Theoretical Economics Letters, 2023, 13, 1548-1556
https://www.scirp.org/journal/tel
ISSN Online: 2162-2086
ISSN Print: 2162-2078

Real Options Adoption with Poisson Price, Quantity, and Policy Uncertainty Jumps

Chong (Andrea) Zhao[1], Gregory Colson[2], Hazel Wetzstein[3], Michael Wetzstein[2*]

[1]Wells Fargo, Charotte, North Carolina, USA
[2]Department of Agricultural and Applied Economics, University of Georgia, Athens, Georgia, USA
[3]Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, Indiana, USA
Email: *mwetz@uga.edu

How to cite this paper: Zhao, C., Colson, G., Wetzstein, H., & Wetzstein, M. (2023). Real Options Adoption with Poisson Price, Quantity, and Policy Uncertainty Jumps. *Theoretical Economics Letters, 13,* 1548-1556.
https://doi.org/10.4236/tel.2023.136087

Received: October 11, 2023
Accepted: December 19, 2023
Published: December 22, 2023

Abstract

A unifying methodology is presented, which jointly considers correlated Brownian motion processes with Poisson jumps in both revenue and policy. The methodology is unique in considering price and quantity as geometric Brownian motion processes with jumps following a Poisson process in revenue from market shocks and policy uncertainty.

Keywords

Asset Replacement, Brownian Motion, Investment, Poisson Jumps

1. Introduction

The literature is rich in employing real options analysis in determining investment entry and exit. Recent literature includes Agaton (2021), Araya et al. (2021), Bakker et al. (2021), Deeney et al. (2021), and Ioulianou et al. (2021). The general assumption is returns follow a Markov property with only small changes. Merton (1976) states the antipathetical process to this continuous stochastic process is a jump stochastic process. This precipitates the composition of returns to investment is of three types: 1) Normal trends in price and quantity with variation around these trends resulting from marginal market change. Modeling of these processes is generally with geometric Brownian motion (GMB). 2) Jumps in price and quantity from market shocks more than a marginal effect. Such shocks may be firm- or industry-specific and they arrive at discrete points in time. Through a Poisson jump process, it is possible to incorporate these shocks into models. 3) Policy uncertainty where policymakers establish mechanisms, which create uncertainty through the prospect of policy change (Dixit and Pindyck, 1994). Changes in incentives to establish a firm or industry that reduces sunk costs can heighten uncertainty. Modeling this switching among policies can also involve an additional Poisson jump.

Lacking is an integrated method, which jointly considers these three processes. Our unique feature is considering both price and quantity following correlated GMB with Poisson jumps. Considering the resulting revenue process, an additional Poisson jump results from government policy uncertainty. The aim is to extend the literature by developing this theoretical integration.

This theoretical result is not without practical applications. One application is technical advancements resulting in the development of a commercially viable new business investment opportunity. Zhao (2018) presents this application for the case study if Artemisinin efficiency improvements can result in the development of a commercially viable U.S. agribusiness investment opportunity. Other applications of the theory are in the renewable energy sector characterized by technical advancements in energy generation and policy shifts. Solar energy is a specific application.

2. Literature

There are real options considering correlated Brownian processes price and quantity (Price and Wetzstein, 1999) and independently considering jump diffusion (Lin and Huang, 2010; Yang and Zhang, 2005; Wang, 2007). The logical next direction is considering jointly stochastic price and quantity processes with independent Poisson jumps.

The literature is rich in considering GBM with Poisson jumps. Recent investigations include fuel prices (Agaton, 2022; Batac et al., 2022) and demand shocks along with investment (Wu and Hu, 2022). Volk-Makarewicza et al. (2022) develop a test to determine if a Poisson jump significantly influences a GBM real option. One closely related effort is by Pimentel et al. (2018) who consider both the number of mass-transportation passengers and investment expenditures as stochastic processes with Poisson jumps.

