

Investment Decisions of a New Linerboard Mill under Market Uncertainty

Bin Mei*
David Swinarski
Michael L. Clutter
Thomas G. Harris

Abstract

The pulp and paper sector is a key component of the forest products industry in the United States. Pulp and paper production is highly capital-intensive and asset-specific. The installment of a pulp and paper mill is functionally irreversible and the return from such an investment is uncertain. Both irreversibility and uncertainty should be considered when making the investment decision. In this study, we applied the real options approach to examine investment triggering conditions for heterogeneous linerboard producers under two different price assumptions: random walk vs. mean reversion. The solution was solved by complex analytical methods and the application extended the discussion of investment models under uncertainty. The results indicate that investment-triggering prices differed under alternative price assumptions and that the uncertainty premium depends on the producer's efficiency.

Keywords: Evaluation, forest products, mean-reverting, random walk, real options.

Introduction

The forest products industry in the United States consists of three sectors: the lumber sector (NAICS 321), the furniture sector (NAICS 327), and the pulp and paper sector (NAICS 322). Of the three, the pulp and paper sector is the key component, generating about 50% of the total value of shipments in the industry over the past several decades (U.S. Bureau of Census 1987-2007). Despite its declining global share, the U.S. continues to be the world's largest wood pulp producer and Kraft linerboard exporter (Siry et al. 2007, Sun 2006).

Linerboard is used to make corrugated containers for shipping consumer and industrial goods. Its annual production accounts for about 50% of the total domestic paperboard production. There are several grades of linerboard products, the majority being unbleached Kraft linerboard. Historically, unbleached Kraft linerboard makes up about 80% of total U.S. linerboard production (American Forest & Paper Association 2001-2010). Unbleached Kraft linerboard is produced in a series of basis weights (lb/1000 sq. ft.). The most common grade, representing roughly 50% of the total, is 42 lb. Other important grades include 26, 33, 38, 69, and 90 lb. Real prices of domestic linerboard (42 lb.) for January 1980-June 2011 are plotted in Figure 1. The stochastic nature of linerboard prices is related to flexibility in capacity management and control, business cycles, fiber supply, inventory level, and technical changes (Li and Luo 2008, Marko 2003).

Pulp and paper production has several key features.

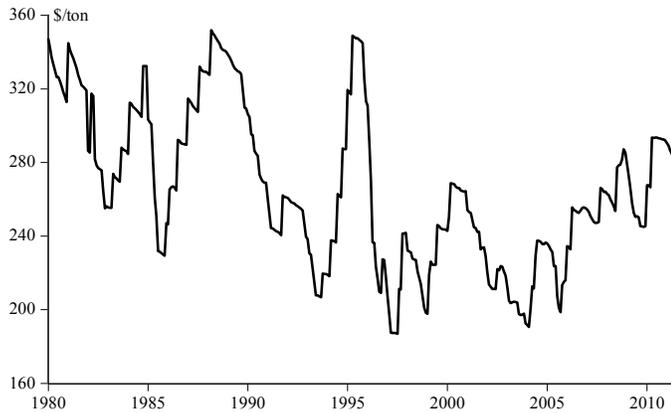
Foremost, it requires a large financial commitment. More than 60% of the industry capacity is accounted by mills with production of over 300,000 tons per year (Pulp & Paper Week 1980-2011). The capital intensity of pulp and paper industry is usually twice that of other major industries (Butner and Stapley 1997). Next, pulp and paper production is highly asset-specific. Pulp and paper mills lose a great portion of their value if they are set aside from their primary use (Yin et al. 2000). Third, the pulp and paper industry has been gradually more concentrated with recent mergers and acquisitions. The largest four companies control about 50% of the total supply in recent years (U.S. Bureau of Census 1987-2007). Fourth, pulp and paper mills have been less integrated with timberland management but more integrated with converting factories (Mei and Clutter 2010). Finally, the pulp and paper mar-

The authors are, respectively, Assistant Professor, Warnell School of Forestry and Natural Resources, University of Georgia, 180 E. Green St., Athens, GA 30602, e-mail: meib@warnell.uga.edu; Assistant Professor, Mathematics Department, Fordham University, John Mulcahy Hall, Bronx, NY 10458, e-mail: dswinarski@fordham.edu; Dean and Professor, Warnell School of Forestry and Natural Resources, University of Georgia, 180 E. Green St., Athens, GA 30602, e-mail: mclutter@warnell.uga.edu; and Professor, Warnell School of Forestry and Natural Resources, University of Georgia, 180 E. Green St., Athens, GA 30602, e-mail: harris@warnell.uga.edu.

