difference from baseline)

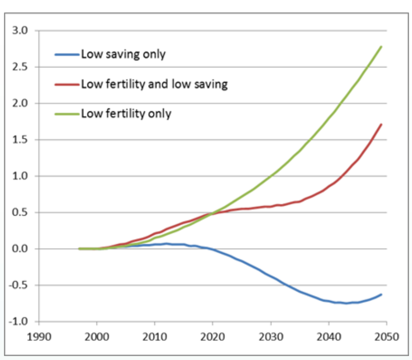


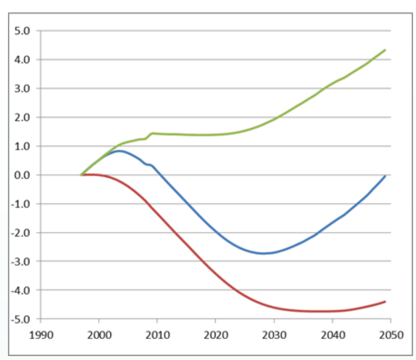
Low fertility causes largest increase in real wages, especially low skilled

Low saving reduces investment and so (in long run) reduces low-skilled wages

Skill share of labour force and Wage Premium

(% point differences from baseline)



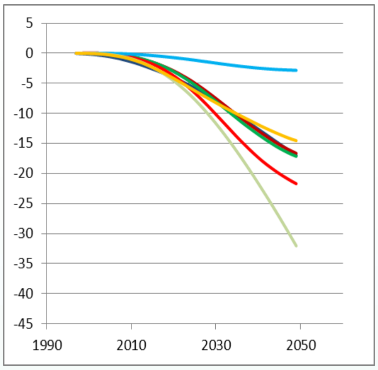


The skill share depends on differential fertility and on the rate of skill upgrading

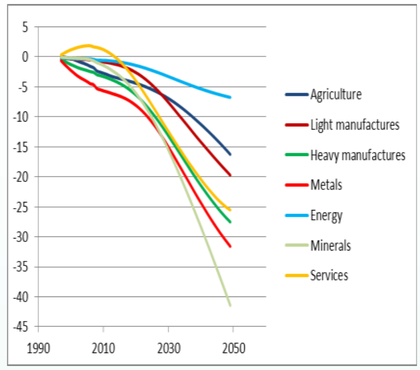
The skill upgrading rate depends on real per capita income and the skill premium

China's real output by sector

Low fertility



Low fertility, low saving



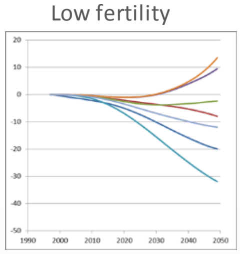
Output contracts in all sectors of the economy (extent depending on factor intensities)

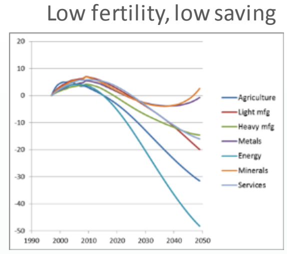
China's import volumes and value shares

Low fertility

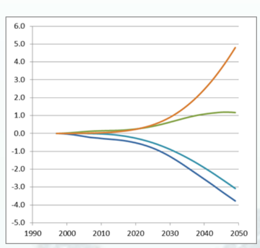
Low fertility, low saving

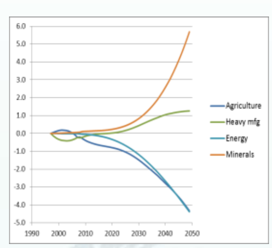
Volumes





Value shares





Change in real per capita income
(% relative to baseline)

	Low fertility, high saving	High fertility, low saving	Low fertility, low saving
Australia	-0.1	-2.9	-3.0
USA	-0.3	-1.1	-1.4
Canada	-1.5	-3.5	-4.8
Mexico	-0.8	-6.2	-6.9
Western Europe	-0.9	-1.4	-2.2
Russia and Eastern Europe	-3.2	-5.2	-8.3
Japan	-1.0	0.8	-0.4
China	**20.7**	**-15.4**	**-2.7**
Taiwan	-0.7	-1.0	-1.8
Hong Kong	-1.3	-1.4	-2.6
Indonesia	-0.1	-2.9	-2.8
Other East Asia	-0.6	-3.6	-4.0
India	4.6	-0.3	3.9
Other South Asia	0.8	-1.6	-0.8
Latin America	-1.5	-4.7	-5.9
ME and Nth Africa	-1.7	-4.7	-6.1
Sub-Saharan Africa	-0.9	-2.7	-3.3
Rest of world	-1.6	-3.2	-4.7

- Bottom line: Chinese growth slowdown hits everywhere but India.
- But good news is that impacts not huge for Australia

MODELLING THE POTENTIAL IMPACTS OF ECONOMIC REFORM IN A PARTNERSHIP BETWEEN AUSTRALIA AND CHINA

Paul Gretton
East Asian Bureau of Economic Research, ANU

Presentation to: National CGE Workshop
Old Parliament House, Canberra, 8 August 2016

Context and scenarios modelled

- Joint study of the economic relationship between Australia and China
  - by East Asian Bureau of Economic Research (EABER), ANU; China Center for International Economic Exchanges (CCIEE), Bejing.
- The effects of an economic reform program are specific to the reform modalities, the barriers to efficiency, economic structure
- GTAP model used to project the implications for Australia & China of
  - Preferential, unilateral and broader approaches to trade liberalisation
  - A broad agenda for productivity improving reform across services
  - Financial market reform

Modelling approach

- GTAP variant that used by PC (2010) study on trade agreements
- Database
  - 20 national economies – Australia and China separate
  - plus, 5 multi-country regions
  - 57 industry groups – 14 Agriculture etc; 4 Mining; 24 Manufacturing; 15 Services
- Comparative-static – compares the global economy with and without the changes applied, allowing for full adjustment
- Longer term – regional industry rates of return fixed; industry capital stocks adjust
- Aggregate labour supply unchanged by policies, labour mobile between regional industries
- DB for 2004 year, abstracts from GFC and ToT boom, but misses longer-term changes

Reduction in border assistance

- The border protection represented by the tariff revenue associated with the protection measure (not power of tariff)
- Tariff revenue recorded on bilateral basis – enables simulation of preferential, unilateral and multilateral scenarios
  - Key assumption – all 'tariff assistance' is measured in the tariff revenue variable: tms (i, r, s)
- Some mfn tariff reductions since 2004 – broad policy message robust

Gains from bilateral reductions modest, unilateral liberalisation likely to dominate

	Simulation	Australia Share of world %	China Share of world %
T1	Australia-China bilateral	23	4
T2	Australia unilateral	**60**	1
T3	China unilateral	13	**78**
T4	RCEP open regionalism	94	81
T5	World MFN liberalization	100	100
	Projected change in GDP	0.94	2.94

Productivity improving services reform

- Services activities diverse
  - Collectively dominant: 80% of VA in Australia; 60% of VA in China & growing
- Because of diversity, productivity improvements most likely be secured by a broad reform agenda, or agendas
- Elasticities approach adopted in illustrative modelling: the impact of a 1% uniform change in ‘productivity’
  - Modelled as a service industry-specific value added augmenting technological and organisational change - avaall (j,r) ∈ ava(j,r)
- Industry demand for value added services determined by relation
- = -ava(j,r) + qo(j,r) - ao(j,r) - ESUBT(j) * **[...]**

