Real Options and Merchant Operations of Energy and Other Commodities

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Nicola Secomandi

Carnegie Mellon University
Pittsburgh, PA 15213-3890
USA
ns7@andrew.cmu.edu

Duane J. Seppi

Carnegie Mellon University
Pittsburgh, PA 15213-3890
USA
ds64@andrew.cmu.edu

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Real Options and Merchant Operations of Energy and Other Commodities

Nicola Secomandi[1] and Duane J. Seppi[2]

[1] *Tepper School of Business, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213-3890, USA, ns7@andrew.cmu.edu*
[2] *Tepper School of Bushiness, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213-3890, USA, ds64@andrew.cmu.edu*

Abstract

The value chain for energy and other commodities entails physical conversions through refineries, power plants, storage facilities, and transportation and other capital-intensive infrastructure. When the operation of such commodity conversion assets occurs alongside liquid markets for the input and output commodities, the operating flexibility of conversion assets can be managed as real options on the underlying commodity prices. Merchant operations is an integrated trading and operations approach that (i) buys and sells commodities to support market-value maximizing operating policies and (ii) values conversion assets, for capital budgeting and trading purposes, based on the cash flows such policies produce. This monograph provides a unique integrated finance and operations perspective on the topic of merchant operations. In particular, this monograph introduces the concept of merchant operations; presents the basic principles of option valuation; surveys foundational models of commodity and energy price evolution; analyzes the structure of optimal operating policies for commodity

conversions, focusing specifically on inventory and other intertemporal linkages in storage, inventory acquisition and disposal, and swing assets; considers a variety of heuristic storage operating policies; and discusses future trends in this multidisciplinary area of research and business applications.

In honor of the late Professor Paul R. Kleindorfer

Contents

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Aim and Scope

Commodity conversion assets perform various transformation processes, including the production, refining, industrial and commercial consumption, and distribution of physical commodities and energy sources, such as grains, metals, electricity, coal, crude oil, and natural gas. This monograph deals with the management and valuation of conversion assets. Commodities and energy are traded on physical markets. It is thus natural to approach the management of commodity conversion assets from a merchant perspective, which adjusts the level of the conversion activities to profit from the dynamics of commodity prices. We introduce the expression *merchant operations* to describe this approach.

Implementing merchant operations to maximize the market value of commodity conversion assets is a complex task. It requires both models of the evolution of commodity prices and stochastic optimization models of the conversion activities. The existence of traded contracts on commodities and energy sources allows commodity conversion assets to be interpreted as real options on the prices of the underlying commodities. This real option interpretation greatly facilitates formulating the necessary mathematical models.

The valuation of real options shares the same theoretical foundations as the valuation of financial options. However, the real options that arise in the context of merchant operations are distinguished from financial options by one or more of the following features: (i) decisions at multiple dates, (ii) intertemporal linkages across decisions, (iii) multiple underlying variables, (iv) payoffs determined by operational costs and contractual provisions, (v) engineering-based constraints on operating decisions, and (vi) quantity decisions rather than binary exercise/no-exercise decisions. American and Bermudan financial options also involve decisions at multiple dates with intertemporal linkages, but the other features in this list are largely unique to merchant operations. Intertemporal linkages are particularly important in merchant operations and are related to inventory, the scale of operations, and delays and costs incurred when switching between operating modes. Moreover, even when the structure of an optimal operating (exercise) policy can be explicitly characterized, determining such a policy typically involves numerical computation and approximations. Closed-form solutions are rare in merchant operations, while they are more widespread for financial options.

The aim of this monograph is to present the basic tenets of merchant operations, that is, the management of commodity conversion assets as real options on commodity prices. The scope of this monograph is on the foundational principles that underlie the valuation of real options, on basic models of both the evolution of commodity and energy prices and commodity conversion assets, and on optimal and heuristic operating policies with a focus on commodity storage assets.

A unique aspect of merchant operations is the integration of financial and operational management aspects. This monograph reflects this integrated perspective. Section 2 introduces commodity conversion assets and merchant operations. Sections 3 and 4 discuss the valuation of commodity options and models of the evolution of commodity and energy prices, respectively. Sections 5 and 6 describe the merchant management of commodity storage assets. Section 7 deals with inventory disposal/acquisition and swing assets. Future trends in merchant-operations research and applications are discussed in Section 8.

References

[1] D. Adelman, "Math programming approaches to approximate dynamic programming," Tutorial, INFORMS Annual Meeting, Pittsburgh, PA, USA, 2006.

[2] R. Adkins and D. Paxson, "Reciprocal energy-switching options," *Journal of Energy Markets*, vol. 4, no. 1, pp. 91–120, 2011.

[3] F. Allen and D. Gale, "Optimal security design," *Review of Financial Studies*, vol. 1, no. 3, pp. 229–263, 1988.

[4] L. Andersen and M. Broadie, "Primal-dual simulation algorithm for pricing multidimensional American options," *Management Science*, vol. 50, no. 9, pp. 1222–1234, 2004.

[5] O. Arvesen, V. M. ø, S.-E. Fleten, and A. T. S. Westgaard, "Linepack storage valuation under price uncertainty," *Energy*, vol. 52, no. 1, pp. 155–164, 2013.

[6] D. Backus, B. R. Routledge, and S. E. Zin, "Exotic preferences for macroeconomists," in *NBER Macroeconomics Annual 2004,* vol. 19 of *NBER Chapters*, pp. 319–414, National Bureau of Economic Research, Inc., 2005.

[7] S. Baker and B. Routledge, "The price of oil risk," Working Paper, 2012.

[8] R. Bansal and A. Yaron, "Risks for the long run: A potential resolution of asset pricing puzzles," *Journal of Finance*, vol. 59, no. 4, pp. 1481–1509, 2004.

[9] C. Barrera-Esteve, F. Bergeret, C. Dossal, E. Gobet, A. Meziou, R. Munos, and D. Reboul-Salze, "Numerical methods for the pricing of swing options: A stochastic control approach," *Methodology And Computing In Applied Probability*, vol. 8, no. 4, pp. 517–540, 2006.

[10] R. Bellman, "On the theory of dynamic programming — A warehousing problem," *Management Science*, vol. 2, no. 3, pp. 272–275, 1956.