*Corresponding author

© Forest Products Society 2011
Journal of Forest Products Business Research
Volume 8, Article No. 1

Figure 1. Real prices of linerboard 42-lb for January 1980-June 2011 (Consumer Price Index, 1982–1984=100).



ket is facing greater foreign competition from an increasingly open world economy (Siry et al. 2007). In summary, investment in pulp and paper production is functionally irreversible and future rewards are uncertain. As a result, both irreversibility and uncertainty should be taken into account in evaluating pulp and paper projects.

Literature Review

Applying the dynamic programming or the contingent claims approach, several studies inspected the managerial flexibility in forest businesses. Miller and Voltaire (1980, 1983), Brazee and Mendelsohn (1988), Clarke and Reed (1989), Morck et al. (1989), Thomson (1992), Forboseh et al. (1996), Brazee and Bulte (2000), Buongiorno (2001), Gjolberg and Guttormsen (2002), Lu and Gong (2003), Duku-Kaakyire and Nanang (2004), Gong and Yin (2004), among others, reinvestigated the Faustmann rotation rule (Faustmann 1849) with stochastic timber prices and/or tree growth. Burnes et al. (1999) incorporated price volatility and harvesting costs into determining the minimum bid for a federal timber lease. Yin and Newman (1999) studied various real options of a timber producer. Yap (2004) modeled the Philippine forest plantation lease as a real option. Insley (2002) and Insley and Rollins (2005) inspected the forest valuation and timber harvest problem with one and multiple rotations.

Specifically, a number of studies examined various issues in linerboard production. Dubois (1998) applied the residual valuation method to compare stumpage used in linerboard production and suggested that strategies for pricing stumpage for linerboard production should focus on product yield rather than volume or weight. Yin et al. (2000) evaluated the option value of timberland ownership for a linerboard producer and showed that holding timberland could result in financial success in the long run. Marko (2003) modeled linerboard prices via a variety of econometric techniques and found that inventories had a significant impact on price changes. Siry et al. (2007) assessed the competitive position of the linerboard industry in the U.S. South. They claimed that the industry was about average with respect to techno-

logical assets and operating costs so that it might lose its leading position in the world. Li and Luo (2008) investigated the impact of industry consolidation on linerboard price. They found a low elasticity of linerboard demand, a slow adjustment of linerboard price over time, and a small impact of industry-operating rate on linerboard price.

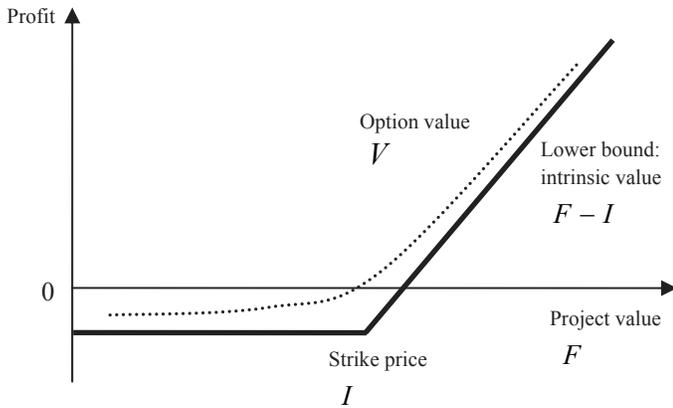
A review of the past research reveals several features. First, most previous studies assumed the price to follow a random walk,¹ e.g., Yin and Newman (1999), Yin et al. (2000), and Duku-Kaakyire and Nanang (2004). The exceptions are Gjolberg and Guttormsen (2002), Gong and Yin (2004), Insley (2002) and Insley and Rollins (2005), who considered mean-reverting stumpage prices in the Faustmann model. Dixit and Pindyck (1994) discussed the investment models when a project's value is mean-reverting. However, they provided no justification of why. In contrast, we assume more generally that the end product (linerboard) price to be mean-reverting and provide a rationale for it. Accordingly, the solution method becomes more complicated (Metcalf and Hassett 1995). Second, most previous studies assumed manufactures to be homogeneous, i.e., all manufactures have the same production costs (e.g., Price and Wetzstein 1999, Yin and Newman 1999). However, theoretical models, e.g., the selection model proposed by Jovanovic (1982), emphasize heterogeneity in explaining diverse growth paths among producers over the industry life. Novy-Marx (2007) showed that option premia remained significant with a large number of competitive heterogeneous firms.² Drakos (2011) found empirical evidence of heterogeneous capital using plant-level data and uncertainty decreased the likelihood of investment with a higher number of capital types. Therefore, we propose to extend the literature by considering the impact of alternative price assumptions and heterogeneous productivity on the entry conditions of a new linerboard mill. The results indicate that investment-triggering conditions differed under two different price assumptions and that more efficient producers required a lower uncertainty premium. This study sheds light on our understanding of investment decision making under market uncertainty in the U.S. pulp and paper industry.