With differing industry structures, impact differs between Australia and China

	Simulation	GDP gain Australia	GDP gain China
		% change	% change
S1	Australian services	1.13	..
S2	Chinese services	0.01	0.68

- As China transitions toward a more open and services oriented economy, the dividend could rise commensurately
- Sectoral impacts vary [qva (prodcomm, reg)]

	Primary	Manufacturing	Services
Australia	+	+	+
China	+	+	-

Financial market reform

- Financial market reform can help facilitate the flow of savings to the most productively efficient investments, improve access to capital & reduce the risk premium on capital finance
- Basic concept: $r_t^i = r_t^U + e_t^i + \varepsilon_t^i$, where
  - r is the real rate of interest in period t in region r
  - r_t^U is the real rate of interest in a reference economy – the US
  - e_t^i is the error in expectation of the real exchange rate
  - ε_t^i is a measure of factors including sovereign risk, impediments to financial flows and other factors affecting real interest rates differentials
- Shift term in the relation rorc_(r,s) = rorc_s(r) + **f_rorc_(r,s)** targeted – new to PC variant → ↓ pK (r,s) – the rental price of capital

Some information available on ror wedges between China and US

	G-Cubed	GTAP model data base	
	1996	2004	2011
	%	%	%
China	4.15	5.08	2.12

- Modelled elimination of ½ of the wedge in 2011 – ie, a permanent 106 basis point (1.06 percentage point) reduction
- Lower end of possible range?

Key results (% change)

- Financial market reform in China

Australia		China	
GDP	GNP	GDP	GNP
% change	% change	% change	% change
0.06	0.06	5.72	5.51

- Some regional reallocation of activity projected

Suppliers to China	Competitors (eg Korea, Thailand, Philippines, India)	US	EU	Other
+	-	+	-	+/-

Conclusion and further research

- Significant economic gains are available from trade liberalising, service industry productivity and financial market reforms
    - Bilateral preferential liberalisation is least advantageous strategy
- Opportunities for further research
    - links between individual reform proposals and potential economic gains
    - the distributional effects of potential impacts – industry, region, households
    - the time horizon over which reforms may be implemented and take effect – a dynamic approach …
    - … effects of changing industry , trade and institutional environment in China, Australia and other trading partners

Australian Government
Productivity Commission

Solving a partial equilibrium model in a CGE framework: the case of a BMS model

Xiao-guang Zhang

Productivity Commission, Australia

National CGE Workshop, August 8, 2016, Canberra

Motivation (1)

- CGE models abstract from details
  - *Stylised policies*
  - *Stylised production structures*
  - *Aggregate household*
- PE models don't account for GE effects that can matter
  - *Microsim models take price as given*
  - *Sectoral models take demand as given*

Motivation (2)

- Two conventional approaches
  - *Integrate PE into GE model*
  - *Link PE model with GE model iteratively*
- Problems
  - *Integrated models: too large to solve; inflexible*
  - *Linked models: no guarantee for solution*

An alterative approach

- Basic idea
  - *to solving PE model within a GE framework iteratively*
- Easy to implement
  - *No need for additional algorithms*
- Guarantee that
  - *Solution converges*
  - *GE solution*

What we're doing today

- Explain basic principle and strategy
- Two examples, using
  - *MS household model*
  - *Conventional CGE model*
- Some observations
  - *Principles apply for production sector*

Basic principles

- Make PE model as a part of the GE model
  - *Fully consistent data*
  - *No overlap in theory*
- Impose GE constrain on PE behavior in iteration
  - *Use slack variables to realign spending income*

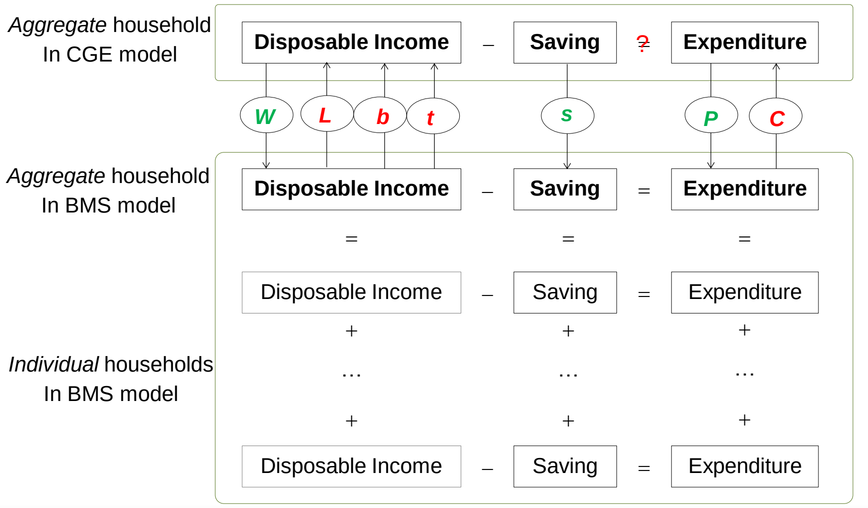
Strategy to build and link models

- Start with an integrated CGE model
  - *Ensure data consistency*
  - *Verify solution*
- Excise the household sector
  - *Build a behavioural MS model*
  - *Link it with the aggregate CGE model*
- Solve the two models iteratively
  - *Find and verify solution*

'Solve the two models iteratively'

- CGE model:
  - *takes consumer demand (and labour supply) as given*
  - *produces GE prices and wages*
- BMS model:
  - *takes prices and wages as given*
  - *produces goods demands and labour supplies*

Household budgets in the CGE and BMS models



Add a slack variable in the CGE model

Slack Variable = **Disposable Income** – ***Saving*** – **Expenditure**

- Captures the *imbalance* in the CGE household budget
  - *caused by the 'delayed' responses in GE prices to changes in BMS quantities*

Two possible outcomes in iteration

- Solution *converges*
  - *Models "well-behaved"*
  - *Is this the right solution?*
- Solution *diverges*
  - *Models "not well-behaved"*
  - *Does this mean no solution exits?*

Two examples of solving linked models iteratively

- A *well-behaved* model
  - *Model solutions converge*
- A *not-well-behaved* model
  - *Model solutions diverge*

Example 1: a well-behaved model

- Same strategy to build and link two models
  - *ABS 2012-13 IO table and 2009-10 HES-SIH data*
- Simulation in the CGE model
  - *a reduction in all import tariffs*