[11] D. Belomestny, C. Bender, and J. Schoenmakers, "True upper bounds for Bermudan products via non-nested Monte Carlo," *Mathematical Finance*, vol. 19, no. 1, pp. 53–71, 2009.
[12] C. Bender, "Dual pricing of multi-exercise options under volume constraints," *Finance and Stochastics*, vol. 15, no. 1, pp. 1–26, 2011.
[13] F. E. Benth, J. Š. Benth, and S. Koekebakker, *Stochastic Modeling of Electricity and Related Markets*. Singapore: World Scientific Publishing, 2008.
[14] P. Berling and V. Martínez-de-Albéniz, "Optimal inventory policies when purchase price and demand are stochastic," *Operations Research*, vol. 59, no. 1, pp. 109–124, 2011.
[15] D. P. Bertsekas, *Dynamic Programming and Optimal Control — Volume I*. Belmont, MA, USA: Athena Scientific, third ed., 2005.
[16] D. P. Bertsekas and J. N. Tsitsiklis, *Neuro-Dynamic Programming*. Belmont, MA, USA: Athena Scientific, 1996.
[17] H. Bessembinder, "Systematic risk, hedging pressure, and risk premiums in futures markets," *Review of Financial Studies*, vol. 5, no. 4, pp. 637–667, 1992.
[18] H. Bessembinder and K. Chan, "Time varying risk premia and forecastable returns in futures markets," *Journal of Financial Economics*, vol. 32, no. 2, pp. 169–193, 1992.
[19] P. Bjerksund, G. Stensland, and F. Vagstad, "Gas storage valuation: Price modeling v. optimization methods," *The Energy Journal*, vol. 32, no. 1, pp. 203–227, 2011.
[20] F. Black, "The pricing of commodity contracts," *Journal of Financial Economics*, vol. 3, no. 1–2, pp. 167–179, 1976.
[21] F. Black and M. Scholes, "The pricing of options and corporate liabilities," *Journal of Political Economy*, vol. 81, no. 3, pp. 637–654, 1973.
[22] C. Blanco, D. Soronow, and P. Stefiszyn, "Multi-factor models for forward curve analysis: An introduction to Principal Component Analysis," *Commodities Now*, pp. 76–78, June 2002.
[23] J. F. Bonnans, Z. Cen, and T. Christel, "Energy contracts management by stochastic programming techniques," *Annals of Operations Research*, vol. 200, no. 1, pp. 199–222, 2012.
[24] J. F. Bonnans, Z. Cen, and T. Christel, "Sensitivity analysis of energy contracts by stochastic programming techniques," in *Numerical Methods in Finance,* Springer Proceedings in Mathematics, (R. Carmona, P. D. Moral, P. Hu, and N. Oudjane, eds.), pp. 447–471, Berlin Heidelberg: Springer-Verlag, 2012.
[25] A. Boogert and C. de Jong, "Gas storage valuation using a Monte Carlo method," *Journal of Derivatives*, vol. 15, no. 3, pp. 81–98, 2008.
[26] A. Boogert and C. de Jong, "Gas storage valuation using a multifactor price process," *Journal of Energy Markets*, vol. 4, no. 4, pp. 29–52, 2011/12.
[27] A. Boogert and D. Maziéres, "A radial basis function approach to gas storage valuation," *Journal of Energy Markets*, vol. 6, no. 2, pp. 19–50, 2013.
[28] S. Borovkova and H. Geman, "Seasonal and stochastic effects in commodity forward curves," *Review of Derivatives Research*, vol. 9, no. 2, pp. 167–186, 2006.

[29] S. Borovkova and H. Geman, "Forward curve modeling in commodity markets," in *Risk Management in Commodity Markets: From Shipping to Agriculturals and Energy*, (H. Geman, ed.), pp. 9–32, Chichester, UK: John Wiley & Sons, 2008.

[30] O. Boyabatli, P. R. Kleindorfer, and S. R. Koontz, "Integrating long-term and short-term contracting in beef supply chains," *Management Science*, vol. 57, no. 10, pp. 1771–1787, 2011.

[31] P. P. Boyle, M. Broadie, and P. Glasserman, "Monte Carlo methods for security pricing," *Journal of Economic Dynamics and Control*, vol. 21, no. 8–9, pp. 1267–1321, 1997.

[32] A. Brace, D. Gatarek, and M. Musiela, "The market model of interest rate dynamics," *Mathematical Finance*, vol. 7, no. 2, pp. 127–155, 1997.

[33] L. E. T. Brandão, G. Master Penedo, and C. Bastian-Pinto, "The value of switching inputs in a biodiesel production plant," *European Journal of Finance*, vol. 19, no. 7–8, pp. 674–688, 2013.

[34] D. Breeden and R. Litzenberger, "Prices of state-contingent claims implicit in option prices," *Journal of Business*, vol. 51, no. 4, pp. 621–651, 1978.

[35] M. J. Brennan, "Stochastic models and option models," in *The price of convenience and the valuation of commodity contingent claims*, (D. L. and B. Oksendal, eds.), pp. 33–71, North Holland, Amsterdam: North Holland, 1991.

[36] M. J. Brennan and E. S. Schwartz, "Evaluating natural resource investments," *Journal of Business*, vol. 58, no. 2, pp. 135–157, 1985.

[37] M. Broadie and P. Glasserman, "Estimating security price derivatives using simulation," *Management Science*, vol. 42, no. 2, pp. 269–285, 1996.

[38] D. B. Brown and J. E. Smith, "Optimal sequential exploration: Bandits, clairvoyants, and wildcats," *Operations Research*, vol. 61, no. 3, pp. 644–665, 2013.

[39] D. B. Brown, J. E. Smith, and P. Sun, "Information relaxation and duality in stochastic dynamic programs," *Operations Research*, vol. 58, no. 4, pp. 785–801, 2010.

[40] B. Burger, B. Graeber, and G. Schindlmayr, *Managing Energy Risk: An Integrated View on Power and Other Energy Markets*. Chichester, UK: John Wiley & Sons, 2007.