Independent of this literature is research addressing policy uncertainty (Anderson and Weersink, 2014; David et al., 2000; Dimos and Pugh, 2016; Fuss et al., 2008; Fuss et al., 2009; Fuss et al., 2012; Hassett and Metcalf, 1999; Liu et al., 2018; Mauer and Ott, 1995; Price et al., 2005; Reedman et al., 2006; Rodrik, 1991; Yang et al., 2008; Zhou et al., 2010).

3. Methodology

The problem is determining at what revenue thresholds is it optimal to invest with and without a government subsidy. The investment expected value, V, is a function of the revenue stream, R, $V(R)$. Consider this revenue as a product of price, P, and quantity, Q, stochastic processes with jumps. The optimal revenue-threshold triggers are also determined under policy uncertainty. Specifically, consider the following GBM processes with Poisson jump processes

$$dX(t) = \alpha_X X(t^-)dt + \sigma_X X(t^-)dz_X + S_X X(t^-)dq_X, \; X = P, Q,$$

where $dX(t)$ represents the change in stochastic process X, $X(t^-)$ is the value just prior to a possible jump at t, α_X is the drift, σ_X denotes the volatility, dt is an infinitesimal time step, dz_X follows a Wiener process with $z_X(0) = 0$, $E(dz_X^2) = dt$, dq_X is a Poisson variable representing the total number of events in dt, and S_X denotes the size of jumps in dt.

Assume $E(dz_P z_Q) = \rho_{PQ} dt$, where ρ_{PQ} represents the correlation between P and Q. Then the stochastic process of revenue, $R = PQ$, remains a GBM process with Poisson jumps, regardless of the correlation between dP and dQ. As derived in Dixit and Pindyck (1994), the general form of the correlated Brownian motion processes for R is

$$\begin{aligned} dR &= \frac{\partial R}{\partial P}dP + \frac{\partial R}{\partial Q}dQ + \frac{\partial^2 R}{\partial P \partial Q}dPdQ + \frac{1}{2}\frac{\partial^2 R}{\partial P^2}dP^2 + \frac{1}{2}\frac{\partial^2 R}{\partial Q^2}dQ^2 \\ &\quad + \left\{R\left[(1+S_P)P, Q\right] - R\left[P, Q\right]\right\}dq_P \\ &\quad + \left\{R\left[P, (1+S_Q)Q\right] - R\left[P, Q\right]\right\}dq_Q. \end{aligned} \tag{1}$$

The first five terms in (1) result from applying Ito's lemma (Bjork, 2009). The last term represents the revenue change if a jump occurs in X over time interval dt with probability $\gamma_X dt$.

Simplifying (1) by omitting higher order dt terms, assuming $E(dq_X dt) = E(dz_X dq_X) = 0$, and given $dPdQ = \sigma_P \sigma_Q \rho_{PQ} R$, yields

$$\begin{aligned} dR &= QdP + PdQ + dPdQ + \gamma_P dt S_P R + \gamma_Q dt S_Q R \\ &= Rdt\left(\alpha_P + \alpha_Q + \sigma_P \sigma_Q \rho_{PQ}\right) + R\left(\sigma_Q dz_Q + \sigma_P dz_P\right) \\ &\quad + \gamma_P R S_P dt + \gamma_Q dt R S_Q dt. \end{aligned}$$

Allowing both the unit price and quantity to fluctuate randomly, two-correlated GBM processes result with jump processes, yielding the stochastic differential equation

$$dR = \alpha_R R dt + \sigma_R R dz_R + JR, \tag{2}$$

where $\alpha_R = \alpha_P + \alpha_Q + \sigma_P \sigma_Q \rho_{PQ} + \gamma_P \mu_P^S + \gamma_Q \mu_Q^S$, $\sigma_R = \left(\sigma_Q^2 + \sigma_P^2 + 2\sigma_P \sigma_Q \rho_{PQ}\right)^{1/2}$. The Wiener process dz_R represents $N\left(0, \sqrt{dt}\right)$, and J is assumed to be a Chi-square random variable with mean $\left(\mu_P^S \gamma_P^S + \mu_Q^S \gamma_Q^S\right)dt$ and variance $2\left(\mu_P^S \gamma_P^S + \mu_Q^S \gamma_Q^S\right)dt$, where μ_X^S is the jump mean, $X = P, Q$. In (2), R fluctuates as a GBM process, but over each time interval dt, it will change by J times its original value and then continue fluctuating.

