The Pass-Through Cost of Carbon in Australian Electricity Markets

Stefan Trück

Department of Applied Finance and Actuarial Studies
Macquarie University, Sydney

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Outline

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- **The Australian National Electricity Market**
- **Electricity Futures Markets**
- **Empirical Analysis**
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Motivation

Controversy about impacts of Clean Energy Legislation Package

- Two stage carbon policy mechanism: commencing with a fixed price carbon period from 07/2012 and transitioning to an emissions trading scheme (ETS) in 07/2015
- One carbon permit will allow the discharge of 1 tonne of CO_2 in a compliance year.
- Carbon tax came into effect on July 1, 2012 with an initial price of $23
- Price of carbon permits will increase to $24.15 in 2013–14 and $25.40 in 2014-15 (reflecting a 2.5% increase in real terms).

The Australian Carbon Policy Mechanism

More facts

- Cap will be set by the Government during the flexible price period as to the amount of greenhouse gases that may be emitted during each compliance year
- Annual caps of the first five years of the ETS flexible price period will be announced by 31 May 2014
- Price floor was initially set at $15, but this rule has been replaced by a quantitative limit on the use of cheap international emissions units (CDM credits)
- Price ceiling will be set at $20 above the expected international price for 2015-16

Motivation

Research Questions

- What is the impact of the Australian carbon tax on electricity prices?
- What can we expect from considerations based on generation mix / emission intensities?
- How did actual electricity (futures) prices react to the introduction of the tax?