[41] B. Buyuksahin, M. S. Haigh, J. H. Harris, J. A. Overdahl, and M. A. Robe, "Fundamentals, trader activity and derivative pricing," Working Paper, 2008.

[42] A. S. Cahn, "The Warehouse Problem," *Bulletin of the American Mathematical Society*, vol. 54, no. 11, no. 11, p. 1073, 1948.

[43] L. Caramellino and A. Zanette, "Monte Carlo methods for pricing and hedging American options in high dimensions," *Risk and Decision Analysis*, vol. 2, no. 4, pp. 207–220, 2010/2011.

[44] M. Carlson, Z. Khokher, and S. Titman, "Equilibrium exhaustible resource price dynamics," *Journal of Finance*, vol. 62, no. 4, pp. 1663–1703, 2007.

[45] R. Carmona and V. Durrleman, "Pricing and hedging spread options," *Society for Industrial and Applied Mathematics Review*, vol. 45, no. 4, pp. 627–685, 2003.

[46] R. Carmona and M. Ludkovski, "Valuation of energy storage: An optimal switching approach," *Quantitative Finance*, vol. 10, no. 4, pp. 359–374, 2010.
[47] A. Carverhill, "When is the short rate Markovian?," *Mathematical Finance*, vol. 4, no. 4, pp. 305–312, 1994.
[48] J. Casassus and P. Collin-Dufresne, "Stochastic convenience yields implied from interest rates and commodity futures," *Journal of Finance*, vol. 60, no. 5, pp. 2283–2331, 2005.
[49] J. Casassus, P. Collin-Dufresne, and B. R. Routledge, "Equilibrium commodity prices with irreversible investment and non-linear technologies," Working Paper, 2008.
[50] B. Casselman, "Natural-gas forecast is hot," *The Wall Street Journal*, June 23 2008.
[51] S. Chandramouli and M. B. Haugh, "A unified approach to multiple stopping and duality," *Operations Research Letters*, vol. 40, no. 4, pp. 258–264, 2012.
[52] S. H. Chang, M. C. Fu, J. Hu, and S. I. Marcus, *Simulation-based Algorithms for Markov Decision Processes*. London, UK: Springer, 2007.
[53] A. Charnes and W. W. Cooper, "Generalization of the warehousing model," *Operational Research Quarterly*, vol. 6, no. 4, pp. 131–172, 1955.
[54] A. Charnes, J. Drèze, and M. Miller, "Decision and horizon rules for stochastic planning problems: A linear example," *Econometrica*, vol. 34, no. 2, pp. 307–330, 1966.
[55] C. Chaton and L. Durand-Viel, "Real asset valuation under imperfect competition: Can we forget about market fundamentals?," *Journal of Economics & Management Strategy*, vol. 22, no. 1, pp. 125–139, 2013.
[56] G. Chazan, "Russia outflanks EU's pipeline plan," *The Wall Street Journal*, June 16 2008.
[57] N. Chen and Y. Liu, "American option sensitivities estimation via a generalized IPA approach," Working Paper, Department of Systems Engineering and Engineering Management, The Chinese University of Hong Kong, 2012.
[58] Z. Chen and P. A. Forsyth, "A semi-Lagrangian approach for natural gas storage valuation and optimal operation," *SIAM Journal on Scientific Computing*, vol. 30, no. 1, pp. 339–368, 2007.
[59] C. Chiarella, B. Kang, C. Nikitopoulos-Sklibosios, and T. To, "The return-volatility relation in commodity futures markets," Working Paper 336, Quantitative Finance Research Centre, University of Technology, Sidney, Australia, 2013.
[60] L. Clewlow and C. Strickland, *Energy Derivatives: Pricing and Risk Management*. London, UK: Lacima Publications, 2000.
[61] G. Cortazar, M. Gravet, and J. Urzua, "The valuation of multidimensional American real options using the LSM simulation method," *Computers & Operations Research*, vol. 35, no. 1, pp. 113–129, 2008.
[62] G. Cortazar and E. S. Schwartz, "The valuation of commodity-contingent claims," *Journal of Derivatives*, vol. 1, no. 4, pp. 27–39, 1994.
[63] J. C. Cox, S. A. Ross, and M. Rubinstein, "Option pricing: A simplified approach," *Journal of Financial Economics*, vol. 7, no. 3, pp. 229–263, 1979.

[64] Q. Dai and K. J. Singleton, "Specification analysis of affine term structure models," *Journal of Finance*, vol. 55, no. 5, pp. 1943–1978, 2000.
[65] A. Davis, "Morgan Stanley trades energy the old-fashioned way: In barrels," *The Wall Street Journal*, March 2 2005.
[66] A. Davis and R. Gold, "Surge in natural-gas price stoked by new global trade," *The Wall Street Journal*, April 18 2008.
[67] M. Davis and I. Karatzas, "A deterministic approach to optimal stopping, with applications," in *Probability, Statistics and Optimization: A Tribute to Peter Whittle*, (P. Kelly, ed.), pp. 455–466, Chichester, UK: John Wiley & Sons, 1994.
[68] D. P. de Farias and B. V. Roy, "The linear programming approach to approximate dynamic programming," *Operations Research*, vol. 51, no. 6, pp. 850–865, 2003.
[69] C. de Jong and K. Walet, "Gas storage management," in *Managing Energy Price Risk*, pp. 631–647, London, UK: Risk Publications, 2004.
[70] A. Deaton and G. Laroque, "On the behaviour of commodity prices," *Review of Economic Studies*, vol. 59, no. 1, pp. 1–23, 1992.
[71] A. Deaton and G. Laroque, "Competitive storage and commodity price dynamics," *Journal of Political Economy*, vol. 104, no. 5, pp. 896–923, 1996.
[72] F. Delbaen and W. Schachermayer, "A general version of the fundamental theorem of asset pricing," *Mathematische Annalen*, vol. 300, pp. 463–520, 1994.
[73] M. Denault, J. G. Simonato, and L. Stentoft, "A simulation-and-regression approach for stochastic dynamic programs with endogenous state variables," *Computers & Operations Research*, vol. 40, no. 11, pp. 2760–2769, 2013.
[74] S. J. Deng, B. Johnson, and A. Sogomonian, "Exotic electricity options and the valuation of electricity generation and transmission assets," *Decision Support Systems*, vol. 30, no. 3, pp. 383–392, 2001.
[75] V. V. Desai, V. F. Farias, and C. C. Moallemi, "Pathwise optimization for optimal stopping problems," *Management Science*, vol. 58, no. 12, pp. 2292–2308, 2012.
[76] S. K. Devalkar, R. Anupindi, and A. Sinha, "Integrated optimization of procurement, processing and trade of commodities in a network environment," *Operations Research*, vol. 59, no. 6, pp. 1369–1381, 2011.
[77] M. Dewally, L. Ederington, and C. Fernando, "Determinants of trader profits in commodity futures markets," *Review of Financial Studies*, vol. 26, no. 10, pp. 2648–2683, 2013.
[78] A. K. Dixit and R. S. Pindyck, *Investment under Uncertainty*. Princeton, NJ, USA: Princeton University Press, 1994.
[79] J. Dockendorf and D. Paxson, "Continuous rainbow options on commodity outputs: what is the real value of switching facilities?," *European Journal of Finance*, vol. 19, no. 7–8, pp. 645–673, 2013.
[80] S. E. Dreyfus, "An analytic solution of the warehouse problem," *Management Science*, vol. 4, no. 1, pp. 99–104, 1957.