As presented in Dixit and Pindyck (1994), the Bellman equation for $F(R)$, the value of the investment opportunity, is then

$$rFdt = E(dF), \tag{3}$$

where r is the discount rate. Transforming the Bellman equation by expanding dF using Ito's lemma for combined Brownian and Poisson processes yields

$$dF = F'(R)dR + \frac{1}{2}F''(R)(dR)^2.$$

Note that $(dR)^2 = \sigma_R^2 R^2 dt$ and dividing by dt, (3) is then

$$\frac{1}{2}\sigma_R^2 R^2 F''(R) + \left(\alpha_R + \mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S\right)RF'(R) - rF(R) = 0, \quad (4)$$

where $\alpha_R = r - \delta_R$ with δ_R denoting the short-fall rate. Equation (4) is a second-order nonhomogeneous differential equation for determining when to invest. Following Dixit and Pindyck (1994) the solution is

$$F(R) = A_1 R^{\beta_1},$$

where A_1 is a constant to be determined and

$$\beta_1 = \frac{1}{2} - \frac{\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S + r - \delta_R}{\sigma_R^2} + \sqrt{\left[\frac{\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S + r - \delta_R}{\sigma_R^2} - \frac{1}{2}\right]^2 + \frac{2r}{\sigma_R^2}}.$$

The project's expected present value, $V(R)$, is

$$V(R) = E\left\{\int_0^\infty R(t)\mathrm{e}^{-rt}dt\right\}.$$

Equating the normal return on $V(R)$ at rate r to the sum of revenue and the expected capital gain yields

$$rV(R)dt = R(t)dt + E(dV),$$

where the expected capital gain is

$$E(dV) = E\left\{\left(\frac{dV}{dR}\right)\left(\frac{dR}{dt}\right)dt\right\} = \frac{\left[\alpha_P + \alpha_Q + \sigma_P\sigma_Q\rho_{PQ} + 2\left(\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S\right)\right]R}{r}.$$

From (2)

$$E(dR) = \alpha_R R dt + \left(\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S\right)$$
$$= \alpha_P + \alpha_Q + \sigma_P\sigma_Q\rho_{PQ} + \gamma_P\mu_P^S + \gamma_Q\mu_Q^S + 2\left(\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S\right).$$

Then,

$$V(R) = \frac{R(t)dt}{rdt} + \frac{E(dV)}{r} = \frac{R}{r} + \left[\alpha_P + \alpha_Q + \sigma_P\sigma_Q\rho_{PQ} + 2\left(\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S\right)\right]\frac{R}{r^2}.$$

Denote $\alpha_m = \alpha_P + \alpha_Q + \sigma_P\sigma_Q\rho_{PQ} + 2\left(\mu_P^S\gamma_P^S + \mu_Q^S\gamma_Q^S\right)$. From the optimal switching revenue threshold solve for the boundary conditions

$$R^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)\left(\frac{r^2}{r + \alpha_m}\right)\left(K + \frac{C}{r}\right),$$

where K is the initial sunk investment cost and C denotes operating costs.