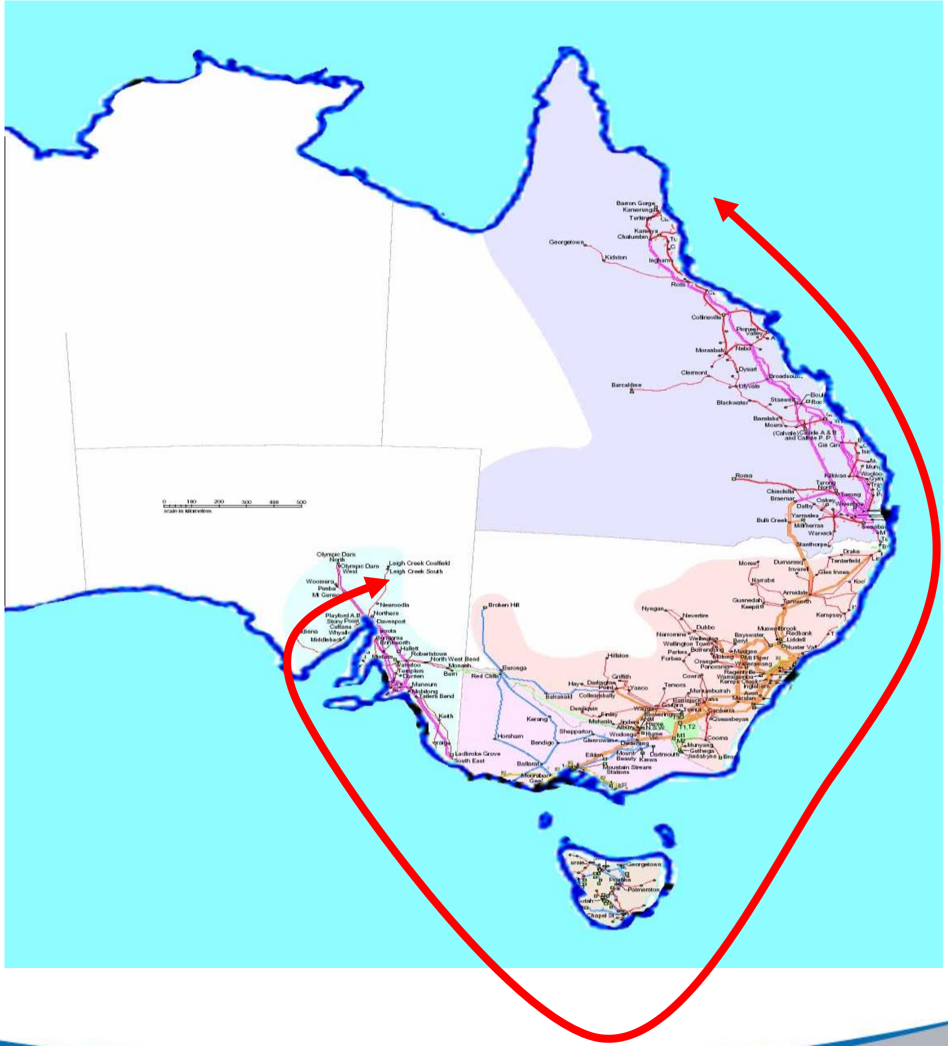
Motivation

Contributions

- One of the first studies to investigate the **actual** impact of carbon tax on futures prices in Australian electricity markets
- We consider not only emission intensities and historical electricity prices but also **risk premiums** inherent in Australian electricity futures quotes
- We find that the additional premium for the price of carbon is significant, however, it is **lower than what could be expected from considerations of emission intensities**

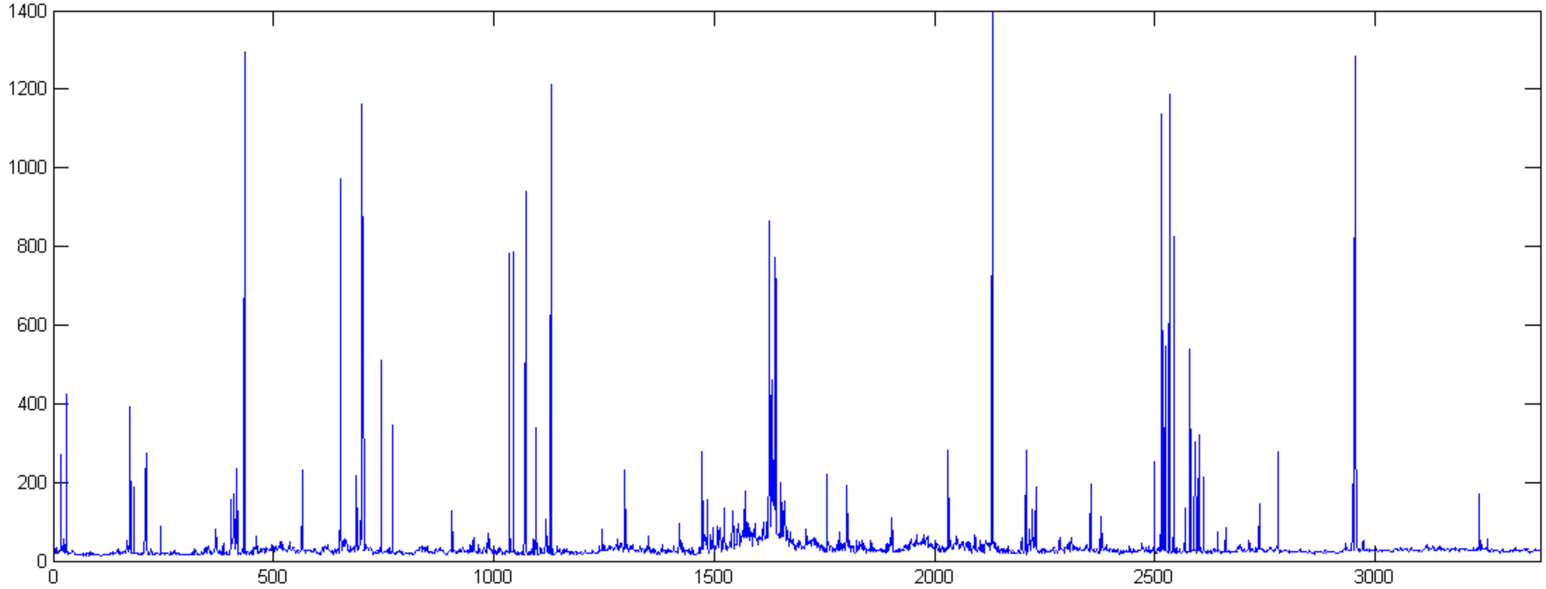
The Australian National Electricity Market (NEM)

