# **Pricing and Risk Management for**

## **Highly Cyclical Commodity Markets**

by

### Joe Maisano

A thesis submitted for the degree of Doctor of Philosophy

**University of Technology Sydney** 

**May 2016** 

## Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:			
Date:			

#### **Acknowledgments**

For the chapter (and paper) titled *A Lognormal Model for PASA-Based Load Forecasting in the NEM* the authors would like thank Ben Vanderwaal from Roam Consulting for helpful feedback on the draft of this paper and a fruitful discussion around the MTPASA process.

For the chapter (and paper) titled *A method of forecasting wholesale electricity market prices* the authors would like to thank Prof. Alex Novikov and Prof. Pavel Shevchenko<sup>1</sup> for proof reading and comments.

For the chapter (and paper) titled *An Analytical Model for Standard and Volumetric Cap Pricing in Electricity Markets* the authors would like to thank Dr. Igor Skryabin<sup>2</sup> for proof reading and comments.

For the chapter titled *Parametric Distributions for Price Simulation in Electricity Markets* the authors would like to express their gratitude to Prof. Alex Novikov for general guidance and feedback. We would also like to thank Mr. Mal Campbell, Senior Business Consultant, Energy One Ltd., for fruitful and robust discussions.

For this thesis as a whole, I would like to thank my supervisor, Prof. Alex Novikov (Professor of Mathematics at the Department of Mathematical Sciences, University of Technology Sydney). I would also like to thank the Australian Technology Network's Industry Doctoral Training Centre (of which I have been a student while writing this thesis), it's past directors Prof. Lee White, Prof. Murray Cameron and Dr. Matt Brown and the UTS IDTC Node Leader Associate Prof. Yakov Zinder. I thank the IDTC industry partner Trading Technology Australia Pty. Ltd. for partly funding this research, identifying the research problem and supplying a full-time employee (myself) for the duration of the research.

I would also like to personally thank my co-authors Dr. Alex Radchik, Dr. Igor Skryabin and Dr. Tim Ling for their work on the four papers which have been included in this thesis.

Finally I would especially like to thank my co-supervisor, Dr. Alex Radchik for providing the inspiration for many of the approaches we took, and his general hard work and patience over the years.

<sup>&</sup>lt;sup>1</sup>Senior Principal Research Scientist at CSIRO, Adjunct Professor, School of Mathematics and Statistics, University of NSW, Adjunct Professor, School of Mathematical Sciences, University of Technology Sydney.

<sup>&</sup>lt;sup>2</sup>Business Development Managers, Centre for Sustainable Energy Systems at Australian National University.

## **Contents**

1	Intr	oductio	n	1
	1.1	Abstra	ct	1
	1.2	Thesis	Structure	2
	1.3	Object	ives and Scope	4
	1.4	List of	Publications	6
2	Mar	ket Ov	erview and Literature Review	7
	2.1	Marke	t Overview	8
		2.1.1	The Physical Market	8
		2.1.2	The Spot Market	0
	2.2	NEM I	Principles of Operation	1
		2.2.1	Dispatch	3
		2.2.2	Settlement residues	6
	2.3	Electri	city Risk Management	9
		2.3.1	Types of Risk	9
		2.3.2	Risk Measures	0
		2.3.3	Earnings at Risk	1
		2.3.4	Value at Risk	3
		2.3.5	EaR and VaR as Risk Management Tools	4
		2.3.6	How the NEM differs from Financial Markets	5
	2.4	Hedgi	ng	9
		2.4.1	Swaps	0
	2.5	The Fu	utures Market	5