Following Dixit and Pindyck (1994), consider market uncertainty resulting from time inconsistent subsidy policies on adoption. Suppose the policy instrument is an investment subsidy, θ. When the policy is in effect, a lower sunk cost of investment exists $(1-\theta)K$. The optimal investment threshold is then

$$R_1^{NRS} = \left(\frac{\beta_1}{\beta_1 - 1}\right)\left(\frac{r^2}{r + \alpha_m}\right)\left(\frac{C}{r} + (1-\theta)K\right).$$

The government may switch between the regimes of the discrete subsidy policy (**Figure 1**). In a Poisson process, regime-switching conditions affect revenue threshold for adoption. Denote the effects on the thresholds by R_1, when the subsidy policy is currently in effect and R_0 when it is not in effect. The probability of enactment, λ_1, and removal, λ_0, for the investment subsidy are random uniform variables over the range [0, 1].

Assume the initial investment in exercising the option to invest is equal to the revenue difference between implementing subsidy and not. Then, for revenue beyond R_0, the firm always invests at once. The investment opportunity with subsidy is then

$$F_1(R) = \left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right)R - \frac{C}{r} - (1-\theta)K. \quad (5)$$

For the absence of a governmental subsidy, the option to invest yields

$$F_0(R) = \left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right)R - \frac{C}{r} - K.$$

Over the revenue range (R_1, R_0), the investment is undertaken with subsidies, and it waits to exercise the option, otherwise. Note that within the range of revenues (R_1, R_0), we know the expression for the value of the investment opportunity (5) if the investment is subsidized. As derived by Dixit and Pindyck (1994), the investment opportunity without subsidy is

$$F_0^{(1)}(R) = B_1 R^{\beta_1^{(1)}} + B_2 R^{\beta_2^{(1)}} + \left(\frac{\lambda_1}{\lambda_1 + r - \alpha_m}\right)\left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right)R - \frac{\lambda_1}{r + \lambda_1}\left[\frac{C}{r} + (1-\theta)K\right],$$

where B_1 and B_2 are constants to be determined. In the range $(0, R_1)$, postpone the investment, so the total expected value of the investment opportunity yields

$$F_0^{(2)}(R) = \frac{\lambda_0 \lambda_1 G_a R^{\beta_a} - \lambda_1 D_s R^{\beta_s}}{\lambda_1 + \lambda_0},$$

and

$$F_1^{(2)}(R) = \frac{\lambda_0 \lambda_1 G_a R^{\beta_a} + \lambda_0 D_s R^{\beta_s}}{\lambda_1 + \lambda_0},$$

where

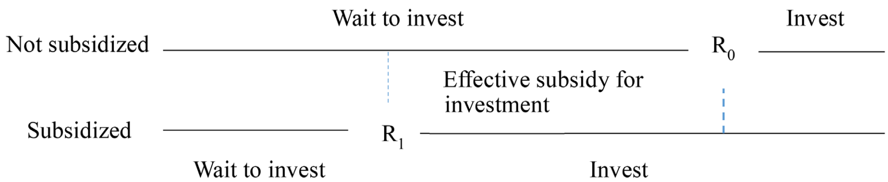

Figure 1. Investment threshold revenues for a subsidy policy scenario.

$$\beta_a = \frac{-\left(\alpha_m - \frac{1}{2}\sigma_R^2\right) + \sqrt{\left(\alpha_m - \frac{1}{2}\sigma_R^2\right)^2 + 2r\sigma_R^2}}{\sigma_R^2},$$

$$\beta_s = \frac{-\left(\alpha_m - \frac{1}{2}\sigma_R^2\right) + \sqrt{\left(\alpha_m - \frac{1}{2}\sigma_R^2\right)^2 + 2\left(r + \lambda_0 + \lambda_1\right)\sigma_R^2}}{\sigma_R^2},$$

and G_a and D_a are parameters to be determined.