- NEM includes six price regions:
  - Queensland (QLD),
  - New South Wales (NSW)
  - Victoria (VIC)
  - South Australia (SA),
  - Tasmania (TAS)
  - Aus Cap Territory (ACT)



Electricity Prices in Australia

Spot price behavior (daily)



Daily electricity spot prices for NSW market (01.01.2003 - 25.03.2012)

Electricity Prices in Australia

- In 2007 Australian residential electricity prices were the fourth lowest of all OECD countries (ABARES, 2008)
- Electricity prices charged to consumers have increased significantly between 2007-2011 (AEMC, 2012)
- Australia's electricity consumption is predominantly fuelled by coal-fired power plants
- Electricity spot prices can range from -$1,000 / MWh to $12,000 / MWh

Emission Intensity in Australian Electricity Markets

- Australian emission per unit of GDP are 0.78kg of carbon dioxide equivalent in comparison to 0.43kg of carbon dioxide equivalent in OECD (IEA, 2009)
- The average emission intensity of the NEM in Australia is estimated 0.94 tonnes CO_2 per MWH (Simshauser & Doan, 2008)
- Intensities vary significantly across states, e.g. 1.23 t CO_2 / MWH for Victoria, 0.32 t CO_2 / MWH in Tasmania
- In comparison the European average is 0.35 t CO_2 / MWH

Electricity Futures Markets

Cost-of-Carry Relationship (Kaldor, 1939)

$$F = S\, e^{cT}$$

F = futures price, S = spot price, c = cost of carry, T = time

However, electricity is non-storable, thus it is very difficult to apply no-arbitrage theory (see e.g. Pirrong and Jermakyan, 1999; Eydeland and Geman,1999; Bessembinder and Lemmon, 2002; Longstaff and Wang, 2004)

Electricity Futures Markets

Equilibrium Relationship (Keynes, 1930)

$$\mathrm{F}_{t,[T_1,T_2]} = E\left(S_{[T_1,T_2]}\right) + \pi_{R,[T_1,T_2]}$$

$F_{t,[T_1,T_2]}$ = futures quote at time t for delivery period $[T_1,T_2]$

$E(S_{[T_1,T_2]})$ = expected spot price for delivery period

$\pi_{R[T_1,T_2]}$ = risk premium

Provides more suitable approach to investigate forward premiums.

Electricity Futures Markets

Ex-ante and ex-post futures premium

- Futures premium is simply calculated as the difference between futures and spot price

$$\pi = F_{t,[T_1,T_2]} - S_{[T_1,T_2]}$$

- **Ex-ante futures premium:** use expected (model based) spot price at point in time $t<T_1$ and compare it to quoted futures price at some point in time $t<T_1$
- **Ex-post futures premium:** use realized spot price during the period $[T_1,T_2]$ and calculate premium by comparing realized spot to futures quote at some point in time $t<T_1$

Electricity Futures Markets

Empirical Intuition

- Empirical intuition suggests that we will probably observe **short-term positive risk premiums** and **long-term negative risk premium** (e.g. Benth et al., 2008)
- **Short-term:** retailers hedge risk of price spikes and are willing to pay a premium for it
- **Long-term:** producers hedge their future production using long-term contracts and are willing to accept lower prices in futures market in order to facilitate long-term planning / pricing of power plants

Electricity Futures Markets

Results on risk premiums in electricity markets

Previous studies on electricity forward premium:

- **Negative and significant ex-ante premium** using one-month futures in PJM and CALPX market (Bessembinder & Lemmon, 2002, JF)
- Negative **ex-ante forward premium** for monthly, quarterly and yearly contracts at the EEX (Kolos and Ronn, 2008, EE)
- **Positive** and significant **ex-post premium** in the EEX (Redl et al, 2009, EE) using monthly and yearly futures contracts
- **Positive** and significant **ex-post premium** in the NEM (Handika & Trück, 2012) using quarterly futures contracts for NSW, QLD, SA and VIC