Real Options Approach

The static net present value (NPV) analysis is based on projected future cash flows. A project is undertaken whenever the expected revenues exceed the expected costs in present values. However, the NPV analysis ignores managerial flexibility. The ability to delay an irreversible investment expense can significantly affect an investor's decision. To help inform strategic decision-making, the real options approach has been developed (Dixit and Pindyck 1994). An investment opportunity is just like a financial call option (Figure 2). The premium paid for this option is the cost for activities such as information collection, market research, feasibility analysis and business planning, which represents the maximum an investor can lose as long as he/she keeps the option alive. Once the investment decision is made, the option is killed with the initial investment cost I as the strike price, and in return, the investor holds the project whose value F is uncertain. At that

moment, the option's value V equals its intrinsic value $F - I$, whereas before that, there exists a time premium for the option, i.e., $V > F - I$, so that the investor can time the market or wait for more information. Among others, Dixit and Pindyck (1994) used the Ito control method to assess irreversibility and uncertainty. Their model has been widely used in evaluating natural resources investments (e.g., Price and Wetzstein 1999, Yin et al. 2000).

Figure 2. Analogy between the financial call option and the option to invest in a project.



Economic theory suggests that commodity price should reflect its marginal cost of production, and that supply and demand dynamics should keep the price at its long-run equilibrium level. That is, even commodity prices may have sensible short-term oscillations, they tend to revert back to a normal long-term mean. This is particularly the case for the pulp and paper industry, where raw timber inputs account for more than 50% of the total production cost (Li and Luo 2008, Mei and Sun 2008). Therefore, we considered mean-reverting prices in addition to random prices in evaluating the optimal entry thresholds for a linerboard producer. Furthermore, without losing generality, we assumed producers to be heterogeneous and thus have different profit margins.

For simplicity, we normalize the output per period of time to one. The investor's problem is therefore to determine the optimal time T to invest so as to maximize the expected NPV (V) from such an investment, i.e.,

$$(1) \quad \max_T V = E \left[\int_T^\infty \delta p_t e^{-rt} dt - I e^{-rT} \right]$$

where p_t is the output price (net of variable operating cost), r is the discount rate, I is the initial investment cost, and δ ($\delta \in [0, 1]$) is the heterogeneous parameter that indicates the rate of productivity per unit of capital (Metcalf and Hassett 1995). The higher the δ value, the more efficient a producer is. Thus, the return on one unit capital invested is δp_t . Note that there is a discounting factor e^{-rT} associated with the investment cost I . This is because the investment itself is not a now-or-never opportunity, but is contingent on the market condition. An investor may get better off by investing

(exercising the option) at a later time ($T > 0$) rather than investing right away ($T = 0$).