Following the policy uncertainty section in Dixit and Pindyck (1994), results are given by the following six equations.

$$\frac{\lambda_0\lambda_1 G_a R_1^{\beta_a} + \lambda_0 D_s R_1^{\beta_s}}{\lambda_1 + \lambda_0} = \left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right) R_1 - \frac{C}{r} - (1-\theta)K, \tag{6a}$$

$$\frac{\beta_a\lambda_0\lambda_1 G_a R_1^{\beta_a - 1} + \beta_s\lambda_0 D_s R_1^{\beta_s - 1}}{\lambda_1 + \lambda_0} = \frac{1}{r} + \frac{\alpha_m}{r^2}, \tag{6b}$$

$$\begin{aligned} &B_1 R_0^{\beta_1^{(1)}} + B_2 R_0^{\beta_2^{(1)}} + \left(\frac{\lambda_1}{\lambda_1 + r - \alpha_m}\right)\left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right) R_0 - \frac{\lambda_1}{r + \lambda_1}\left[\frac{C}{r} + (1-\theta)K\right] \\ &= \left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right) R_0 - \left(\frac{C}{r} + K\right), \end{aligned} \tag{6c}$$

$$\beta_1^{(1)} B_1 R_0^{\beta_1^{(1)} - 1} + \beta_2^{(1)} B_2 R_0^{\beta_2^{(1)} - 1} + \left(\frac{\lambda_1}{\lambda_1 + r - \alpha_m}\right)\left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right) = \frac{1}{r} + \frac{\alpha_m}{r^2}, \tag{6d}$$

$$\begin{aligned} &\frac{\lambda_0\lambda_1 G_a R_1^{\beta_a} - \lambda_1 D_s R_1^{\beta_s}}{\lambda_1 + \lambda_0} \\ &= B_1 R_1^{\beta_1^{(1)}} + B_2 R_1^{\beta_2^{(1)}} + \left(\frac{\lambda_1}{\lambda_1 + r - \alpha_m}\right)\left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right) R_1 - \frac{\lambda_1}{r + \lambda_1}\left[\frac{C}{r} + (1-\theta)K\right], \end{aligned} \tag{6e}$$

$$\begin{aligned} &\frac{\beta_a\lambda_0\lambda_1 G_a R_1^{\beta_a - 1} - \beta_s\lambda_1 D_s R_1^{\beta_s - 1}}{\lambda_1 + \lambda_0} \\ &= \beta_1^{(1)} B_1 R_1^{\beta_1^{(1)} - 1} + \beta_2^{(1)} B_2 R_1^{\beta_2^{(1)} - 1} + \left(\frac{\lambda_1}{\lambda_1 + r - \alpha_m}\right)\left(\frac{1}{r} + \frac{\alpha_m}{r^2}\right). \end{aligned} \tag{6f}$$

This set of six Equation (6) are solved numerically for the two revenue thresholds R_1 and R_0 and four parameters B_1, B_2, G_a and D_s. For an application in solving (6), refer to Zhao (2018), which provides details on the theory, numerical estimation, and application results.

4. Conclusions and Policy Implications

The unifying methodology considers correlated Brownian motion processes with Poisson jumps in both revenue and policy. An integrated procedure for evaluating investments is now provided as an aid for decision makers. Specifically, the extended methodology considers normal trends in price and quantity with variation around these trends as a geometric Brownian motion and jumps following a Poisson process in revenue from market shocks and policy uncertainty.

Further research should be directed toward applying the theory to other industries. Possible applications include energy with both fuel price and volume uncertainty within an uncertain government policy; firm investment decisions with asset price and output uncertainty along with possible government subsidy uncertainty; and game-theoretic market structure issues of leader's and followers' real options in revenue uncertainty. Such applications will provide feedback on the direction of further theoretic advancements. For policy, when considering uncertain revenue, the interplay of price, quantity, and policy uncertainty is important when calculating real options. Failure to consider this interplay may result in erroneous policy.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Agaton, C. (2021). Application of Real Options in Carbon Capture and Storage Literature: Valuation Techniques and Research Hotspots. *Science of the Total Environment, 795,* Article ID: 148683. https://doi.org/10.1016/j.scitotenv.2021.148683

Agaton, C. (2022). Will a Geopolitical Conflict Accelerate Energy Transition in Oil-Importing Countries? A Case Study of the Philippines from a Real Options Perspective. *Resources, 11,* Article No. 59. https://doi.org/10.3390/resources11060059

Anderson, R., & Weersink, A. (2014). A Real Options Approach for the Investment Decisions of a Farm-Based Anaerobic Digester. *Small Business Economics, 41,* 837-863.