[81] N. Drouin, A. Gautier, B. F. Lamond, and P. Lang, "Piecewise affine approximations for the control of a one-reservoir hydroelectric system," *European Journal of Operational Research*, vol. 89, no. 1, pp. 53–69, 1996.

[82] D. Duffie, *Futures Markets*. Englewood Cliffs, NJ, USA: Prentice Hall, 1989.

[83] D. Duffie, *Dynamic Asset Pricing Theory*. Princeton, NJ, USA: Princeton University Press, 2001.

[84] P. Enders, A. Scheller-Wolf, and N. Secomandi, "Interaction between technology and extraction scaling real options in natural gas production," *IIE Transactions*, vol. 49, no. 9, pp. 643–655, 2010.

[85] L. Epstein and S. Zin, "Substitution, risk aversion, and the temporal behavior of consumption growth and asset returns I: A theoretical framework," *Econometrica*, vol. 57, no. 4, pp. 937–969, 1989.

[86] A. Eydeland and K. Wolyniec, *Energy and Power Risk Management: New Developments in Modeling, Pricing, and Hedging*. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2003.

[87] E. Fama and K. French, "Commodity futures prices: Some evidence on forecast power, premiums and the theory of storage," *Journal of Business*, vol. 60, no. 1, pp. 55–73, 1987.

[88] E. Fama and K. French, "Business cycles and the behavior of metals prices," *Journal of Finance*, vol. 43, no. 5, pp. 1075–1093, 1988.

[89] FEA, "@ENERGY/Storage," http://www.fea.com/products/energy/storage/, 2014.

[90] Federal Energy Regulatory Commission, "Current state of and issues concerning underground natural gas storage. Staff report, docket no. AD04-11-000," Federal Energy Regulatory Commission, Washington, DC, USA, 2004.

[91] B. Felix, O. Woll, and C. Weber, "Gas storage valuation under limited market liquidity: an application in Germany," *European Journal of Finance*, vol. 19, no. 7–8, pp. 715–733, 2013.

[92] J. Felix and C. Weber, "Gas storage valuation applying numerically constructed recombining trees," *European Journal of Operational Research*, vol. 216, no. 1, no. 1, pp. 178–187, 2012.

[93] S. Fiorenzani, *Quantitative Methods for Electricity Trading and Risk Management: Advanced Mathematical and Statistical Methods for Energy Finance*. Basingstoke, UK: Palgrave Macmillan, 2006.

[94] S. Fiorenzani, S. Ravelli, and E. Edoli, *The Handbook of Energy Trading*. Chichester, UK: John Wiley & Sons, 2012.

[95] S.-E. Fleten, A. M. Heggedal, and A. Siddiqui, "Transmission capacity between Norway and Germany — a real options analysis," *Journal of Energy Markets*, vol. 4, no. 1, pp. 121–147, 2011.

[96] S.-E. Fleten and T. K. Kristoffersen, "Short-term hydropower production planning by stochastic programming," *Computers & Operations Research*, vol. 35, no. 8, pp. 2656–2671, 2008.

[97] S.-E. Fleten and S. W. Wallace, "Delta-hedging a hydropower plant using stochastic programming," in *Optimization in the Energy Industry*, (K. J., P. M. Pardalos, S. Rebennack, and M. Scheidt, eds.), pp. 507–524, Berlin, Germany: Springer, 2009.