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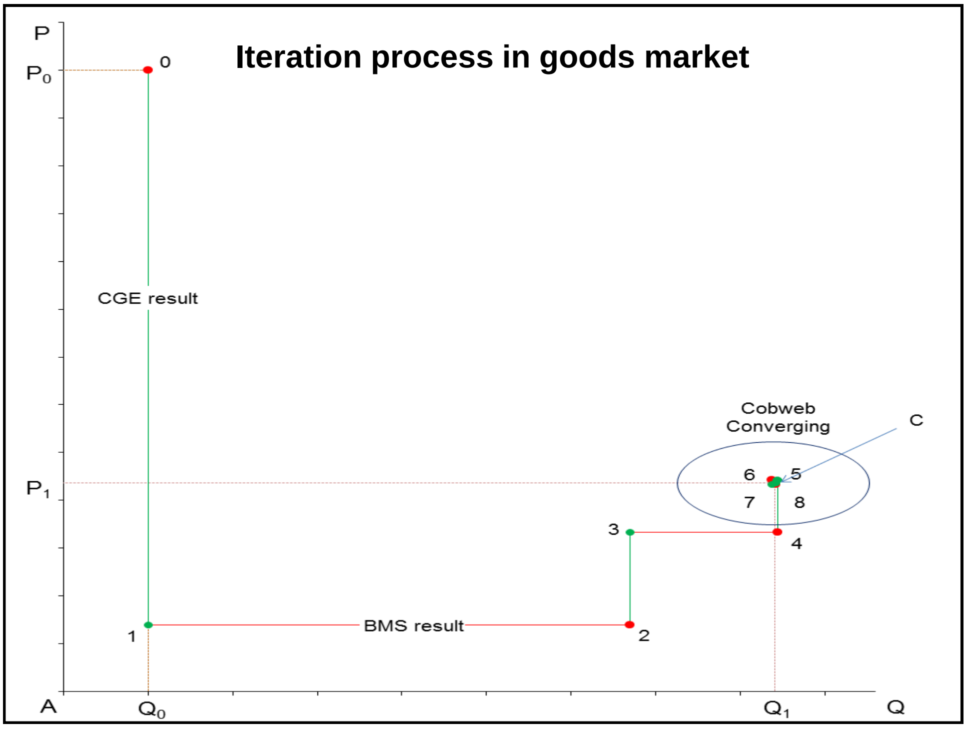
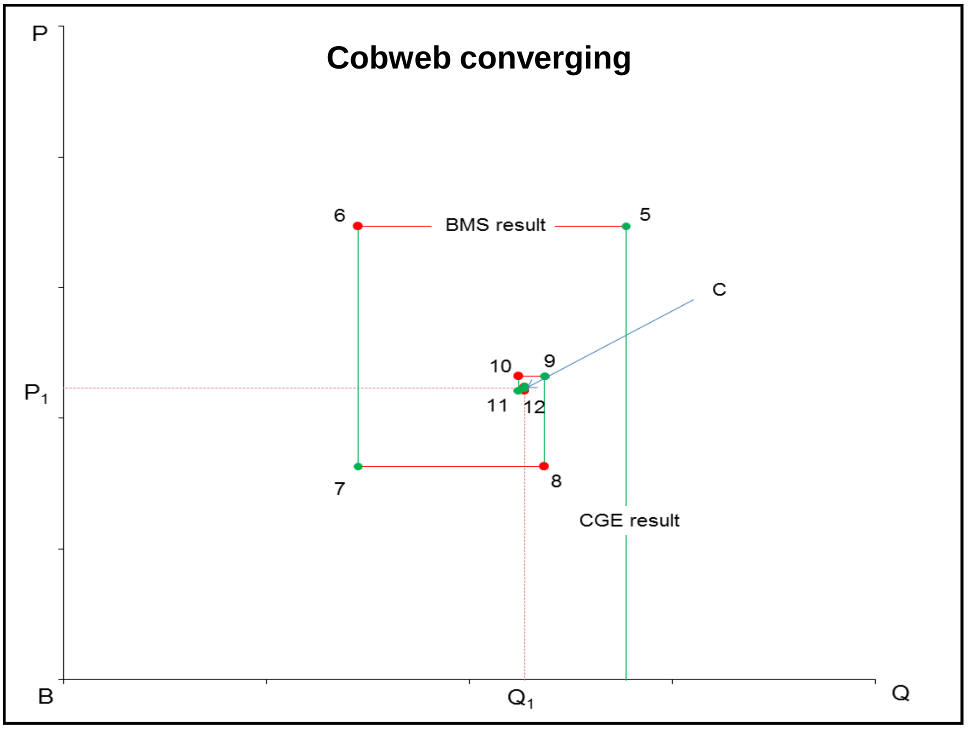
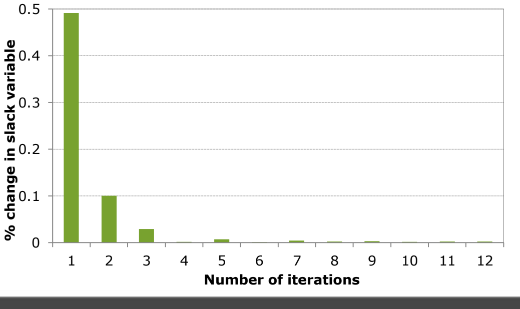




Two checks

1. Integrated model and iterative models produce the same solution
2. Changes in slack variable go to zero



Example 2: a not-well-behaved model

- Same strategy to build and link two models
  - *MMRF database and 1993 HES data*
- Simulation in the BMS model
  - *Increase the supply of 'labourers'*

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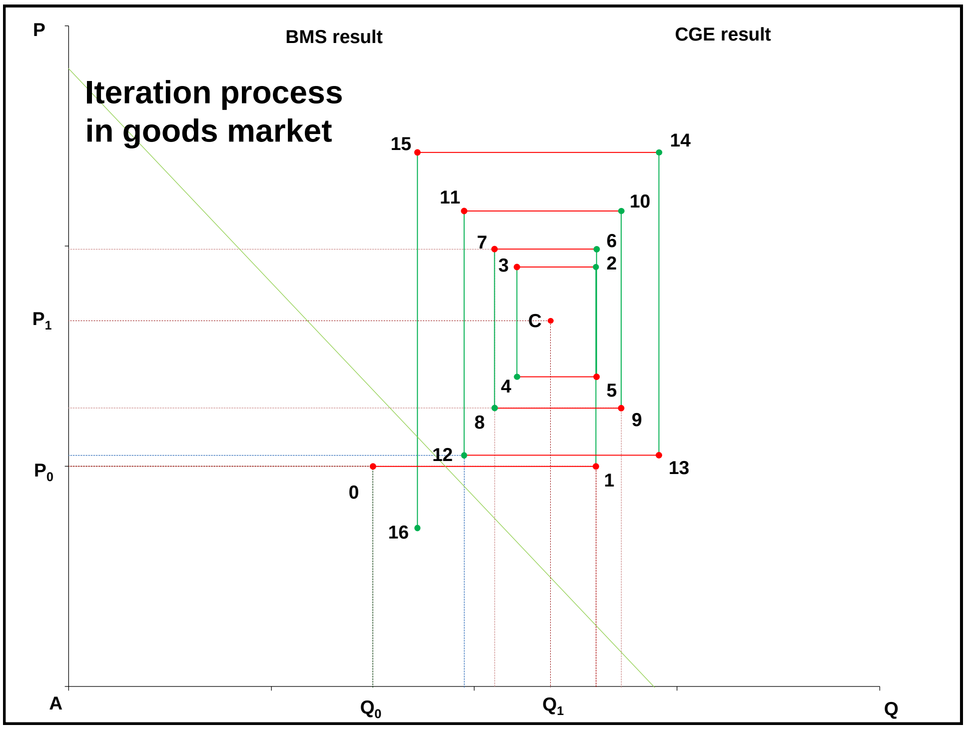
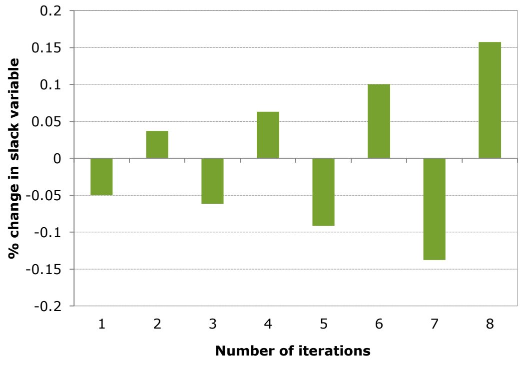


Check the slack variable (%)

Slack Variable = **Disposable Income** – ***Saving*** – **Expenditure**



Question: does a convergent solution exist?