Araya, N., Ramírez, Y., Kraslawski, A., & Cisternas, L. (2021). Feasibility of Re-Processing Mine Tailings to Obtain Critical Raw Materials Using Real Options Analysis. *Journal of Environmental Management, 284,* Article ID: 112060. https://doi.org/10.1016/j.jenvman.2021.112060

Bakker, S., Kleiven, A., Fleten, S., & Tomasgard, A. (2021). Mature Offshore Oil Field Development: Solving a Real Options Problem Using Stochastic Dual Dynamic Integer Programming. *Computers & Operations Research, 136,* Article ID: 105480. https://doi.org/10.1016/j.cor.2021.105480

Batac, K., Collera, A., Villanueva, R., & Agaton, C. (2022). Decision Support for Investments in Sustainable Energy Sources under Uncertainties. *International Journal of Renewable Energy Development, 11,* 801-814. https://doi.org/10.14710/ijred.2022.45913

Bjork, T. (2009). *Arbitrage Theory in Continuous Time.* Oxford University Press.

David, P., Hall, B., & Toole, A. (2000). Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence. *Research Policy, 29,* 497-529. https://doi.org/10.1016/S0048-7333(99)00087-6

Deeney, P., Cummins, M., Heintz, K., & Pryce, M. (2021). A Real Options Based Decision Support Tool for R&D Investment: Application to CO_2 Recycling Technology. *European Journal of Operational Research, 289,* 696-711. https://doi.org/10.1016/j.ejor.2020.07.015

Dimos, C., & Pugh, G. (2016). The Effectiveness of R&D Subsidies: A Meta-Regression Analysis of the Evaluation Literature. *Research Policy, 45,* 797-815. https://doi.org/10.1016/j.respol.2016.01.002

Dixit, A. K., & Pindyck, R. S. (1994). *Investment under Uncertainty.* Princeton University

Press. https://doi.org/10.1515/9781400830176

Fuss, S., Johansson, D., Szolgayova, J., & Obersteiner, M. (2009). Impact of Climate Policy Uncertainty on the Adoption of Electricity Generating Technologies. *Energy Policy, 37,* 733-743. https://doi.org/10.1016/j.enpol.2008.10.022

Fuss, S., Szolgayova, J., Khabarov, N., & Obersteiner, M. (2012). Renewables and Climate Change Mitigation: Irreversible Energy Investment under Uncertainty and Portfolio Effects. *Energy Policy, 40,* 59-68. https://doi.org/10.1016/j.enpol.2010.06.061

Fuss, S., Szolgayova, J., Obersteiner, M., & Gusti, M. (2008). Investment under Market and Climate Policy Uncertainty. *Applied Energy, 85,* 708-721. https://doi.org/10.1016/j.apenergy.2008.01.005

Hassett, K., & Metcalf, G. (1999). Investment with Uncertain Tax Policy: Does Random Tax Policy Discourage Investment. *The Economic Journal, 109,* 372-393. https://doi.org/10.1111/1468-0297.00453

Ioulianou, S., Leiblein, M., & Trigeorgis, L. (2021). Multinationality, Portfolio Diversification, and Asymmetric MNE Performance: The Moderating Role of Real Options Awareness. *Journal of International Business Studies, 52,* 388-408. https://doi.org/10.1057/s41267-020-00357-3

Lin, T., & Huang, S.-L. (2010). An Entry and Exit Model on the Energy-Saving Investment Strategy with Real Options. *Energy Policy, 38,* 794-802. https://doi.org/10.1016/j.enpol.2009.10.024