[98] D. Frestad, "Common and unique factors influencing daily swap returns in the Nordic electricity market, 1997–2005," *Energy Economics*, vol. 30, no. 3, pp. 1081–1097, 2008.
[99] M. C. Fu and J. Hu, "Sensitivity analysis for Monte Carlo simulation of option pricing," *Probability in the Engineering and Information Sciences*, vol. 9, no. 3, pp. 417–449, 1995.
[100] S. Gavirneni, "Periodic review inventory control with fluctuating purchasing costs," *Operations Research Letters*, vol. 32, no. 4, pp. 374–379, 2004.
[101] H. Geman, *Commodities and Commodity Derivatives: Modeling and Pricing for Agriculturals, Metals and Energy*. Chichester, UK: John Wiley & Sons, 2005.
[102] H. Geman and V.-N. Nguyen, "Soybean inventory and forward curve dynamics," *Management Science*, vol. 51, no. 7, pp. 1076–1091, 2005.
[103] C. S. Ghiuvea, J. P. Lehoczky, and D. Seppi, "Pricing swing and other generalized American options," Working Paper, Carnegie Mellon University, Pittsburgh, PA, USA, 2003.
[104] R. Gibson and E. S. Schwartz, "Stochastic convenience yield and the pricing of oil contingent claims," *Journal of Finance*, vol. 45, no. 3, pp. 959–976, 1990.
[105] P. Glasserman, *Monte Carlo Methods in Financial Engineering*. New York, NY, USA: Springer, 2004.
[106] A. Goel and G. Gutierrez, "Integrating commodity markets in the optimal procurement policies of a stochastic inventory system," Working Paper, University of Texas, Austin, TX, USA, 2009.
[107] A. Goel and G. Gutierrez, "Multiechelon procurement and distribution policies for traded commodities," *Management Science*, vol. 57, no. 12, pp. 2228–2244, 2011.
[108] R. Gold, "ConocoPhillips, BP plan pipeline for Alaska gas," *The Wall Street Journal*, April 9 2008.
[109] R. Goldstein, "The term structure of interest rates as a random field," *Review of Financial Studies*, vol. 13, no. 2, pp. 365–384, 2000.
[110] G. Gorton, F. Hayashi, and K. G. Rouwenhorst, "The fundamentals of commodity futures returns," *Review of Finance*, vol. 17, no. 1, pp. 35–105, 2013.
[111] J. Gray and P. Khandelwal, "Realistic natural gas storage models II: Trading strategies," *Commodities Now*, pp. 1–5, September 2004.
[112] J. Gray and P. Khandelwal, "Towards a realistic natural gas storage model," *Commodities Now*, pp. 1–4, June 2004.
[113] V. Guigues, C. Sagastizábal, and J. P. Zubelli, "Robust management and pricing of liquefied natural gas contracts with cancelation options," *Journal of Optimization Theory and Applications*, vol. 161, no. 1, pp. 179–198, 2014.
[114] G. Guthrie, *Real Options in Theory and Practice*. New York, NY, USA: Oxford University Press, Inc., 2009.
[115] P. S. Hagan, D. Kumar, A. S. Lesniewski, and D. E. Woodward, "Managing smile risk," *WILMOTT Magazine*, pp. 84–108, September 2002.
[116] W. J. Hahn and J. S. Dyer, "Discrete time modeling of mean-reverting stochastic processes for real option valuation," *European Journal of Operational Research*, vol. 184, no. 2, pp. 534–548, 2008.

[117] M. Harrision and D. Kreps, "Martingales and arbitrage in multi-period securiteis markets," *Journal of Economic Theory*, vol. 20, no. 3, pp. 381–408, 1979.
[118] M. B. Haugh and L. Kogan, "Pricing American options: A duality approach," *Operations Research*, vol. 52, no. 2, pp. 258–270, 2004.
[119] D. Heath, R. Jarrow, and A. Morton, "Bond pricing and the term structure of interest rates: A new methodology for contingent claim valuation," *Econometrica*, vol. 60, no. 1, pp. 77–105, 1992.
[120] S. L. Heston, "A closed-form solution for options with stochastic volatility with applications to bond and currency options," *Review of Financial Studies*, vol. 6, no. 2, pp. 327–343, 1993.
[121] D. P. Heyman and M. J. Sobel, *Stochastic Models in Operations Research: Volume II, Stochastic Optimization*. Mineola, N.Y., USA: Dover Publications, Inc., 2004.
[122] J. C. Hull, *Risk Management and Financial Institutions*. Boston, MA, USA: Prentice Hall, second ed., 2010.
[123] J. C. Hull, *Options, Futures, and Other Derivatives Securities*. Englewood Cliffs, NJ, USA: Prentice Hall, eight ed., 2012.
[124] B. Jafarizadeh, "Analysis of oil-storage trading using two-factor price model and simulation," *International Journal of Engineering Management and Economics*, vol. 2, no. 1, pp. 20–38, 2011.
[125] P. Jaillet, E. I. Ronn, and S. Tompaidis, "Valuation of commodity-based swing options," *Management Science*, vol. 50, no. 7, pp. 909–921, 2004.
[126] F. Jamshidian, "LIBOR and swap market models and measures," *Finance and Stochastics*, vol. 1, no. 4, pp. 293–330, 1997.
[127] Y. Kabanov and M. Safarian, *Markets with Transaction Costs: Mathematical Theory*. Berlin, Germany: Springer-Verlag, 2009.
[128] N. Kaldor, "Speculation and economic stability," *Review of Economic Studies*, vol. 7, no. 1, pp. 1–27, 1939.
[129] B. A. Kalymon, "Stochastic prices in a single-item inventory purchasing model," *Operations Research*, vol. 19, no. 6, pp. 1434–1458, 1971.
[130] V. Kaminski, ed., *Managing Energy Price Risk*. London, UK: Risk Publications, third ed., 2004.
[131] V. Kaminski, Y. Feng, and Z. Pang, "Value, trading strategies and financial investment of natural gas storage assets," Working Paper, 2008.
[132] V. Kaminski and R. Prevatt, "The natural gas market," in *Managing Energy Price Risk*, pp. 263–323, London, UK: Risk Publications, 2004.
[133] B. Kamrad and R. Ernst, "An economic model for evaluating mining and manufacturing ventures with output yield uncertainty," *Operations Research*, vol. 49, no. 5, no. 5, pp. 690–699, 2001.
[134] R. Kaniel, S. Tompaidis, and A. Zemlianov, "Efficient computation of hedging parameters for discretely exercisable options," *Operations Research*, vol. 56, no. 4, pp. 811–826, 2008.
[135] B. Kazaz and S. Webster, "The impact of yield-dependent trading costs on pricing and production planning under supply uncertainty," *Manufacturing & Service Operations Management*, vol. 13, no. 3, pp. 404–417, 2011.