- Yes, because we already know
  - *from the integrated model, such a solution exists, and also,*
  - *from the figure, the solution visible at point C*
- How to get there?

Solution: the role of the slack variable

Slack Variable	=	Disposable Income	–	Saving	–	Expenditure

- Swap slack variable with saving rate
  - *Exogenise slack variable*
  - *Endogenise saving rate*
- Restart the iteration
  - *Fix consumption demand*
  - *Find a temporary solution*

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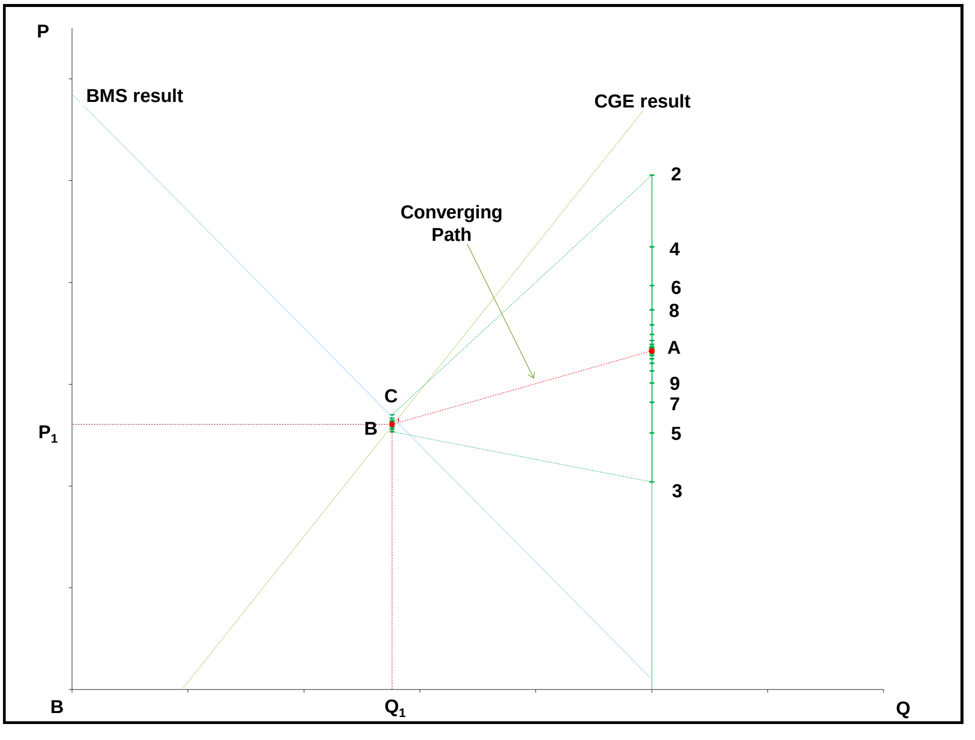

Why do the two models behave differently?

- The well-behaved model
  - *A small saving rate (2.2%): a more balanced budget*
  - *Enables income 'self-realignment'*
- The not-well-behaved model
  - *A large saving rate (30%): a larger budget imbalance to adjust*
  - *Must rely on saving rate shocks to induce income realignment*

Revise the BMS model

- Use a different program
  - *from that for the CGE model*
- Introduce complex functions/policies
  - *i.e. discrete, conditional functions*
  - *real policy rules/conditions*
- Still to be solve as a part of the CGE model
  - *GE solution ensured*

Concluding remarks – way forward

- Principles applicable to other sectors
  - *Ensure PE behaviour based on GE constraint*
- More challenges on linking PE models with other sectors of GE models
  - *Industrial sectors, etc.*
  - *New issues resolved on a case-by-case basis*

Concluding remarks – GEMPACK

- For GEMPACK users
  - *Flexible functional forms can be readily introduced if the sub-model is written in COEFFICIENT and FORMULA*
  - *Computing time can be further reduced if the sub-model is attached to the TABLO code of the linked CGE model*

Contact details

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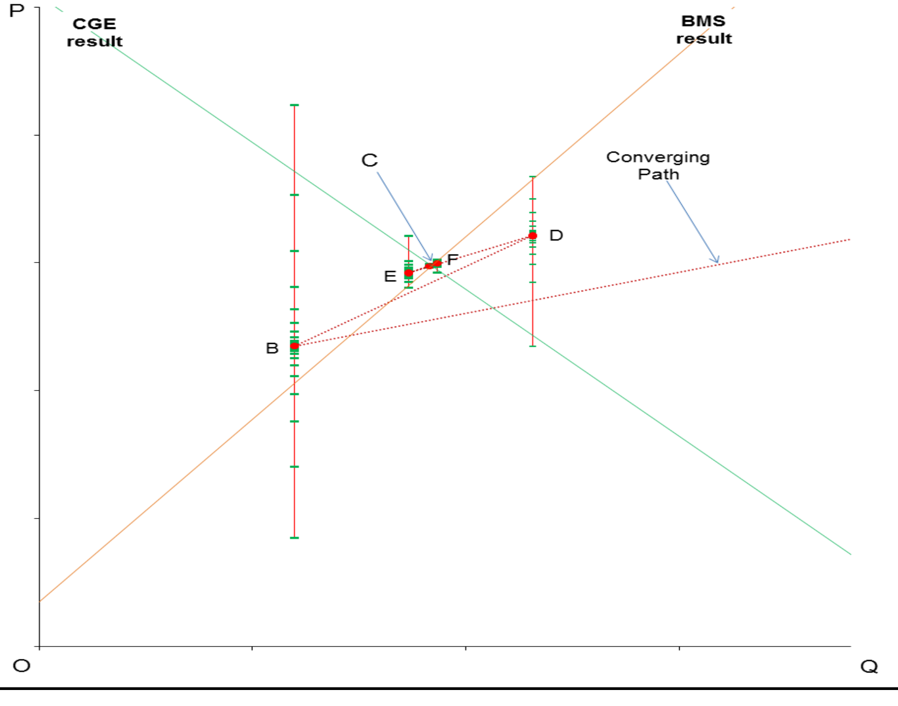


Economic benefits from Fisheries reforms

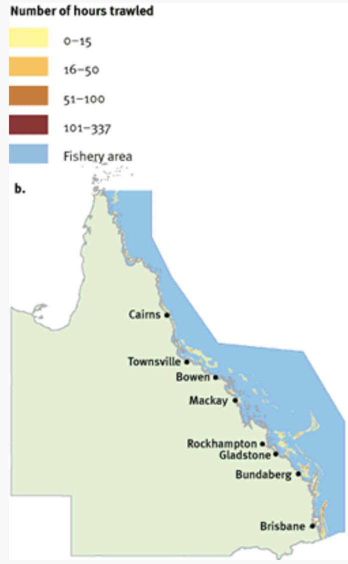
How CGE modelling should influence policy advice