Impact of Carbon Prices on Electricity Prices

Results for Europe and Australia

- Experience from EU-ETS suggests that expectation about carbon price was added to electricity futures prices
- Mixed results on relationship between carbon and electricity spot prices (Bunn & Fezzi, 2009; Nazifi & Milunovich, 2010)
- Strong relationship between returns of EU-ETS carbon futures and electricity futures prices (Gronwald et al, 2011)
- For Australia, simulation studies on carbon pass-through suggest a range from 17% (McLennan Magasanik Associates 2006), 100% (ROAM Consulting 2008), up to more than 300% (Simshauser & Doan 2009)

Empirical Analysis

The Data

- Model for spot price behaviour in regional markets is calibrated based on daily price observations from 2003-2012
- Futures contracts are available in states of NSW, VIC, QLD and SA operated by NEMMCO
- We consider futures quotes from d-cypha trade for **baseload futures contracts** Q2-Q4 2012, Q1 2013 and yearly contracts for 2012, 2013 and 2014
- Expected increase in electricity prices is calculated based on carbon price and average emission intensities per MWh electricity and for each regional market individually

Empirical Analysis

Calculating a premium for the carbon price

- We assume the following relationship between futures quotes and expected spot prices:

$$F_{t,[T_1,T_2]} = E\left(S_{[T_1,T_2]}\right) + \pi_{R,[T_1,T_2]} + \pi_{C,[T_1,T_2]}$$

- Futures quotes $F_{t,[T_1,T_2]}$ are taken from D-Cypha trade
- Expected spot price $E(S_{[T_1,T_2]})$ simulated from spot price model
- Risk premiums $\pi_{R[T1,T2]}$ are calculated as mean of historical ex-post risk premiums (2003-2012)
- Additional premium for carbon price $\pi_{C[T1,T2]}$ is calculated

Empirical Analysis

Modeling spot price behavior

- A common approach is to split the observed system prices P_t into a deterministic part f(t) that comprises all kinds of seasonal behavior and a purely stochastic component S_t which represents the only source of uncertainty in prices:

$$P_t = f(t) + S_t$$

- Seasonality is often modeled using constant step functions (Lucia and Schwartz, 2000), sinusoidal functions with trend (Bierbrauer et al, 2007), Wavelets (Weron, 2006), sinus with additional EWMA component (De Jong, 2006) etc.