Geometric Brownian Motion Price

Random prices can be modeled by a geometric Brownian motion

$$(2) \quad dp = \alpha p dt + \sigma_1 p dz$$

where α is the drift rate, σ_1 is the volatility parameter, dz is the increment of a Wiener process with $E(dz) = 0$ and $E(dz^2) = dt$. Using Itô's lemma, it can be shown that $\ln(p)$ follows a generalized Wiener process with drift rate $\alpha - \sigma_1^2 / 2$ and variance rate σ_1^2 :

$$(3) \quad d \ln(p) = \left(\alpha - \frac{\sigma_1^2}{2} \right) dt + \sigma_1 dz$$

Tsay (2005) demonstrated a way to estimate α and σ_1 by letting $r_t = d \ln(p_t) = \ln(p_t) - \ln(p_{t-1})$ be the continuously compounded return in the t^{th} time interval. Namely, $\hat{\alpha} = \bar{r} / \Delta + s^2 / 2\Delta$ and $\hat{\sigma}_1 = s / \sqrt{\Delta}$, where \bar{r} and s are the sample mean and standard deviation of the series r_t and Δ is the equally spaced time interval measured in years. Then, the value function in equation (1) can be expressed as

$$(4) \quad V(p) = \begin{cases} A(\delta p)^\beta, & \delta p < H \\ (\delta p/r) - I, & \delta p \geq H \end{cases}$$

where $H = \frac{\beta}{\beta-1} rI$ is the threshold condition, $\beta = 0.5 - \alpha / \sigma_1^2 + [(\alpha / \sigma_1^2 - 0.5)^2 + 2r / \sigma_1^2]^{0.5} > 1$ and $A = (H - rI) / (rH^\beta)$ (Dixit 1992, Pindyck 1991).

Geometric Ornstein-Uhlenbeck Price

Mean-reverting prices can be modeled by a geometric Ornstein-Uhlenbeck process

$$(5) \quad dp = \eta(\bar{p} - p)p dt + \sigma_2 p dz,$$

where η is the speed of mean reversion, \bar{p} is the long-term mean, and σ_2 is the volatility parameter. Unlike the geometric Brownian motion, the drift parameter depends on the current price. That is, if p_t is below the long-term mean \bar{p} , p_{t+1} tends to rise, and vice versa. Taking $x = \ln(p)$ and applying Itô's lemma to equation 5 results in, $dx = \eta^* (\bar{x}^* - x) dt + \sigma_2 dz$ where $\eta^* = \eta p / \ln p$ and $\bar{x}^* = (\bar{p} - \sigma_2^2 / 2\eta) (\ln \bar{p} / p)$. Parameters η^* , \bar{x}^* and σ_2 can be estimated from the regression $x_t - x_{t-1} = a + bx_{t-1} + \varepsilon_t$ by $\eta^* = -\ln(1+b)$, $\bar{x}^* = -a/b$,

$$\text{and } \sigma_2 = \sigma_\varepsilon \sqrt{\frac{2 \ln(1+b)}{(1+b)^2 - 1}} \quad (\text{Dixit and Pindyck 1994}).$$

When price is geometric mean-reverting, the value function in equation (1) can be expressed as

$$(6) \quad V(p) = \begin{cases} Bp^v H\left(\frac{2\eta}{\sigma_2^2} p, v_1, Z(v_1)\right), & p < H^* \\ \delta \left\{ Dp^v H\left(\frac{2\eta}{\sigma_2^2} p, v_1, Z(v_1)\right) + G^p \right\} - I, & p \geq H^* \end{cases}$$

where B and D are constants, v_i 's are the roots ($v_1 > 0$) of the quadratic equation $0.5\sigma_2^2 x(x-1) + \eta\bar{p}x - r = 0$,

$Z(v_1) = 2v_1 + 2\eta\bar{p}/\sigma_2^2$, $G^p = \sum_{i=1}^{\infty} c_i p^i$ is a power series

with $c_0 = 0$, $c_1 = \frac{1}{r - \eta\bar{p}}$, $c_i = \frac{2\eta(i-1)}{\sigma_2^2(i-v_1)(i-v_2)} c_{i-1}$,

for $I = 2, 3, \dots$, and $H(x, \theta, b) = 1 + \frac{\theta}{b}x + \frac{\theta(\theta+1)}{2!b(b+1)}x^2 + \dots$

is the confluent hypergeometric function, (Dixit and Pindyck 1994, Metcalf and Hassett 1995). The threshold condition H^* cannot be solved analytically but numerically.