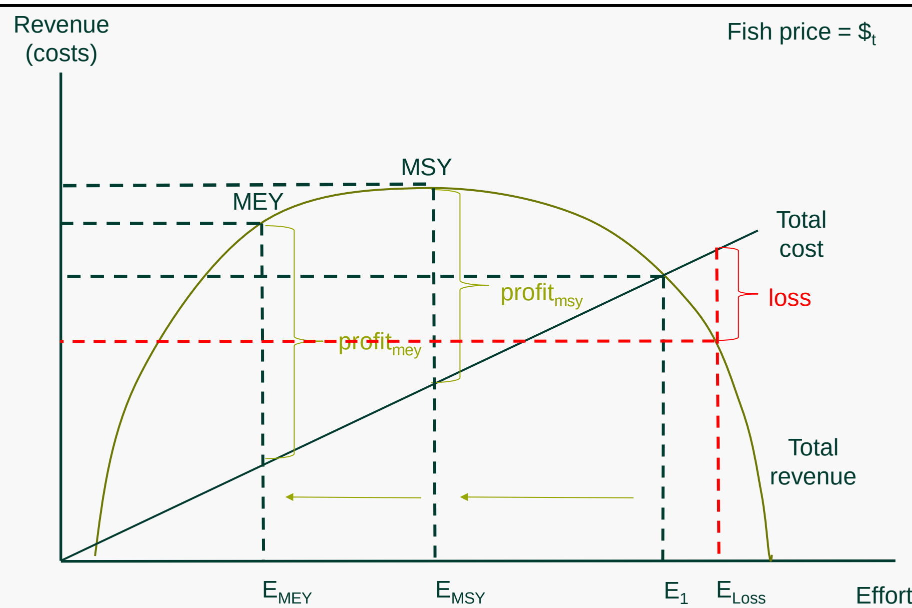
Context – how much should Govt be willing to spend on reform?

- We can work through the problem logically using a CGE model to shed light on the issue in question
- Government should be willing to spend an amount up to the economic benefits reforms might bring, taking into account the likelihood that the reform actions would work, and less the deadweight loss from taxation
- The East Coast Trawl Fishery as an example

The East Coast Trawl Fishery

- Largest fishery in Queensland (~ $100m GVA pa)
- Mainly prawns and scallops
- Compete with cheap (inferior) imports
- 2000's – high exchange rates, high fuel prices and labour costs





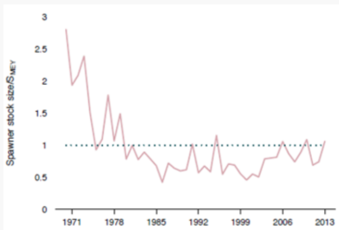
Current regulation – a lesson in how not to do it?

- Effort units (EU's) - regulated fishing time
- Input controls - restrictions on boat size and gear (non-environmental)
- Closures
- Significant effort creep
- 2.9 million EU's ~ half unused = no regulation
- Net economic returns = 0 (Review of Qld Fisheries, 2015)
- Reforms are difficult (buybacks, quota, other?)

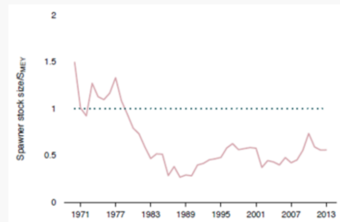
Northern Prawn Fishery

- 51 boats (down from >300)
- Explicit targeting of MEY
- Cooperative management – from 2009
  - Relaxation of input controls
  - Industry manages data collection, management, and monitoring (including environmental)
- Large productivity gains

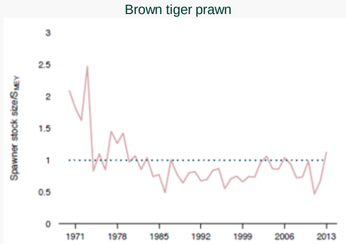
Spawner stock as a % of stock$_{MEY}$



Brown tiger prawn

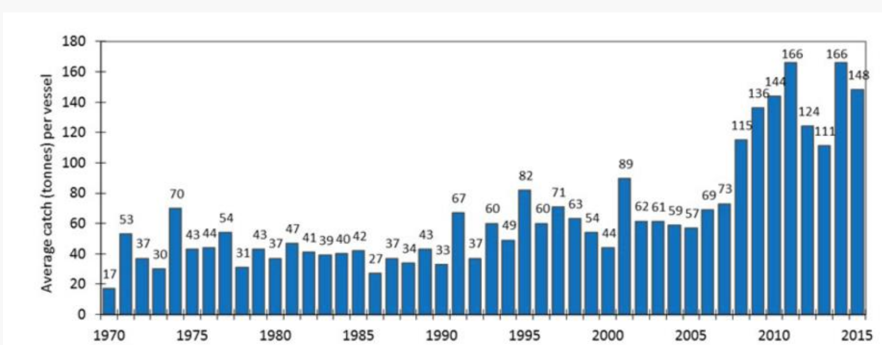


Blue Endeavour Prawn tiger prawn



Grooved tiger prawn

Average total catch per vessel in NPF



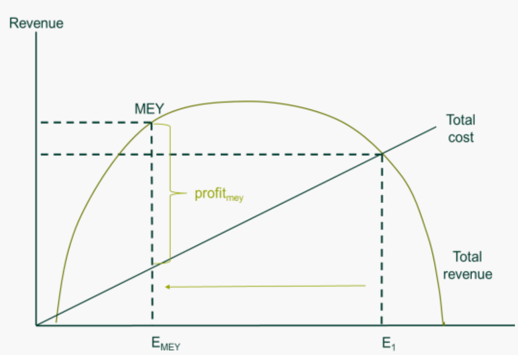
Source: NPF data summary, 2015

Productivity indices - NPF

Source: ABARES, 2015

Benefits from reforms

- Increased productivity
- Small impact on catch
- Small impact on prices
- Generation of economic rent



How it was modelled in MMRF

Introduce a phantom tax :

- **Wedge between basic price and purchasers price**

$$PP_{(c,q)} = BP_{(c,q)} + TAX_{(c,q)} + PHANTOM_{(c,q)}$$

- **Add to household income**

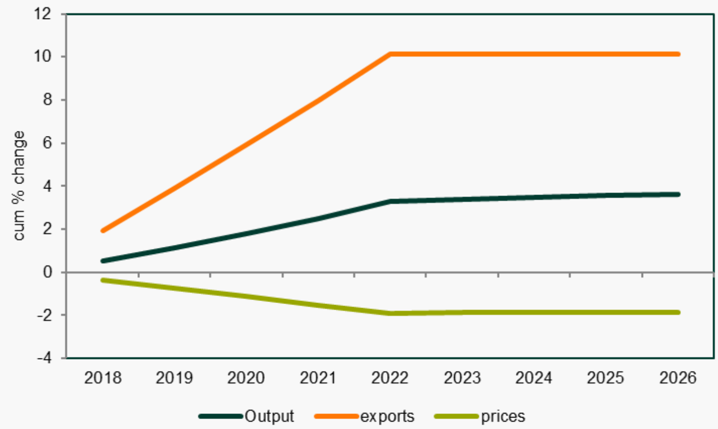
$$INC_{(q)} = LAB_{(q)} + K_{(q)} + OTHER_{(q)} + PHANTOM\_C_{(q)}$$

- **Ensure model passes homogeneity**
  - **Affects tax base (PP’s, GST etc)**
  - **GSP, GSP deflator**