[136] D. P. Kennedy, "The term structure of interest rates as a Gaussian random field," *Mathematical Finance*, vol. 4, no. 3, pp. 247–258, 1994.
[137] D. P. Kennedy, "Characterizing Gaussian models of the term structure of interest rates," *Mathematical Finance*, vol. 7, no. 2, pp. 107–118, 1997.
[138] J. Keppo, "Pricing of electricity swing options," *Journal of Derivatives*, vol. 11, no. 3, pp. 26–43, 2004.
[139] J. M. Keynes, *A Treatise on Money*. London: Volume 2, MacMillan, 1930.
[140] J. H. Kim and W. B. Powell, "Optimal energy commitments with storage and intermittent supply," *Operations Research*, vol. 59, no. 6, pp. 1347–1360, 2011.
[141] J. D. Kobasa, "Management's perspective on underground gas storage," in *Underground Storage of Natural Gas: Theory and Practice*, (M. R. Tek, ed.), pp. 3–13, Norwell, MA, USA: Kluwer Academic Publishers, 1988.
[142] L. Kogan, D. Livdan, and A. Yaron, "Oil futures prices in a production economy with investment constraints," *Journal of Finance*, vol. 64, no. 3, pp. 1345–1375, 2009.
[143] P. Kouvelis, R. Li, and Q. Ding, "Managing storable commodity risk: Role of inventories and financial hedges," in *Handbook of Integrated Risk Management in Global Supply Chains*, (P. Kouvelis, O. Boyabatli, L. Dong, and R. Li, eds.), pp. 127–155, Hoboken, NJ, USA: John Wiley & Sons, Inc., 2011.
[144] P. Kouvelis, R. Li, and Q. Ding, "Managing storable commodity risks: The role of inventory and financial hedge," *Manufacturing & Service Operations Management*, vol. 15, no. 3, pp. 507–521, 2013.
[145] D. Kreps and E. Porteus, "Temporal resolution of uncertainty and dynamic choice theory," *Econometrica*, vol. 46, no. 1, pp. 185–200, 1978.
[146] KYOS, "KYSTORE GAS STORAGE VALUATION — OPTIMAL DECISIONS IN FORWARD AND SPOT MARKETS," http://www.kyos.com/files/uploads/modeling/KyStore_brochure.pdf, 2014.
[147] Lacima, "Lacima Analytics — Valuation & Optimisation Suite," http://control.visionscape.com.au/SiteFiles/lacimagroupcomau/Lacima_Analytics_brochure.pdf, 2014.
[148] G. Lai, F. Margot, and N. Secomandi, "An approximate dynamic programming approach to benchmark practice-based heuristics for natural gas storage valuation," *Operations Research*, vol. 58, no. 3, pp. 564–582, 2010.
[149] G. Lai, M. Wang, S. Kekre, A. Scheller-Wolf, and N. Secomandi, "Valuation of storage at a liquefied natural gas terminal," *Operations Research*, vol. 59, no. 3, pp. 602–616, 2011.
[150] B. F. Lamond, S. L. Monroe, and M. J. Sobel, "A reservoir hydroelectric system: Exactly and approximately optimal policies," *European Journal of Operational Research*, vol. 81, no. 3, pp. 535–542, 1995.
[151] S. Leppard, *Energy Risk Management: A Non-technical Introduction to Energy Derivatives*. London, UK: Risk Books, 2005.
[152] L. Li and P. R. Kleindorfer, "On hedging spark spread options in electricity markets," *Risk and Decision Analysis*, vol. 1, no. 4, pp. 211–220, 2009.
[153] R. Litterman and J. Scheinkman, "Common factors affecting bond returns," *Journal of Fixed Income*, vol. 1, no. 1, pp. 54–61, 1991.

[154] R. H. Litzenberger and N. Rabinowitz, "Backwardation in oil futures markets: Theory and empirical evidence," *Journal of Finance*, vol. 50, no. 5, pp. 1517–1545, 1995.

[155] F. A. Longstaff, P. Santa-Clara, and E. S. Schwartz, "The relative valuation of caps and swaptions: Theory and empirical evidence," *Journal of Finance*, vol. 56, no. 6, pp. 2067–2109, 2001.

[156] F. A. Longstaff and E. S. Schwartz, "Valuing American options by simulation: A simple least-squares approach," *Review of Financial Studies*, vol. 14, no. 1, pp. 113–147, 2001.

[157] D. G. Luenberger, *Investment Science*. New York, NY, USA: Oxford University Press, second ed., 2014.

[158] M. Manoliu, "Storage options valuation using multilevel trees and calendar spreads," *International Journal of Theoretical and Applied Finance*, vol. 7, no. 4, pp. 425–464, 2004.

[159] M. Manoliu and S. Tompaidis, "Energy futures prices: Term structure models with Kalman filter estimation," *Applied Mathematical Finance*, vol. 9, no. 1, pp. 21–43, 2002.

[160] S. Maragos, "Valuation of the operational flexibility of natural gas storage reservoirs," in *Real Options and Energy Management Using Options Methodology to Enhance Capital Budgeting Decisions*, pp. 431–456, London, UK: Risk Publications, 2002.

[161] V. Martínez-de-Albéniz and J. M. Vendrell Simón, "A capacitated commodity trading model with market power," Working Paper, IESE Business School, University of Navarra, Barcelona, Spain, 2009.

[162] R. L. McDonald and D. R. Siegel, "Investment and the valuation of firms when there is an option to shut down," *International Economic Review*, vol. 26, no. 2, pp. 331–349, 1985.

[163] N. Meinshausen and B. M. Hambly, "Monte Carlo methods for the valuation of multiple-exercise options," *Mathematical Finance*, vol. 14, no. 4, pp. 557–583, 2004.

[164] K. Miltersen and E. Schwartz, "Pricing of options on commodity futures with stochastic term structures of convenience yields and interest," *Journal of Financial and Quantitative Analysis*, vol. 33, no. 1, pp. 33–59, 1998.

[165] A. Müller, "Stochastic ordering of multivariate normal distributions," *Annals of the Institute of Statistical Mathematics*, vol. 53, no. 3, pp. 567–575, 2001.

[166] S. Nadarajah, F. Margot, and N. Secomandi, "Comparison of least squares Monte Carlo methods with applications to energy real options," Working Paper 2012-E54, Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA, USA, 2014.

[167] S. Nadarajah, F. Margot, and N. Secomandi, "Relaxations of approximate linear programs for the real option management of commodity storage," Working Paper 2011-E5, Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA, USA, 2014.

[168] E. Näsäkkälä and J. Keppo, "Hydropower with financial information," *Applied Mathematical Finance*, vol. 15, no. 5–6, pp. 503–529, 2008.