A Numerical Example

Linerboard price data (January 1980-June 2011) were drawn from Pulp & Paper monthly statistical summary (Pulp & Paper Week 1980-2011). Nominal prices were deflated by Consumer Price Index (CPI, 1982-1984=100) to exclude inflation (Bureau of Labor Statistics 2011). Mill specification was the same as given in Yin et al. (2000) (Table 1). The designed capacity was 465,400 tons/year and the initial investment for the 100% virgin fiber mill was \$346 million or \$743/ton (1982 constant dollars). The sample mean and standard deviation of deflated linerboard prices were \$265/ton and \$42.6/ton, respectively. Using these values, we specified the linerboard price to be lognormal and then conducted Monte Carlo simulation on the NPV in @Risk with 1000 iterations (Palisade Corporation 2010). The results showed that nearly half of the time the NPV was negative and the value at risk (VaR) at the 5% level was -\$306 million (Figure 3). For an average producer ($\delta = 0.5$), the break-even price that triggers the investment was \$285/ton.

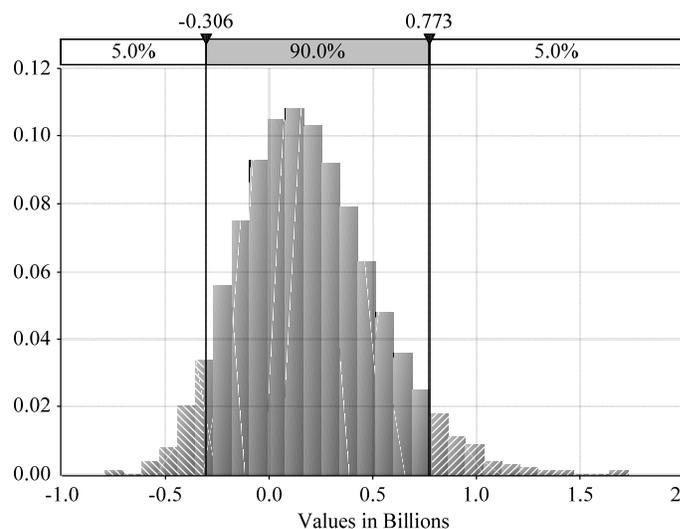
Table 1. Specification of the linerboard mill.

Item	Quantity
Capacity (tons/year)	465,400
Initial investment (\$ million)	346
Operating cost (\$/ton)	196
Number of employees	290
Furnish: wood (bone dry tons/ton)	1.76

Note: All \$ values are of 1982 constant U.S. dollars.

Parameter estimates for both price processes were summarized in Table 2. Drift parameter α and volatility parameter σ_1 corresponding to the geometric Brownian motion were estimated at 0.0003 and 0.1165, respectively. Mean-reverting parameter η , long-run equilibrium price \bar{p} , and volatility parameter σ_2 corresponding to the geometric Ornstein-Uhlenbeck

Figure 3. Simulated NPVs of the linerboard mill with lognormal prices ($p \sim \text{lognorm}(265, 42.6)$).



■ NPV

Minimum	-789,515,117.94
Maximum	1.730E+009
Mean	189,342,163.01
Std Dev	331,748,754.81
Values	1000

Uhlenbeck process were estimated at 0.0066, \$265/ton, and 0.1172, respectively. Should the linerboard price indeed be mean-reverting, the reverting speed was very low. The half-life, the time for the expected value p_t to reach the middle between current value p_0 and the long-run mean \bar{p} , was about 46 months.

The volatility estimates were of similar magnitudes from both price processes. The comparison of investment triggering conditions between the NPV analysis and real options approach were reported in Table 3. The efficient parameter δ has mean 0.5, 5% percentile 0.254, and 95% percentile 0.746. Under the geometric Brownian motion assumption, the trigger price H for an average producer was \$321/ton, or 30% higher than the NPV criterion; whereas under the geometric Ornstein-Uhlenbeck assumption, the trigger price H^* was \$361/ton, or 27% higher than the NPV criterion. The similar results could be due to the low mean-reverting speed and moderate but similar volatility estimates for both price processes. That is, the random effect has dominated the linerboard price over the past 30 years.