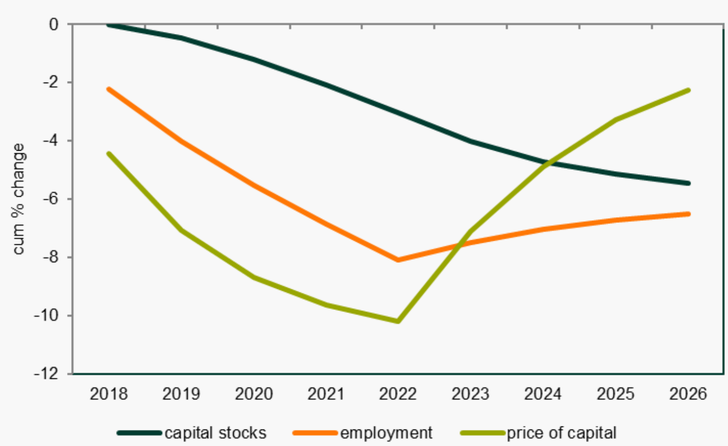
The closure

- Swap
  - export price$_{(fish)}$ = phantom tax on exports$_{(fish)}$
  - household price$_{(fish)}$ = phantom tax on households$_{(fish)}$
  - intermediate price$_{(fish)}$ = phantom tax on intermediates$_{(fish)}$
- Shock
  - productivity of Fisheries industry (50% over 5 years, scaled)
  - Shock purchasers prices (exports, HH and intermediate)
- Other
  - Govt budget balances fixed
  - Sticky wages

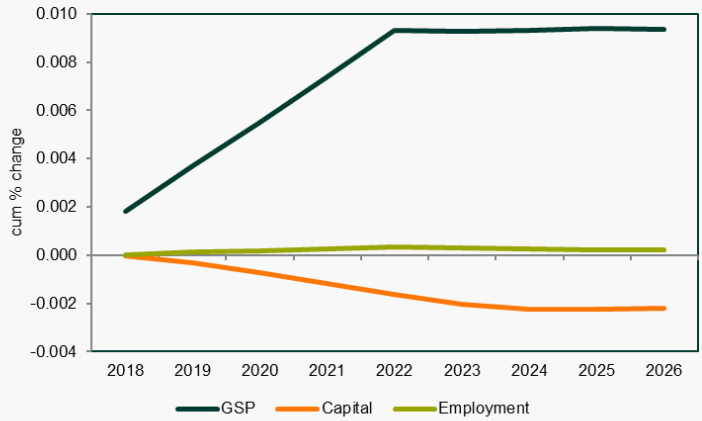
The results - industry



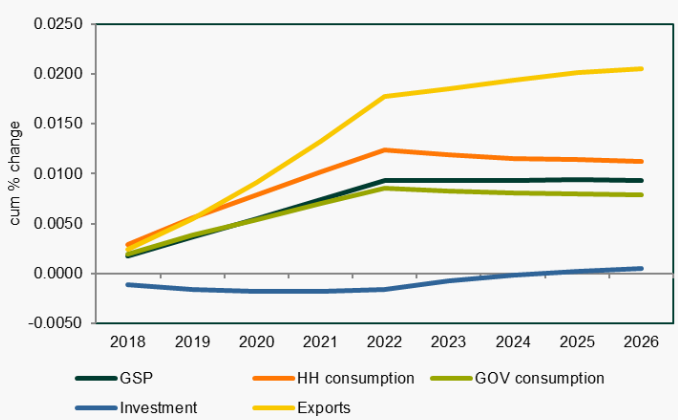
The results - industry



The results - Queensland



The results - Queensland



The results - levels

	2018	2019	2020	2021	2022	2023	2024	2025	2026
Economic rent	9.5	17.9	24.9	31.8	38.5	35.3	33.1	31.9	30.8
Households	4.7	9.2	13.4	17.7	22.1	21.8	21.9	22.2	22.4
Government	0.9	1.7	2.5	3.3	4.1	4.1	4.1	4.2	4.3

Leakages → foreigners and interstate

Synergies ECONOMIC CONSULTING

How the benefits compare

Reform	Benefits
Trading hour restrictions	$200 million pa
Taxi license restrictions	$6 – 20 million pa
Queensland gas scheme	$12 – 53 million pa
East Coast Trawl reforms	$25 + million pa

Source: CIE, prioritisation of regulatory reforms, 2012.

Synergies ECONOMIC CONSULTING

Conclusions

- Evidence suggests reforms work
- Benefits are large - NPV – $250 M (over 30 years)
- Even with licence buybacks, reforms are likely to provide large net economic benefits
- Reduced fishing effort will reduce environmental harm as well
- The only question is who should pay?

The impact of a cut to company tax

Janine Dixon
Centre of Policy Studies, Victoria University
National CGE Workshop, Canberra
August 8 2016

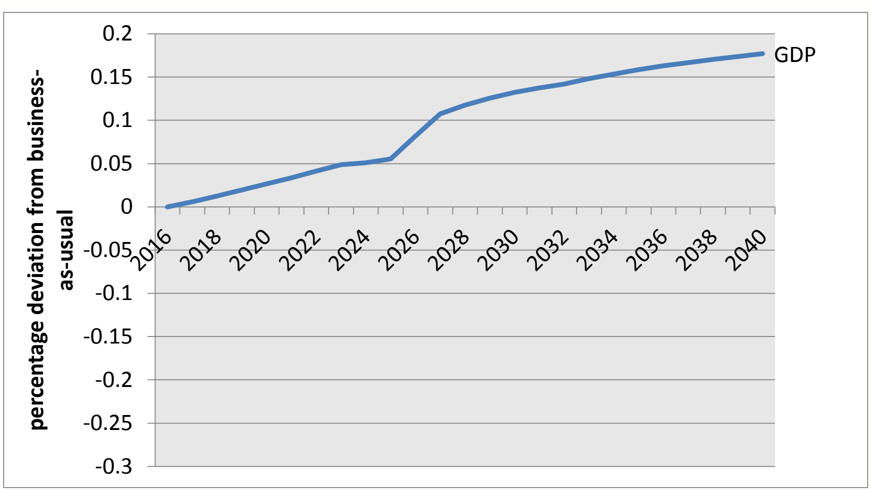
Background

- Australia's company tax rate: 30%
- Government proposal to cut tax rate to 25% phased in over 10 years
- Company tax revenue: $70 billion in 2013-14
  - 20% of aggregate revenue
- Franking credits
  - Not all claimed
- Henry review: recommended 25% in conjunction with Minerals Resource Rent Tax

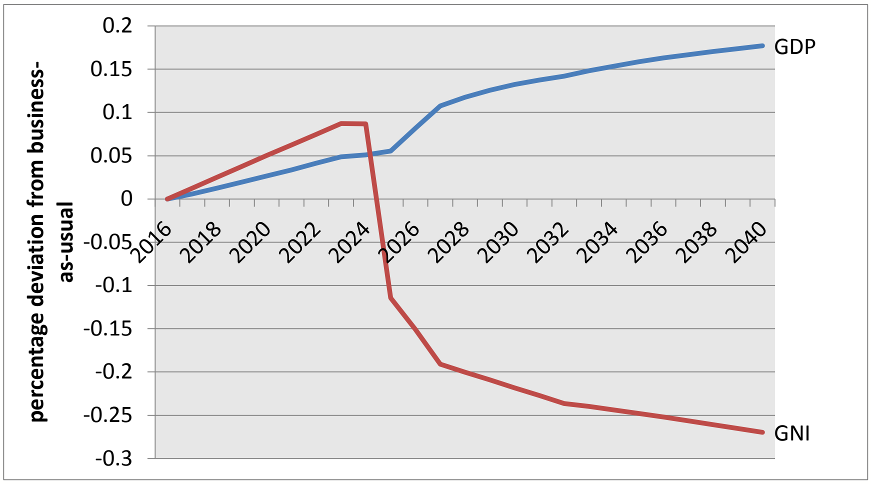
Overview

- Main results
- Alternative simulations
- Complications
  - Labour supply
  - Capital supply
- Further work
- Key points