[169] J. M. Nascimento and W. B. Powell, "An optimal approximate dynamic programming algorithm for the lagged asset acquisition problem," *Mathematics of Operations Research*, vol. 34, no. 1, pp. 210–237, 2009.
[170] J. M. Nascimento and W. B. Powell, "An optimal approximate dynamic programming algorithm for concave, scalar storage problems with vector-valued controls," *IEEE Transactions on Automatic Control*, vol. 58, no. 12, pp. 2995–3010, 2013.
[171] N. Pan, "Investor beliefs and state price densities in the crude oil market," Working Paper, 2011.
[172] C. Parsons, "Quantifying natural gas storage optionality: A two-factor tree model," *Journal of Energy Markets*, vol. 6, no. 1, pp. 95–124, 2013.
[173] D. Pilipovic, *Energy Risk: Valuing and Managing Energy Derivatives*. New York, NY, USA: McGraw-Hill, second ed., 2007.
[174] E. L. Plambeck and T. A. Taylor, "On the value of input efficiency, capacity efficiency, and the flexibility to rebalance them," *Manufacturing & Service Operations Management*, vol. 15, no. 4, pp. 630–639, 2013.
[175] E. L. Porteus, *Foundations of Stochastic Inventory Theory*. Stanford, CA, USA: Stanford Business Books, 2002.
[176] W. B. Powell, *Approximate Dynamic Programming: Solving the Curses of Dimensionality*. Hoboken, NJ, USA: Wiley-Interscience, second ed., 2011.
[177] M. L. Puterman, *Markov Decision Processes: Discrete Stochastic Dynamic Programming*. New York, NY, USA: John Wiley & Sons, 1994.
[178] R. Ready, "Oil prices and long-run risk," Working Paper, 2012.
[179] R. Rempala, *System Modelling and Optimization,* volume 197 of *Lecture Notes in Control and Information Sciences,* chapter Optimal strategy in a trading problem with stochastic prices, pages 560–566. Berlin: Springer, 1994.
[180] L. C. G. Rogers, "Monte Carlo valuation of American options," *Mathematical Finance*, vol. 12, no. 3, pp. 271–286, 2002.
[181] E. Ronn, *Real Options and Energy Management Using Options Methodology to Enhance Capital Budgeting Decisions*. London, UK: Risk Publications, 2002.
[182] S. A. Ross, "Hedging long run commitments: Exercises in incomplete market pricing," *Economic Notes*, vol. 26, no. 2, pp. 385–420, 1997.
[183] S. M. Ross and Z. Zhu, "On the structure of a swing contract's optimal value and optimal strategy," *Journal of Applied Probability*, vol. 45, no. 1, pp. 1–15, 2008.
[184] B. R. Routledge, D. J. Seppi, and C. S. Spatt, "Equilibrium forward curves for commodities," *Journal of Finance*, vol. 55, no. 3, pp. 1297–1338, 2000.
[185] P. Samuelson, "Proof that properly anticipated prices fluctuate randomly," *Industrial Management Review*, vol. 6, no. 2, pp. 41–49, 1965.
[186] S. Schneider, "Power spot price models with negative prices," *The Journal of Energy Markets*, vol. 4, no. 4, pp. 77–102, 2011/12.
[187] N. C. Schofield, *Commodity Derivatives: Markets and Applications*. Chichester, UK: John Wiley & Sons, 2007.
[188] E. S. Schwartz, "The stochastic behavior of commodity prices: Implications for valuation and hedging," *Journal of Finance*, vol. 52, no. 3, pp. 923–973, 1997.

[189] E. S. Schwartz and J. E. Smith, "Short-term variations and long-term dynamics in commodity prices," *Management Science*, vol. 46, no. 7, pp. 893–911, 2000.

[190] N. Secomandi, "An analysis of the control-algorithm re-solving issue in inventory and revenue management," *Manufacturing & Service Operations Management*, vol. 10, no. 3, pp. 468–483, 2008.

[191] N. Secomandi, "On the pricing of natural gas pipeline capacity," *Manufacturing & Service Operations Management*, vol. 12, no. 3, pp. 393–408, 2010.

[192] N. Secomandi, "Optimal commodity trading with a capacitated storage asset," *Management Science*, vol. 56, no. 3, pp. 449–467, 2010.

[193] N. Secomandi, "An opportunity cost view of basestock optimality for the warehouse problem," in *Handbook of Integrated Risk Management in Global Supply Chains*, (P. Kouvelis, O. Boyabatli, L. Dong, and R. Li, eds.), pp. 447–461, John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2011.

[194] N. Secomandi, "Analysis and enhancement of practice-based policies for the real option management of commodity storage assets," Tepper Working Paper 2011-E11, Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA, USA, 2014.

[195] N. Secomandi and S. Kekre, "Optimal energy procurement in spot and forward markets," *Manufacturing & Service Operations Management*, vol. 16, no. 2, pp. 270–282, 2014.

[196] N. Secomandi, G. Lai, F. Margot, A. Scheller-Wolf, and D. J. Seppi, "Merchant commodity storage and term structure model error," Working Paper 2010-E71, Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA, USA, 2012.

[197] N. Secomandi and M. X. Wang, "A computational approach to the real option management of network contracts for natural gas pipeline transport capacity," *Manufacturing & Service Operations Management*, vol. 14, no. 3, pp. 441–454, 2012.

[198] D. J. Seppi, "Risk-neutral stochastic processes for commodity derivative pricing: An introduction and survey," in *Real Options and Energy Management Using Options Methodology to Enhance Capital Budgeting Decisions*, (E. Ronn, ed.), pp. 3–60, London, UK: Risk Publications, 2002.

[199] S. E. Shreve, *Stochastic Calculus for Finance II: Continuous-Time Models*. New York, NY, USA: Springer, 2004.

[200] G. Sick, "Real options," in *Finance,* volume 9 of *Handbooks in Operations Research and Management Science*, (R. A. Jarrow, V. Maksimovic, and W. T. Ziemba, eds.), pp. 631–691, Amsterdam, The Netherlands: Elsevier, 1995.

[201] J. E. Smith, "Alternative approaches for solving real-options problems," *Decisions Analysis*, vol. 2, no. 2, pp. 89–102, 2005.

[202] J. E. Smith and K. F. McCardle, "Valuing oil properties: Integrating option pricing and decision analysis approaches," *Operations Research*, vol. 46, no. 2, pp. 198–217, 1998.