Table 2. Parameter estimates for Geometric Brownian motion and Geometric Ornstein-Uhlenbeck price processes.

	Geometric Brownian motion	Geometric Ornstein-Uhlenbeck	
α	0.0003	η	0.0066
σ_1	0.1165	\bar{p}	265
		σ_2	0.1172

Table 3. Comparison of investment-triggering conditions under different assumptions.

δ	NPV	Geometric Brownian motion	Geometric Ornstein-Uhlenbeck	Geometric Ornstein-Uhlenbeck ^a
0.254	372	442 (19%)	792 (113%)	638 (72%)
0.5	285	321 (30%)	361 (27%)	335 (17%)
0.746	256	280 (9%)	272 (6%)	263 (3%)

Note: ^a Mean-reverting speed is enlarged five times from a small 0.0066 to a moderate 0.0330. Numbers in the parentheses denote uncertainty premium comparing to the static NPV criteria.

However, price thresholds for more (less) efficient producers differed significantly under different price assumptions. The investment triggering prices were lower (higher) for more (less) efficient producers when the price was mean-reverting rather than random. Regardless, the real options approach reported higher trigger prices than the static NPV analysis. To examine the impact of a relatively strong mean-reverting price process on the solutions by the real options approach, we enlarged the mean-reverting speed by six times to a moderate 0.033, and therefore reduced the half-life to 9 months. The corresponding results were reported in the last column of Table 3. The percentage uncertainty premium dropped dramatically. All else being equal, the higher mean-reverting speed led to lower trigger prices. For efficient producers, the trigger price was much lower than that under geometric Brownian motion price and very close to that from the static NPV analysis.

Discussion and Conclusions

In this study, we applied the real options approach to investigate the entry-triggering conditions for a linerboard investor and compared them with the NPV criteria. The results confirmed that irreversibility and uncertainty should be priced and incorporated into investment decision making. However, different uncertainty assumptions led to quite different results. For more efficient producers, a moderate mean-reverting price process resulted in lower entry thresholds than a random walk price process. The effect is more obvious for highly efficient manufacturers. Hence, our results can be used to justify a pulp and paper firm's capital investment in R&D so as to keep its technology state-of-the-art and gain advantage over its competitors.

Besides irreversibility and price uncertainty, other factors should also be taken into consideration when making an investment decision in linerboard production. It's widely known that most pulp and paper mills are vertically integrated with converting plants and only a small portion of linerboard products is sold on the open market. In addition, recent mergers and acquisitions gave pulp and paper producers both oligopoly and oligopsony power in the market (Mei and Sun 2008, Murray 1995, Zhang and Buongiorno 2007). Both vertical integration and market power affect an investor's investment strategy but are beyond the scope of this study. Moreo-

ver, state attributes and geographic locations tend to affect an investor's decisions (Sun and Zhang 2001). Finally, we assumed that a linerboard mill could operate forever in this study. In reality, a typical modern linerboard mill has a life of more than 20 years (Li et al. 2004, Sun 2006).⁴ That is, the cash flow is a terminating annuity instead of an annuity. However, the NPV from the first 20 years of operation may account for as

much as 80% of the NPV of an infinite operation. Therefore, the impact should be minor and the resulting trigger prices should be marginally higher.

Linerboard prices in the past six months averaged at \$286/ton (Pulp & Paper Week 1980-2011), above the thresholds under both price assumptions for an efficient producer. This may help explain the fact that Cascades just announced the construction of a new 500,000 tons/year, state-of-the-art containerboard machine in the State of New York in June 2011. We suspect that there will be more capacity announcements if linerboard price keeps at its current level or rises even higher. At the same time, some previously mothballed pulp and paper mills have recently been reopened with the pulp and paper industry returning to prosperity amid economic recovery. For example, International Paper is making strides toward reopening its linerboard mill in Mississippi after a temporary closure since May 2011. Under the same framework, future research can incorporate more options such as temporary shutdown, reactivation, and abandonment decisions into the analysis.