Results: GDP



Results: GNI



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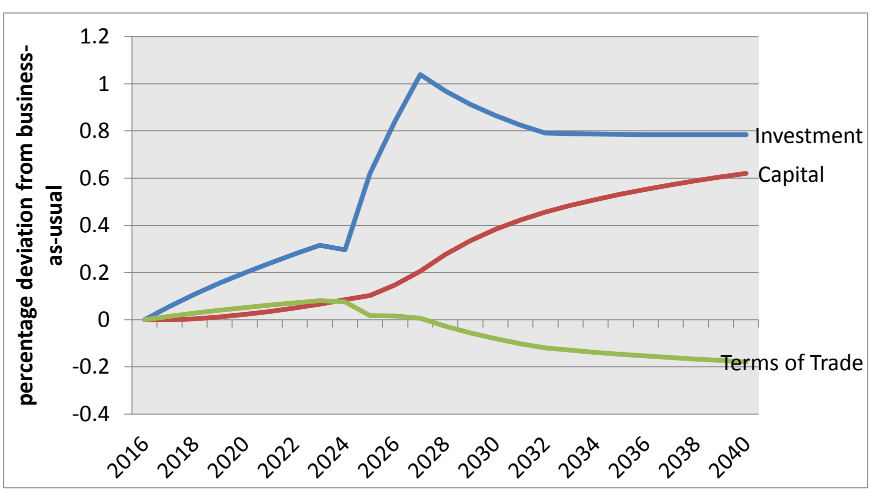
Results: I, K, TOT



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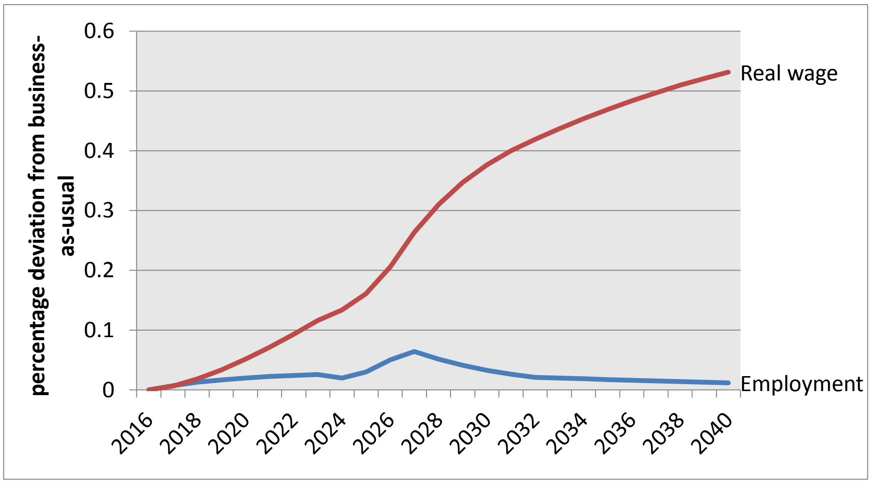
Results: Wage and Employment



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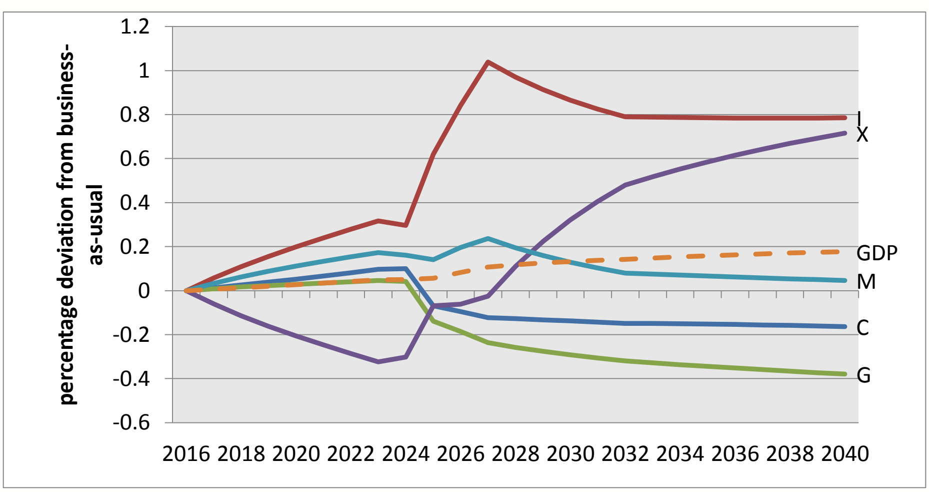
Results: Expenditure



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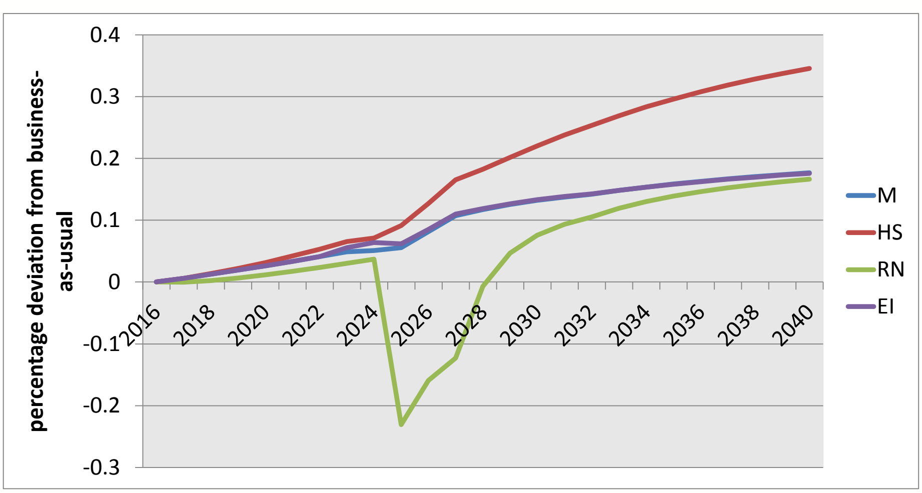
Alternative scenarios

Main (M)	SIGMA_LK = 0.4
High SIGMA (HS)	SIGMA_LK = 0.8
Funded (RN)	TAXREV/GDP fixed, tax on wages increases
Early investment (EI)	Foreign investment starts responding before tax cut