	2.6	Option	S	36
		2.6.1	Swaptions	37
		2.6.2	Caps and Floors	37
		2.6.3	Callable Swap	38
		2.6.4	Future Options	38
		2.6.5	Hedging in Practice	38
	2.7	Deman	nd Forecasting	48
	2.8	Price F	Forecasting	49
		2.8.1	Price Forecasting Literature	49
	2.9	Deriva	tive Pricing	52
		2.9.1	Exchange Settlement Prices	52
		2.9.2	Adjustment for Higher Moments	59
		2.9.3	Cap Contracts	61
3	A Lo	ognorm	al Model for PASA-Based Load Forecasting in the NEM	67
	3.1	Deman	nd Forecasts	68
	3.2	Model		68
		3.2.1	Deriving the Distribution and Forward Curves	70
	3.3	Simplf	ied Model	76
	3.4	Results	s - FLC	77
	3.5	Results	s - SFLC	83
	3.6	Conclu	isions	83
4	A m	ethod o	f forecasting wholesale electricity market prices	85
-	4.1		action	86
	4.2		ations	87
	1.2	4.2.1	Spot price formation and price-demand correlation	87
		4.2.2	Particle Motion Analogy	91
		4.2.3	The Least Action Principle	92
	4.3		The Least Action Finiciple	95
	ਜ.੭		Discrete representation	93
		4 7 1	LAISCLUIG TEULENEULAUUU	4/

	4.4	Results and Discussion	
		4.4.1 Comparison with AEMO forecasts	
		4.4.2 Price of Error	
	4.5	Conclusions	
5	An A	Analytical Model for Standard and Volumetric Cap Pricing in Electricity Market	:s108
	5.1	Introduction	
	5.2	Model	
	5.3	Results and Discussion	
		5.3.1 1 Week Cap	
		5.3.2 Quarterly Cap	
		5.3.3 Cap Price Range	
	5.4	Volumetric Option	
		5.4.1 Volumetric Floor	
		5.4.2 Volumetric Cap	
	5.5	Results	
	5.6	Conclusions	
6	Con	nclusion 125	
	6.1	Major Findings	
	6.2	Applications	
		6.2.1 Portfolio management	
		6.2.2 Renewable generation	
		6.2.3 Demand side and storage	
	6.3	Future directions	
A	Mar	rket Operators and Regulators 131	
	A.1	Jurisdictions and Responsibilities	
	A.2		
	A.3		
	A.4	NEMMCO	

	A.5	Australian Energy Market Operator (AEMO)	135
В	Settl	ement Residue Auctions	136
	B.1	The Auction Process	136
	B.2	Clearing	138
C	Para	nmetric Distributions for Price Simulation in Electricity Markets	139
	C.1	Convergence	144
	C.2	Conclusions	145

# **List of Figures**

2.1	National Electricity Market Pool Model	12
2.2	Typical Bid-stack (as of 18:00, 24/06/2003)	15
2.3	Typical Bid-stack (annotated)	16
2.4	NEM Operational Cycle	17
2.5	Inter-Regional Settlement	18
2.6	Conceptual Earnings at Risk Distribution	23
2.7	Conceptual VaR Distribution	24
2.8	VaR and the Expected Loss Distribution	25
2.9	Conceptual Diagram of Electricity Swap Transaction	31
2.10	Example Swap Transaction	32
2.11	Expected Portfolio Load (1% of State Load)	40
2.12	Expected Base Portfolio Load (1% of State Load)	41
2.13	Expected Peak Portfolio Load (1% of State Load)	42
2.14	Expected and 99% Upper Bound Peak Portfolio Load	43
2.15	Expected and 99% Upper Bound Base Portfolio Load	44
2.16	Typical week in Q3 2009 - Hedge position	46
2.17	Typical week in Q4 2009 - Hedge position	47
2.18	Typical week in Q1 2010 - Hedge position	47
2.19	Typical week in Q2 2010 - Hedge position	48
2.20	A taxonomy of electricity spot forecasting approaches	50
2.21	VIC Calendar Base 2012 Futures Settlement Prices	57
2.22	VIC Calendar Base 2012 Futures Settlement Prices	58
2.23	NSW State Demand and Spot Price	62