Endnotes

- 1 A random walk is a mathematical formulation of a trajectory that consists of taking successive random steps. In finance, if a security's price follows a random walk, that security's price cannot be predicted by using its historical prices.
- 2 For a complete analysis of the optimal investment decisions of heterogeneous firms in a competitive, uncertain environment, refer to Novy-Marx (2007).
- 3 To deal with market uncertainty, the static NPV analysis can be combined with the scenario/sensitivity analysis or the Monte Carlo simulation.
- 4 A 50-year-old mill is not uncommon in the United States, e.g., Inland Paperboard and Packaging's linerboard mill in Rome, Georgia. However, it requires periodic reinvestments to keep the machines in good repair.

References

- American Forest & Paper Association. 2001-2010. Paper, Paperboard & Wood Pulp. Various issues.
- Brazee, J., and Bulte, E. 2000. Optimal harvesting and thinning with stochastic prices. *Forest Science*. 46(1):23-31.
- Brazee, R., and Mendelsohn, R. 1988. Timber harvesting with fluctuating prices. *Forest Science*. 34(2):359-372.
- Buongiorno, J. 2001. Generalization of Faustmann's formula for stochastic forest growth and prices with Markov decision process models. *Forest Science*. 47(4):466-474.
- Bureau of Labor Statistics. 2011. Consumer Price Index Database. Washington DC: U.S. Department of Labor.
- Burnes, E., Thomann, E., and Waymire, E.C. 1999. Arbitrage-free valuation of a federal timber lease. *Forest Science*. 45(4):473-483.
- Butner, R.E., and Stapley, C.E. 1997. Capital effectiveness of the paper industry. *TAPPI Journal*. 80(10):155-165.
- Clarke, H.R., and Reed, W.J. 1989. The tree-cutting problem in a stochastic environment: The case of age-dependent growth. *Journal of Economic Dynamics and Control*. 13(4):569-595.
- Dixit, A.K. 1992. Investment and hysteresis. *Journal of Economic Perspectives*. 6(1):107-132.
- Dixit, A.K., and Pindyck, R.S. 1994. Investment under Uncertainty. Princeton, NJ: Princeton University Press. 468 pp.
- Drakos, K. 2011. Testing Uncertainty's Effect in Real Options with Multiple Capital Goods. *Economica*. 78 (310):330-346.
- Dubois, M.R. 1998. A comparison of stumpage: Valuation methods for procuring wood used in linerboard production. *Forest Products Journal*. 48(10):35-42.
- Duku-Kaakyire, A., and Nanang, D.M. 2004. Application of real options theory to forestry investment analysis. *Forest Policy and Economics*. 6(6):539-552.
- Faustmann, M. 1849. Calculation of the value of which forest land and immature stands possess for forestry. Republished in 1995 with permission from Commonwealth Forestry Association. *Journal of Forest Economics*. 1(1):7-44.
- Forboseh, P.F., Brazee, R.J., and Pickens, J.B. 1996. A strategy for multiproduct stand management with uncertain future prices. *Forest Science*. 42(1):58-66.
- Gjolberg, O., and Guttormsen, A.G. 2002. Real options in the forest: What if prices are mean-reverting? *Forest Policy and Economics*. 4(1):13-20.
- Gong, P., and Yin, R. 2004. Optimal harvest strategy for slash pine plantations: The impact of autocorrelated prices for multiple products. *Forest Science*. 50(1):10-19.
- Inasley, M. 2002. A real options approach to the valuation of a forestry investment. *Journal of Environmental Economics and Management*. 44(3):471-492.
- Inasley, M., and Rollins, K. 2005. On solving the multirotational timber harvesting problem with stochastic prices: A linear complementarity formulation. *American Journal of Agricultural Economics*. 87(3):735-755.
- Jovanovic, B. 1982. Selection and the evolution of industry. *Econometrica*. 50(3):649-670.
- Li, H., and Luo, J. 2008. Industry consolidation and price in the U.S. linerboard industry. *Journal of Forest Economics*. 14(2):93-115.
- Li, X., Buongiorno, J., and Ince, P.J. 2004. Effects of size and age on the survival and growth of pulp and paper mills. *Journal of Forest Economics*. 10(1):3-19.
- Lu, F., and Gong, P. 2003. Optimal stocking level and final harvest age with stochastic prices. *Journal of Forest Economics*. 9(2):119-136.
- Marko, L.S. 2003. Inventory and Price Forecasting: Evidence from U.S. Containerboard Industry. M.S. Thesis, Georgia Institute of Technology, Atlanta. 81 p.
- Mei, B., and Clutter, M.L. 2010. Evaluating the financial performance of timberland investments in the United States. *Forest Science*. 56(5):421-428.
- Mei, B., and Sun, C. 2008. Assessing time-varying oligopoly and oligopsony power in the U.S. paper industry. *Journal of Agricultural and Applied Economics*. 40(3):927-939.
- Metcalf, G.E., and Hassett, K.A. 1995. Investment under Alternative Return Assumptions - Comparing Random-Walks and Mean Reversion. *Journal of Economic Dynamics & Control*. 19(8):1471-1488.
- Miller, R.A., and Voltaire, K. 1980. A sequential stochastic tree problem. *Economics Letters*. 5(2):135-140.
- Miller, R.A., and Voltaire, K. 1983. A stochastic-analysis of the tree paradigm. *Journal of Economic Dynamics & Control*. 6(4):371-386.
- Morck, R., Schwartz, E., and Stangeland, D. 1989. The valuation of forestry resources under stochastic prices and inventories. *Journal of Financial & Quantitative Analysis*. 24(4):473-487.
- Murray, B.C. 1995. Measuring oligopsony power with shadow prices: U.S. markets for pulpwood and sawlogs. *Review of Economics and Statistics*. 77(2):486-498.
- Novy-Marx, R. 2007. An equilibrium model of investment under uncertainty. *Review of Financial Studies*. 20 (5):1461-1502.
- Palisade Corporation. 2010. @RISK Risk Analysis and Simulation Add-In for Excel: A Software Package, Version 5.7. Newfield, NY.
- Pindyck, R.S. 1991. Irreversibility, Uncertainty, and Investment. *Journal of Economic Literature*. 29(3):1110-1148.
- Price, T.J., and Wetzstein, M.E. 1999. Irreversible investment decisions in perennial crops with yield and price uncertainty. *Journal of Agricultural and Resource Economics*. 24(1):173-185.
- Pulp & Paper Week. 1980-2011. Pulp & Paper North American Fact Book. San Francisco, CA: Miller Freeman, Inc.
- Siry, J.P., Harris, T.G., Baldwin, S., Null, D., and Gonzalez, J. 2007. U.S. South linerboard industry: Restoring the competitive edge. *Forest Products Journal*. 57(1-2):78-83.