Liu, S., Colson, G., & Wetzstein, M. (2018). Biodiesel Investment in a Disruptive Tax-Credit Policy Environment. *Energy Policy, 123,* 19-30. https://doi.org/10.1016/j.enpol.2018.08.026

Mauer, D. C., & Ott, S. H. (1995). Investment under Uncertainty: The Case of Replacement Investment Decisions. *Journal of Financial & Quantitative Analysis, 30,* 581-605. https://doi.org/10.2307/2331278

Merton, R. (1976). Option Pricing When Underlying Stock Returns Are Discontinuous. *Journal of Financial Economics, 3,* 125-144. https://doi.org/10.1016/0304-405X(76)90022-2

Pimentel, P., Nunesb, C., & Couto, G. (2018). High-Speed Rail Transport Valuation with Stochastic Demand and Investment Cost. *Transportmetrica A: Transport Science, 14,* 275-291. https://doi.org/10.1080/23249935.2017.1384936

Price, T. J., Lamb, M. C., & Wetzstein, M. E. (2005). Technology Choice under Changing Peanut Policies. *Agricultural Economics, 33,* 11-19. https://doi.org/10.1111/j.1574-0862.2005.00233.x

Price, T., & Wetzstein, M. (1999). Irreversible Investment Decisions in Perennial Crops with Yield and Price Uncertainty. *Journal of Agricultural and Resource Economics, 24,* 173-185.

Reedman, L., Graham, P., & Coombes, P. (2006). Using a Real-Options Approach to Model Technology Adoption under Carbon Price Uncertainty: An Application to the Australian Electricity Generation Sector. *Economic Record, 82,* S64-S73. https://doi.org/10.1111/j.1475-4932.2006.00333.x

Rodrik, D. (1991). Policy Uncertainty and Private Investment in Developing Countries. *Journal of Development Economics, 36,* 229-242. https://doi.org/10.1016/0304-3878(91)90034-S

Volk-Makarewicza, W., Borovkovab, S., & Heidergott, B. (2022). Assessing the Impact of Jumps in an Option Pricing Model: A Gradient Estimation Approach. *European Journal of Operational Research, 298,* 740-751. https://doi.org/10.1016/j.ejor.2021.07.015

Wang, N. (2007). Optimal Investment for an Insurer with Exponential Utility Preference. *Insurance: Mathematics and Economics, 40,* 77-84. https://www.sciencedirect.com/science/journal/01676687/40/1 https://doi.org/10.1016/j.insmatheco.2006.02.008

Wu, X., & Hu, Z. (2022). Investment Timing and Capacity Choice in Duopolistic Competition under a Jump-Diffusion Model. *Mathematics and Financial Economics, 16,* 125-152. https://doi.org/10.1007/s11579-021-00303-3

Yang, H., & Zhang, L. (2005). Optimal Investment for Insurer with Jump-Diffusion Risk Process. *Insurance: Mathematics and Economics, 37,* 615-634. https://doi.org/10.1016/j.insmatheco.2005.06.009

Yang, M., Blyth, W., Bradley, R., Bunn, D., Clarke, C., & Wilson, T. (2008). Evaluating the Power Investment Options with Uncertainty in Climate Policy. *Energy Economics, 30,* 1933-1950. https://doi.org/10.1016/j.eneco.2007.06.004

Zhao, C. (2018). *Can U.S. Agriculture Provide Agro-Pharms for Malaria Treatment*? Thesis Department of Agricultural Economics, Purdue University.

Zhou, W., Zhu, B., Fuss, S., Szolgayova, J., Obersteiner, M., & Fei, W. (2010). Uncertainty Modeling of CCS Investment Strategy in China's Power Sector. *Applied Energy, 87,* 2392-2400. https://doi.org/10.1016/j.apenergy.2010.01.013