Empirical Analysis

Modeling spot price behavior

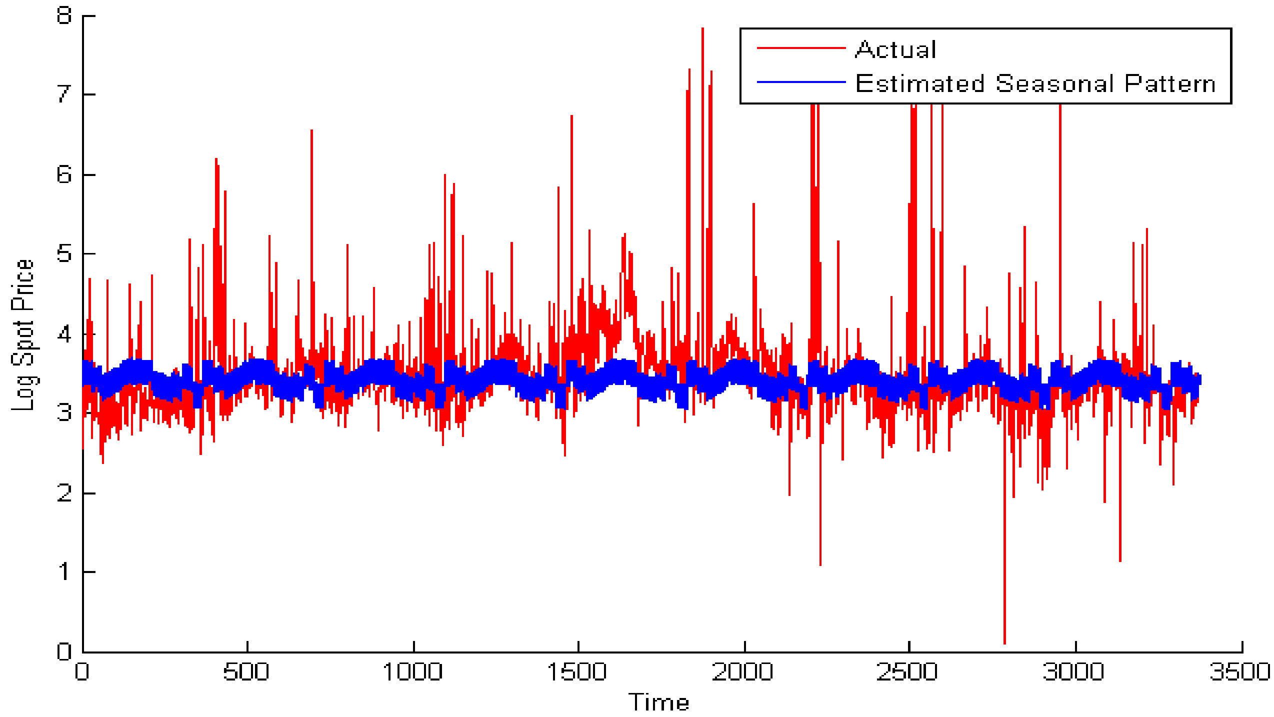
- Due to the extreme volatility in Australian electricity markets, we model log prices instead of the original spot price
- We fit a combination of trend, constant step functions and sinus to model the seasonality in each regional market

$$f(t) = \alpha + \beta t + dD_{\mathrm{day}} + mD_{\mathrm{month}} + \gamma \sin((t+\tau)\frac{2\pi}{365})$$

- To obtain more robust estimates, seasonal pattern estimation is conducted based on data that has been cleaned for extreme observations using a recursive filter, see e.g. Clewlow & Strickland (2000), Janczura et al. (2012)

Empirical Analysis

Modeling the spot price behavior



Log Spot Prices and estimated seasonal pattern for South Australian market (2003-2012)

Empirical Analysis

Modeling spot price behavior

- To model the stochastic component we use a two-state regime switching model (see e.g. Hamilton, 1989; Huisman & De Jong, 2002; Bierbrauer et al., 2007)
- For each regime a separate and independent price process can be specified
- Switching mechanism between the states (or regimes) of a MRS model is assumed to be an unobserved Markov chain R_t described by transition matrix P

$$\mathbf{P} = (p_{ij}) = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix} = \begin{pmatrix} 1 - p_{12} & p_{12} \\ p_{21} & 1 - p_{21} \end{pmatrix}$$

Empirical Analysis

Modeling spot price behavior

- We assume a simple mean-reverting process for the 'base regime' (R_t=1)

$$\ln(S_{1,t}) = \ln(S_{1,t-1}) + \alpha_1(\mu_1 - \ln(S_{1,t-1})) + \varepsilon_{1,t} \qquad \varepsilon_{1,t} \sim N(0, \sigma_1^2)$$