GDP



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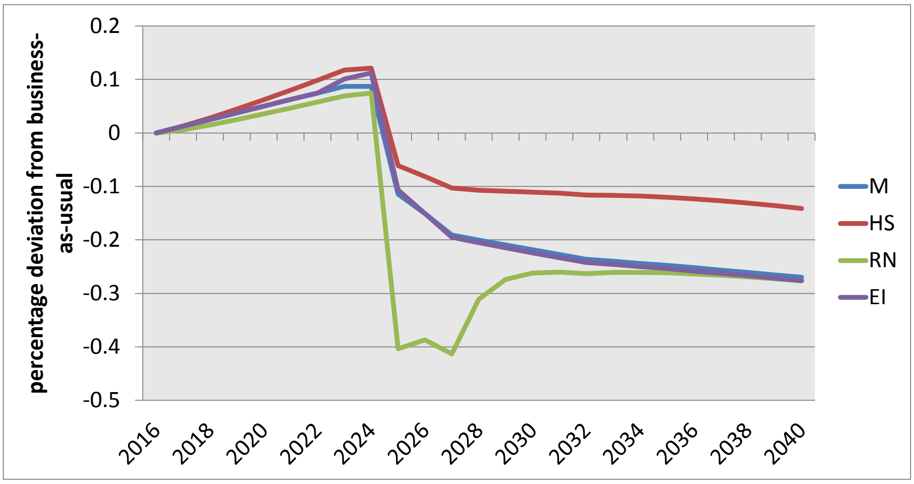
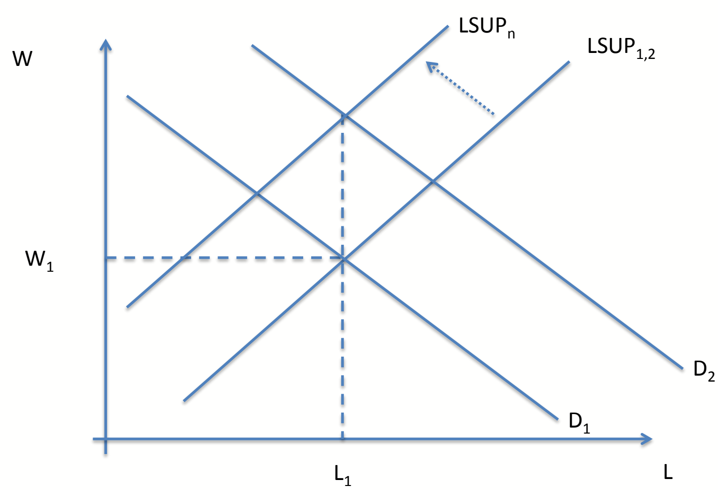
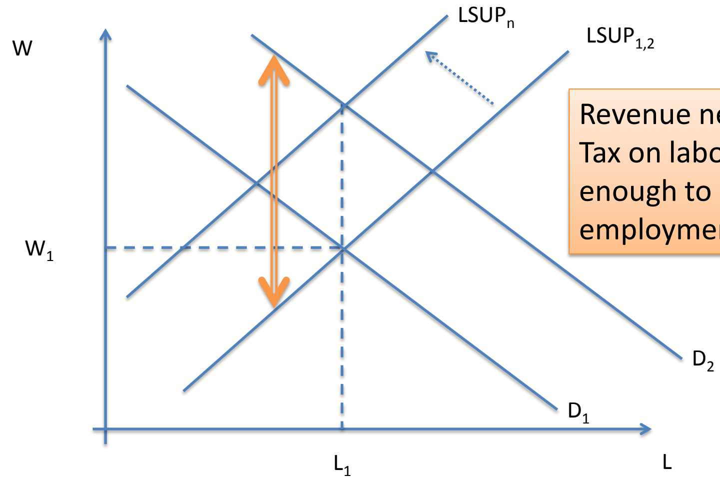
GNI



Labour supply

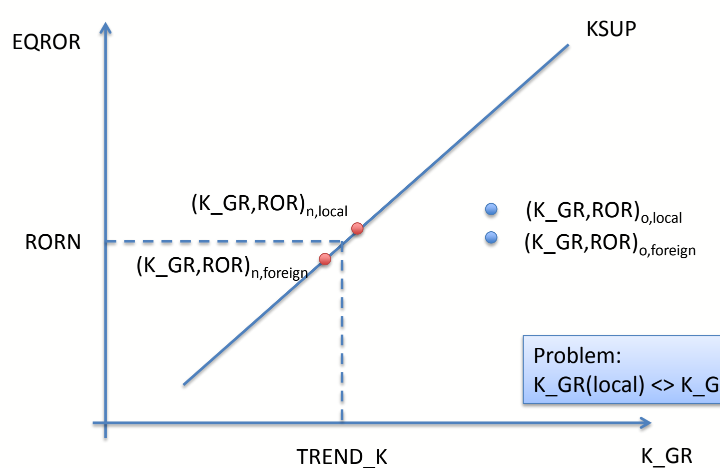


Labour supply



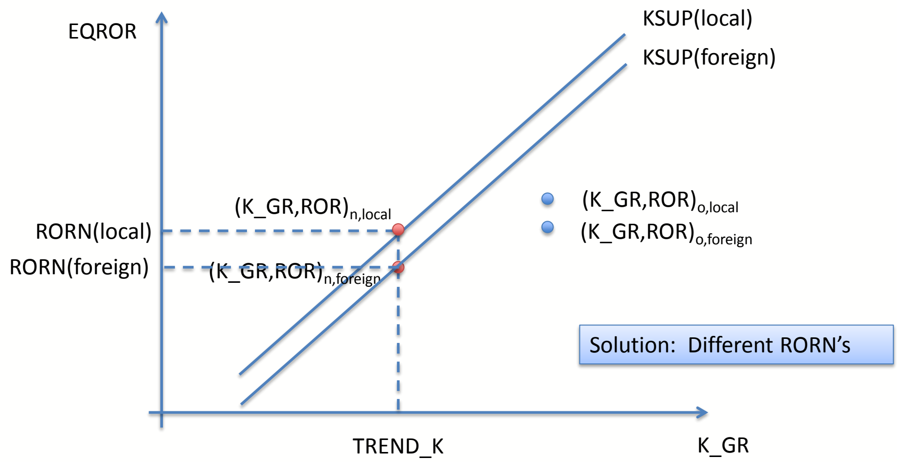
Revenue neutral: Tax on labour large enough to reduce employment

Complication: capital supply

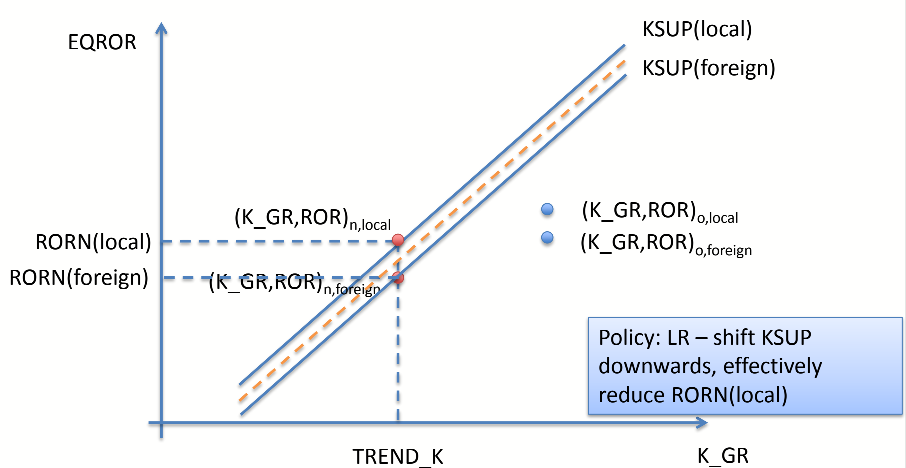


Problem:
K_GR(local) <> K_GR (foreign)

Complication: capital supply



Complication: capital supply



Further work

- Franking
- Optimal tax rate
- Full model
- Funding
- Forward looking expectations
- SIGMA_LK

Key points

- Under a cut to company tax:
  - GDP will increase
  - GNI will fall
- Short run additional negative impact if revenue recovered through tax on wages