[203] J. E. Smith and K. F. McCardle, "Options in the real world: Lessons learned in evaluating oil and gas investments," *Operations Research*, vol. 47, no. 1, pp. 1–15, 1999.

[204] R. Smith, "Can gas undo nuclear power?," *The Wall Street Journal*, January 30 2013.

[205] N. L. Stokey and R. E. Lucas, *Recursive Methods in Economic Dynamics*. Cambridge, MA, USA: Harvard University Press, 1989. With E. C. Prescott.

[206] H. Suenaga, A. Smith, and J. Williams, "Volatility dynamics of NYMEX natural gas futures prices," *Journal of Futures Markets*, vol. 28, no. 5, pp. 438–463, 2008.

[207] K. Tang and W. Xiong, "Index investment and financialization of commodities," Working Paper, 2011.

[208] S. Tayur and W. Yang, "Equilibrium analysis of a natural gas supply chain," Working Paper, Graduate School of Industrial Administration, Carnegie Mellon University, Pittsburgh, PA, USA, 2002.

[209] M. R. Tek, *Natural Gas Underground Storage: Inventory and Deliverability*. Tulsa, OK, USA: PennWell Publishing Co., 1996.

[210] L. G. Telser, "Futures trading and the storage of cotton and wheat," *Journal of Political Economy*, vol. 66, no. 3, pp. 233–255, 1958.

[211] M. Thompson, "Natural gas storage valuation, optimization, market and credit risk management," Working Paper, Queen's School of Business, Queen's University, Kingston, Ontario, CA, 2012.

[212] M. Thompson, "Optimal economic dispatch and risk management of thermal power plants in deregulated markets," *Operations Research*, vol. 61, no. 4, pp. 791–809, 2013.

[213] M. Thompson, M. Davison, and H. Rasmussen, "Valuation and optimal operation of electric power plants in competitive markets," *Operations Research*, vol. 52, no. 4, pp. 546–562, 2004.

[214] M. Thompson, M. Davison, and H. Rasmussen, "Natural gas storage valuation and optimization: A real options application," *Naval Research Logistics*, vol. 56, no. 3, pp. 226–238, 2009.

[215] J. Tirole, *The Theory of Corporate Finance*. Princeton, NJ, USA: Princeton University Press, 2006.

[216] C. Tolmasky and D. Hindanov, "Principal components analysis for correlated curves and seasonal commodities: The case of the petroleum market," *Journal of Futures Markets*, vol. 22, no. 11, pp. 1019–1035, 2002.

[217] D. M. Topkis, *Supermodularity and Complementarity*. Princeton, NJ, USA: Princeton University Press, 1998.

[218] L. Trigeorgis, *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. Cambridge, MA, USA: The MIT Press, 1996.

[219] C. L. Tseng and G. Barz, "Short-term generation asset valuation: A real options approach," *Operations Research*, vol. 50, no. 2, pp. 297–310, 2002.

[220] C. L. Tseng and K. Y. Lin, "A framework using two-factor price lattices for generation asset valuation," *Operations Research*, vol. 55, no. 2, pp. 234–251, 2007.

[221] D. Vayanos and J. Wang, "Market liquidity: Theory and empirical evidence," in *Handbook of the Economics of Finance,* chapter 19, (G. Constantinides, M. Harris, and R. Stulz, eds.), pp. 1289–1361, Amsterdam, The Netherlands: Elsevier, 2012.

[222] S. W. Wallace and S.-E. Fleten, "Stochastic programming models in energy," in *Stochastic programming,* volume 10 of *Handbooks in Operations Research and Management Science*, (A. Ruszczynski and A. Shapiro, eds.), pp. 637–677, Amsterdam, The Netherlands: Elsevier, 2003.

[223] M. X. Wang, "Supply Chain Management and Economic Valuation of Real Options in the Natural Gas and Liquefied Natural Gas Industry," PhD thesis, Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA, USA, 2008.

[224] Y. Wang, M. C. Fu, and S. I. Marcus, "A new stochastic derivative estimator for discontinuous payoff functions with applications to financial derivatives," *Operations Research*, vol. 60, no. 2, pp. 447–460, 2012.

[225] Webster's new universal unabridged dictionary. New York, NY, USA, 1996.

[226] J. C. Williams, *The Economic Function of Futures Markets.* Cambridge, UK: Cambridge University Press, 1986.

[227] J. C. Williams, "Futures markets: A consequence of risk aversion or transaction costs?," *Journal of Political Economy*, vol. 95, no. 5, pp. 1000–1023, 1987.

[228] J. C. Williams and B. D. Wright, *Storage and Commodity Markets.* Cambridge, UK: Cambridge University Press, 1991.

[229] H. Working, "Theory of the inverse carrying charge in futures markets," *Journal of Farm Economics*, vol. 30, no. 1, pp. 1–28, 1948.

[230] H. Working, "The theory of price of storage," *American Economic Review*, vol. 39, no. 6, pp. 1254–1262, 1949.

[231] B. D. Wright and J. C. Williams, "A theory of negative prices for storage," *Journal of Futures Markets*, vol. 9, no. 1, pp. 1–13, 1989.

[232] O. Wu and H. Chen, "Optimal control and equilibrium behavior of production-inventory systems," *Management Science*, vol. 56, no. 8, pp. 1362–1379, 2010.

[233] O. Wu, D. Wang, and Z. Qin, "Seasonal energy storage operations with limited flexibility: The price-adjusted rolling intrinsic policy," *Manufacturing & Service Operations Management*, vol. 14, no. 3, pp. 455–471, 2012.

[234] Y. Zhou, A. Scheller-Wolf, S. Smith, and N. Secomandi, "Is it more valuable to store or destroy electricity surpluses?," Tepper Working Paper 2012-E1, Carnegie Mellon University, Pittsburgh, PA, USA, 2013.

[235] Y. Zhou, A. Scheller-Wolf, S. Smith, and N. Secomandi, "Managing wind-based electricity generation in the presence of storage and transmission capacity," Tepper Working Paper 2011-E36, Carnegie Mellon University, Pittsburgh, PA, USA, 2013.

[236] P. H. Zipkin, *Foundations of Inventory Management.* Boston, MA, USA: McGraw-Hill, 2000.