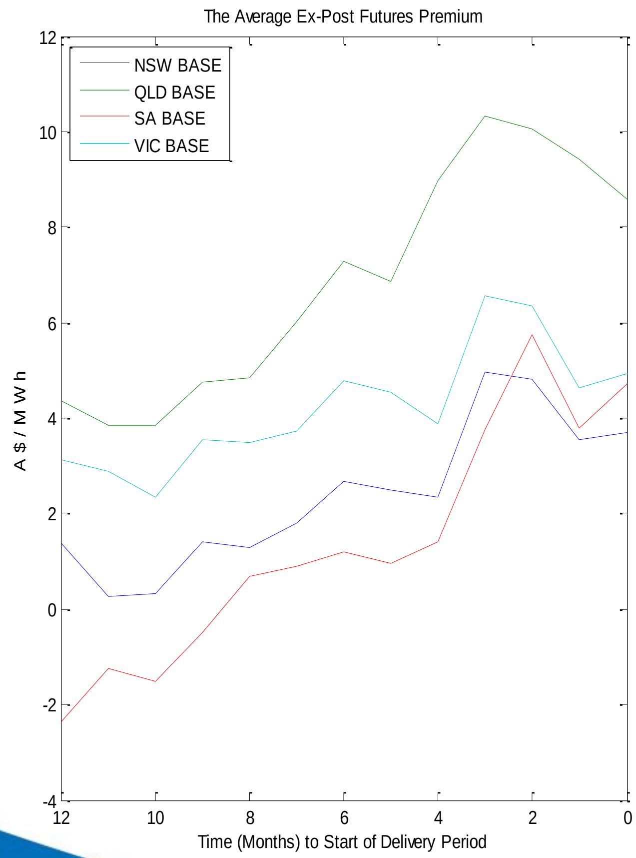
- For the 'spike regime' (R_t=2) we assume a Gaussian distribution with higher volatility (and higher price level)

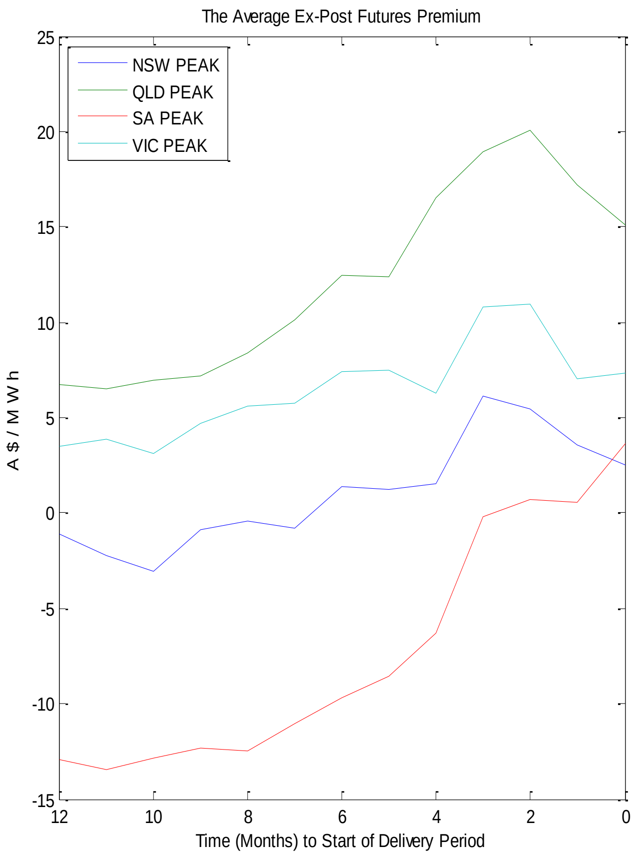
$$\ln(S_{2,t}) = c_2 + \varepsilon_{2,t} \qquad \varepsilon_{2,t} \sim N(0, \sigma_2^2)$$

- Estimation is conducted using Expectation-Maximization (EM) algorithm (Hamilton, 1989; Kim, 1994)

Empirical Analysis

Historical realized risk premiums (Maturity effects)





Empirical Analysis

Historical realized Risk Premiums (Seasonal effects)

State	NSW	QLD	SA	VIC
Base	5.76	6.00	3.94	3.73
Peak	10.26	11.01	9.13	5.73
Q1 (Base)	11.81	15.57	8.37	10.91
Q2 (Base)	4.40	4.27	-1.33	-0.42
Q3 (Base)	7.40	5.60	3.94	6.25
Q4 (Base)	-0.93	5.48	2.67	5.95

Empirical Analysis

Emission Intensities

State	Emission Factor	Estimated Additional Cost (2012-2013)	Output (TwH)
NSW	0.90	$20.70	73.4
QLD	0.89	$20.47	59.3
VIC	1.23	$28.29	56.1
SA	0.60	$13.80	14.3
TAS	0.32	$7.36	8.5