- Sun, C. 2006. Lifetimes of U.S. paper and allied products mills: Insights from a duration analysis. *Southern Journal of Applied Forestry*. 30(1):5-12.
- Sun, C.Y., and Zhang, D.W. 2001. Forest resources, government policy, and investment location decisions of the forest products industry in the southern United States. *Forest Science*. 47(2):169-177.
- Thomson, T.A. 1992. Optimal forest rotation when stumpage prices follow a diffusion process. *Land Economics*. 68(3):329-342.
- Tsay, R.S. 2005. *Analysis of Financial Time Series*, 2nd ed. Hoboken, NJ: John Wiley & Sons. 640 pp.
- U.S. Bureau of Census. 1987-2007. Economic Census, Manufacturing, Subject Series, General Summary. Washington DC: Department of Commerce, EC02-31SG-1.
- Yap, R.C. 2004. Option valuation of Philippine forest plantation leases. *Environment and Development Economics*. 9(3):315-333.
- Yin, R., Harris, T.G., and Izlar, B. 2000. Why forest products companies may need to hold timberland. *Forest Products Journal*. 50(9):39-44.
- Yin, R., and Newman, D.H. 1999. A timber producer's entry, exit, mothballing, and reactivation decision under market risk. *Journal of Forest Economics*. 5(2):305-320.
- Zhang, S.J., and Buongiorno, J. 2007. Does monopolistic competition explain intraindustry trade of forest products? *Forest Science*. 53(4):519-528.