2.24	NSW State Demand and Spot Price	63
2.25	Distributions for NSW Working Wednesdays	65
3.1	Solutions for equation (3.12) (NSW)	73
3.2	Comparison of low and high roots (over time)	75
3.3	NSW backtest, FY 2012 - MTPASA Generated 21 June 2011	78
3.4	VIC backtest, FY 2012 - MTPASA Generated 21 June 2011	78
3.5	NSW backtest, FY 2012 - MTPASA Generated 21 June 2011	79
3.6	NSW backtest, FY 2012 - MTPASA Generated 21 June 2011	79
3.7	NSW backtest, FY 2012 - MTPASA Generated 21 June 2011	80
3.8	NSW backtest, FY 2012 - MTPASA Generated 21 June 2011	80
3.9	VIC backtest, FY 2012 - MTPASA Generated 21 June 2011	81
3.10	VIC backtest, FY 2012 - MTPASA Generated 21 June 2011	81
3.11	VIC backtest, FY 2012 - MTPASA Generated 21 June 2011	82
3.12	VIC backtest, FY 2012 - MTPASA Generated 21 June 2011	82
4.1	Historical (Actual) demand and price (1 week in Jul 2011)	88
4.1 4.2	Historical (Actual) demand and price (1 week in Jul 2011)	88 89
4.2	Demand/Price correlations	89
4.2 4.3	Demand/Price correlations	89 91
4.2 4.3 4.4	Demand/Price correlations	89 91 92 99
4.2 4.3 4.4 4.5	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time	89 91 92 99 100
4.2 4.3 4.4 4.5 4.6	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time  Forward Price Curve and actual (historical) price vs time  FPC, AEMO Forecast and Actual (NSW)- April 2015	89 91 92 99 100
4.2 4.3 4.4 4.5 4.6 4.7	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time  Forward Price Curve and actual (historical) price vs time  FPC, AEMO Forecast and Actual (NSW)- April 2015	89 91 92 99 100 103
4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time  Forward Price Curve and actual (historical) price vs time  FPC, AEMO Forecast and Actual (NSW)- April 2015  AEMO demand forecasts and actual demand (NSW)- April 2015	89 91 92 99 100 103 103
4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time  Forward Price Curve and actual (historical) price vs time  FPC, AEMO Forecast and Actual (NSW)- April 2015  AEMO demand forecasts and actual demand (NSW)- April 2015  FPC, AEMO Forecast and Actual (QLD)- April 2015	89 91 92 99 100 103 103 104
4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time  Forward Price Curve and actual (historical) price vs time  FPC, AEMO Forecast and Actual (NSW)- April 2015  AEMO demand forecasts and actual demand (NSW)- April 2015  FPC, AEMO Forecast and Actual (QLD)- April 2015  AEMO demand forecasts and actual demand (QLD)- April 2015  Cap pricing, July 1st - July 7th, 2011	89 91 92 99 100 103 103 104
4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10 5.1	Demand/Price correlations  Merit Order  Particle Analogy  Forward Price Curve and forecast demand vs time  Forward Price Curve and actual (historical) price vs time  FPC, AEMO Forecast and Actual (NSW)- April 2015  AEMO demand forecasts and actual demand (NSW)- April 2015  FPC, AEMO Forecast and Actual (QLD)- April 2015  AEMO demand forecasts and actual demand (QLD)- April 2015  Cap pricing, July 1st - July 7th, 2011  Q3, 2011	89 91 92 99 100 103 104 104 116

B.1	NEM as system of nodes and Directional Interconnectors	37
C.1	Second derivative for $y_0 = 0$	42
C.2	Second derivative for $y_0 = \sqrt{3}$	42
C.3	Second derivative for $y_0 = -\sqrt{3}$	42
C.4	'Phase diagram' in $\kappa - s$ space	43
C.5	Gram-Charlier density for the point inside the dashed domain	43
C.6	Gram-Charlier density for the point outside of the dashed domain	43
C.7	Series convergence for $R = 0.7$	45

## **List of Tables**

2.1	Changes in Market Price Cap (VoLL)	28
2.2	Hedging - Base Futures	41
2.3	Hedging - Adding Peak Futures	42
2.4	Hedging - Adding Cap Futures	45
2.5	Hedging - Derivative prices as at 30 June 2009	45
5.1	Parameters for Curve	15
5.2	Parameters for Curve	17