Empirical Analysis

NSW Cal2013 Futures price (May 3, 2011 – May 3,2012)

Empirical Analysis

Futures Quotes 25.03.2012 (Base Load)

State	NSW	QLD	SA	VIC
Q1/2012	$25.85	$30.00	$26.15	$24.45
Q2/2012	$31.25	$28.00	$27.00	$27.25
Q3 / 2012	$54.40	$49.30	$47.50	$49.00
Q4 / 2012	$55.35	$51.25	$52.50	$48.65
Q1/ 2013	$64.35	$64.10	$71.75	$62.20
Cal 2013	$58.00	$54.59	$56.50	$52.65
Cal 2014	$59.24	$54.89	$61.84	$53.63

Empirical Analysis

Model for carbon premium

$$\pi_{C,[T_1,T_2]} = \mathrm{F}_{t,[T_1,T_2]} - [E\left(S_{[T_1,T_2]}\right) + \pi_{R,[T_1,T_2]}]$$

- Futures quotes $F_{t,[T1,T2]}$ on March 25, 2012
- Expected spot price $E(S_{[T1,T2]})$ simulated from spot price model (N=1000)
- Risk premiums $\pi_{R[T1,T2]}$ are calculated as median of historical ex-post risk premiums (2003-2011)

Empirical Analysis

Results for Carbon Tax Premium (25.03.2012)

State	NSW	QLD	SA	VIC
Q2/2012	$1.30	-$1.25	$1.03	-$1.51
Expected	$0	$0	$0	$0
Q3 / 2012	$22.10	$17.44	$13.16	$22.95
Q4 / 2012	$18.63	$23.53	$16.53	$28.58
Q1/ 2013	$19.92	$19.14	$12.39	$21.71
Expected	$20.70	$20.47	$13.80	$28.29
Cal 2013	$14.37	$17.02	$9.95	$17.35
Expected	$21.22	$20.98	$14.15	$29.00
Cal 2014	$15.72	$18.58	$12.05	$18.33
Expected	$22.30	$22.05	$14.87	$30.47

Empirical Analysis

Results on premium for carbon price

- Our model yields an appropriate fit to nearest-term futures quotes Q2 2012 that are not affected by carbon price
- We find that the estimated pass-through cost of carbon is in its expected range (between 75%-115%) for the near-term futures contracts Q3/2012, Q4/2012 and Q1/2013
- For yearly contracts with delivery in 2013 and 2014 the estimated pass-through cost is clearly lower and only between 60%-80% of what could be expected based on regional emission intensities

Empirical Analysis

Possible reasons

- Model risk (seasonal pattern, stochastic process, futures risk premiums are all uncertain)
- Risk premiums tend to include a compensation for the risk of price spikes and/or high levels electricity prices.
- In recent periods (Q1/2011-Q1/2012)
  - (i) only very few price spikes could be observed in Australian electricity markets, while
  - (ii) Q1/2012 prices were on a comparably low level
- Potential Policy changes in Australia
- As a result current futures risk premiums and market expectations on seasonal patterns might be lower than assumed in this study.

Conclusions

- One of the first studies to investigate the impact of forthcoming carbon tax on actual futures prices in Australian electricity markets
- We find that after controlling for risk premiums in electricity futures markets, there is still a significant (anticipated) increase in prices by market participants
- However, estimated pass-through costs of carbon for 2013 and 2014 are generally lower than what could be expected based on regional emission intensities
- Results are subject to model risk and uncertainty about actual seasonal pattern, stochastic process, futures risk premiums, policy changes

Future Work

- Re-estimate model for spot prices using alternative techniques for seasonal pattern and stochastic process / inclusion of generation profiles / marginal fuel costs
- Examine carbon premium through time also including the period when the carbon tax has affected spot prices (after July 2012)
- Use model-based ex-ante futures premium in the analysis
- Additional sensitivity tests with respect to futures premiums / estimated model for spot prices might provide more insights in explaining the carbon premium 'anomaly'
- Examine impact of carbon tax on prices that are passed through to end-users by retailers

Thank you!